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Original article

BIOMECHANICAL COMPARISON OF CERAMIC, TITANIUM AND CHROME COBALT POST INLAYS IN POST-TRAUMATIC DENTAL DEFECTS REPAIR

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Abstract. *The aim of the study* is the biomechanical substantiation of restoration of tooth crowns destroyed due to trauma using ceramic post inlays.
Materials and research methods. In order to experimentally compare the strength of pin inlays, tooth root and ceramic crown depending on the material of the inlays, three-dimensional mathematical modeling of the stress-strain state of the pin structure using the method of finite element analysis was carried out. The physical and mechanical properties and size of a single-rooted tooth with a fractured crown (upper central incisor), a ceramic crown and a peg inlay made of a chrome-cobalt alloy, titanium or ceramics corresponded to the natural ones. Calculations were performed using the properties of both the devital and the intact tooth. Situations of early operation of the post construction with close contact of the root, inlay, and crown, as well as possible decay of tooth tissues along the edge of the crown in the long-term operation of the construction were simulated. A functional load of 150N was applied to two areas: the incisal edge and the upper third of the palatal surface of the crown on post inlays with a change in load direction from 0 to 90°.
Research results and their analysis. According to the data of mathematical modeling of functional load, the strength of a post-traumatic tooth defect replacement is sufficient when using both metal and ceramic post inlays; changes in physical and mechanical properties of the tooth with increasing time from the moment of devitalization increase stress in the ceramic crown, and root failure along the edge of the crown causes the ultimate stress at a horizontal shift of load direction.
The biomechanical rationale allows: in case of complete destruction of the crown part of the tooth — to recommend milled dowel ceramic inlays as a support of metal-free artificial crowns; to stick to the technology of their fixation in the root canal and of the fixation of crowns to the inlays; to ensure a strict dispensary of patients with a ceramic crown on milled dowel ceramic inlay to detect and to eliminate tooth root caries in the long term; to provide direction of functional load within 30° from the axis of the restored tooth during prosthetics.

Key words: *ceramics, chrome-cobalt, mathematical modeling, post inlays, post-traumatic tooth defects, stress-strain state*

Conflict of interest. The authors declare no conflict of interest

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Оригинальная статья

БИОМЕХАНИЧЕСКОЕ СРАВНЕНИЕ КЕРАМИЧЕСКИХ, ТИТАНОВЫХ И ХРОМКОБАЛЬТОВЫХ ШТИФТОВЫХ ВКЛАДОК ПРИ ЗАМЕЩЕНИИ ПОСТТРАВМАТИЧЕСКИХ ДЕФЕКТОВ ЗУБА

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Резюме. *Цель исследования* – биомеханическое обоснование восстановления разрушенной вследствие травмы коронки зуба с использованием керамических штифтовых вкладок.
Материалы и методы исследования. В целях экспериментального сравнения прочности штифтовых вкладок, корня зуба и керамической коронки в зависимости от материала вкладок проведено трехмерное математическое моделирование напряженно-деформированного состояния (НДС) штифтовой конструкции с использованием метода конечно-элементного анализа. Физико-механические свойства и размер однокорневого зуба с разрушенной коронкой (верхний центральный резец), керамической коронки и штифтовой вкладки из хромкобальтового сплава, титана или керамики соответствовали естественным. Расчеты проводились с использованием свойств как девитального, так и интактного зуба. Моделировались ситуации ранних сроков эксплуатации штифтовой конструкции с плотным контактом корня, вкладки и коронки, а также возможного разрушения кариесом тканей зуба по краю коронки в отдаленные сроки эксплуатации конструкции. Функциональная нагрузка 150Н прилагалась к двум зонам: режущему краю и верхней трети нёбной поверхности коронки на штифтовых вкладках с изменением направления нагрузки от 0 до 90°.
Результаты исследования и их анализ. По данным математического моделирования функциональной нагрузки, прочность штифтовой конструкции, замещающей посттравматический дефект зуба, достаточна при использовании как металлических, так и керамических штифтовых вкладок; изменение физико-механических свойств зуба с увеличением времени от момента девитализации повышает напряжение в керамической коронке, а разрушение корня по краю коронки вызывает в

нем предельное напряжение при горизонтальном смещении направления нагрузки.
Биомеханическое обоснование позволяет: при полном разрушении коронковой части зуба – рекомендовать в качестве опоры безметалловых искусственных коронок фрезерованные штифтовые керамические вкладки; соблюдать технологию их фиксации в корневом канале и коронок – к вкладкам; проводить строгую диспансеризацию пациентов с керамической коронкой на фрезерованной штифтовой керамической вкладке для выявления и устранения кариеса корня зуба в отдаленные сроки; обеспечивать при протезировании направление функциональной нагрузки в пределах 30° от оси восстанавливаемого зуба.

Ключевые слова: *керамика, математическое моделирование, напряженно-деформированное состояние, посттравматические дефекты зуба, хром-кобальт, штифтовые вкладки*

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Research relevance. The elimination of medical, sanitary and other consequences of emergency situations is associated with a significant stressogenic impact on those who take part in it (disaster medicine specialists, rescuers, workers of rescue units, etc.). This impact is manifested, in particular, in hypertonus of the muscles of the maxillofacial area and in increased strength and duration of the occlusal load on the teeth. Under these conditions, in the presence of extensive carious cavities, crown restoration with light-curing composites is ineffective and short-lived. In this case there is often a loss of fillings and chipping of dental hard tissue, which is associated with the lack of strength of light-curing composites, as well as the brittleness of the enamel of the remaining tissues of the tooth. In addition, adhesive bonding with bonding materials is not sufficient to retain large fillings. The high occlusal load on the filled teeth due to muscle hypertonicity aggravates these problems in liquidators of accidents and disasters.

In these cases the application of methods of orthopedic dentistry is required. Significant defects of the crown of teeth in orthopedic dentistry are restored by post inlays as supports of artificial crowns [1-7]. The vast majority of post inlays are made using casting of chromium-cobalt alloys; titanium and gold alloys are used much less frequently.

Metal inlays are adequate to the metal-ceramic crowns that cover them, but reduce the aesthetic results of ceramic crowns. Empress pressed or CAD/CAM milled dioxide-zirconia frameworks, ceramic crowns are gradually replacing metal-ceramic crowns among prosthetic replacements [7-12].

In this regard, milled ceramic post inlays are of interest, but the biomechanical substantiation of such inlays is currently insufficient [13].

The aim of the study was to provide a biomechanical justification for the restoration of a tooth crown destroyed due to trauma using ceramic post inlays.

Materials and methods of research. In order to experimentally compare the strength of pin inlays, tooth root and ceramic crown depending on the material of the inlays, three-dimensional mathematical modeling of the stress-strain state of the pin structure using the method of finite element analysis and Solid Works program [14, 15]. The physical and mechanical properties and size of a single-rooted tooth with a fractured crown (upper central incisor), ceramic crown, and pin inlay made of a chrome-cobalt alloy, titanium, or ceramic corresponded to the natural ones (Fig. 1, Table 1). Calculations were performed using the properties of both the devitalized and intact tooth, in the latter case to simulate the situation of the functioning of the post structure in the early period after tooth devitalization. Tooth devitalization — removal of the tooth pulp — is always performed after a tooth trauma with a fractured crown; over time, the physical and mechanical properties of the remaining tooth root tissues deteriorate.

Situations of early operation of the post construction with close contact of the root, inlay, and crown were simulated, as well as possible destruction of tooth tissues by caries on the edge of the crown in the long term operation of the construction. A functional load of 150N was applied to two areas: the incisal edge and the upper third of the palatal surface of the crown on post inlays with a change in load direction from 0 to 90°.

Maximum stress (MPa) was reflected in the graphs for all situations of modeling the stress-strain state (SSS) of a tooth with posttraumatic defect replaced by a crown on a post inlay (Fig. 2).

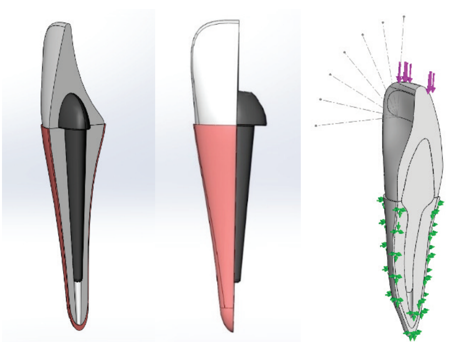

Рис. 1. Модель штифтовой конструкции при замещении посттравматического дефекта зуба
Fig. 1. Model of a pin construction for the replacement of a posttraumatic tooth defect

Таблица 1/Table No. 1

Физико-механические свойства материалов математической модели

Physical and mechanical properties of materials of the mathematical model

Материал Material	Модуль упругости, МПа Elastic modulus, MPa	Коэффициент Пуассона Poisson's ratio	Предел прочности, МПа Tensile strength, MPa
Хромкобальт / Cobalt-chrome	248000	0,3	690
Титан / Titanium	113800	0,32	880
Керамика / Ceramics	22400	0,19	300
Дентин (сразу после девитализации) / Dentin (immediately after devitalization)	14700	0,31	55
Дентин (в отдаленные сроки после девитализации) / Dentin (long after devitalization)	2600	0,31	20

Those differences were considered statistically significant if the probability of error in deviating from the null hypothesis did not exceed 5%, $p<0.05$. Arithmetic mean (M) and standard deviation (SD) as (M±SD) were used to record numerical values.

Results of the study and their analysis. Mathematical modeling has shown the dependence of the SSS in the peg construction (tooth root, peg inlay, ceramic crown): on the material of the peg inlay; the presence of tight contact of the artificial crown with the tooth root; on the direction of the load, as well as on the time elapsed since the tooth devitalization, affecting the physical and mechanical properties of the root dentin.

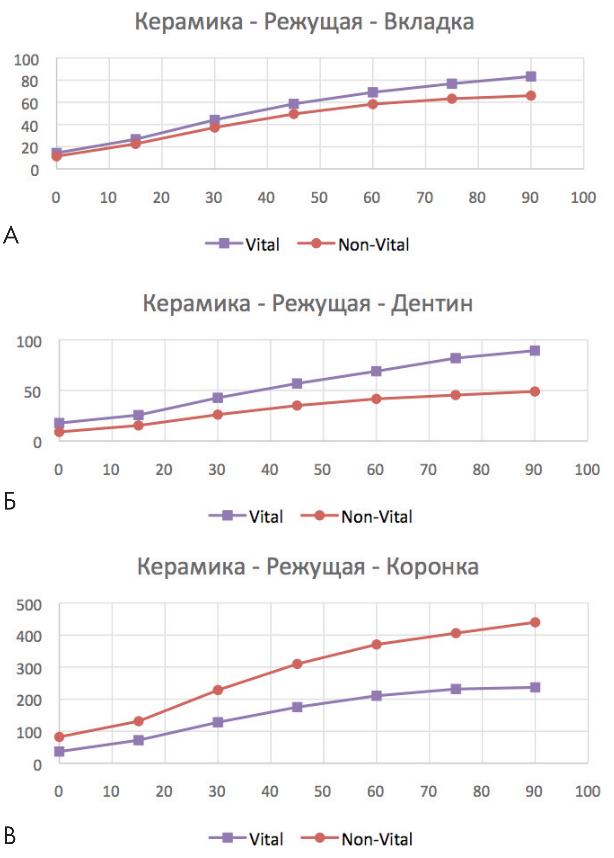

Рис. 2. Графики напряжения (МПа) в керамической вкладке (а), дентине корня (б), керамической коронке (в) при нагрузке режущего края штифтовой конструкции в ранние и отдаленные сроки после девитализации (Vital и Non-Vital)
Fig. 2. Graphs of stresses (MPa) in the ceramic insert (a), root dentin (b), ceramic crown (c) under the loading of the incisal edge of the post construction in the early and long term after devitalization (Vital and Non-Vital)

Under standard conditions, the maximum stress in the metal inlay (149.876 MPa under horizontal loading; 24.611 MPa under vertical loading) was far from the strength limit of chromocobalt when using the chromocobalt post inlay (Table 2, Fig. 3). In the tooth root, the stress approached the strength limit: when the incisal edge was loaded at an angle of more than 30° (from 26.332 MPa at 30° to 50.515 MPa at 90°); when the palatal surface was loaded at an angle of more than 45° (from 27.498 MPa at 45° to 41.430 MPa at 90°). In the artificial crown, maximum stress above the strength limit appeared: when the incisal edge was loaded at an angle of more than 45° (from 311.196 MPa — at 45° to 436.003 MPa — at 90°); when the palatal surface was loaded at an angle of more than 60° (from 298.534 MPa — at 60° to 360.323 MPa — at 90).

The same patterns were repeated when using a titanium post inlay.

When a milled ceramic inlay was used as a support for the artificial crown, no critical stress was detected in the inlay itself (from 11.343 MPa for vertical loading of the incisal edge of the crown to 65.982 MPa for horizontal loading; from 15.177 MPa for vertical loading of the palatal surface of the crown to 56.309 MPa for horizontal loading). In the tooth root, the ultimate stress was detected: with a load of more than 30° of the incisal edge (from 26.030 MPa — at 30° to 48.940 MPa — at 90°); with a palatal surface load — with a load direction more than 45° (from 27.084 MPa — at 45° to 40.061 MPa — at 90°). In the artificial crown, the maximum stress in the incisal edge or palatal surface loading was detected: in the loading angle more than 45° (from 309.942 MPa — at 45° to 439.857 MPa — at 90°); in the loading angle more than 60° (from 296.980 MPa - at 60° to 363.457 MPa - at 90°).

In the pin loading situation, no marginal stress was detected in the VAT of pin inlays and artificial crowns a short time after devitalization of the tooth; in the tooth root, marginal stress was detected with chrome-cobalt and titanium inlays at the same load directions as the dentin model, with a longer time after devitalization, and marginal stress in the dentin developed later when ceramic inlays were used: at 45° loading of the incisal edge and 60° loading of the palatal surface of the crown.

According to the data of mathematical modeling of the post construction, when the contact of the crown edge with the root of the tooth is disturbed due to root caries, there is a strong increase in stress in the post inlays themselves — up to the ultimate stress of 709.505 MPa in the chrome-cobalt

Таблица 2/Table No. 2

Максимальные напряжения (МПа) по Мизесу в модели корня зуба, искусственной коронке и в штифтовой вкладке из разных материалов

Maximum Mises stresses (MPa) in the model of the tooth root, artificial crown and pin inlay made of different materials

CoCr		**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**
Режущий кран Cutting edge	вкладка inlay	24,6	48,3	80,6	107,4	126,9	138,4	149,9
	дентин dentin	9,2	15,6	26,3	35,4	41,9	46,4	50,5
	коронка crown	79,3	132,7	229,6	311,2	371,6	406,7	436,0
Нёбная поверхность Palatal surface	вкладка inlay	33,9	33,9	61,7	85,2	102,9	113,7	126,3
	дентин dentin	12,7	10,7	19,7	27,5	33,5	37,2	41,4
	коронка crown	103,1	90,1	172,4	243,7	298,5	333,1	360,3
Ti		**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**
Режущий кран Cutting edge	вкладка inlay	21,7	42,2	69,7	92,6	109,1	120,1	130,2
	дентин dentin	9,1	15,9	26,2	35,3	41,9	46,0	50,1
	коронка crown	79,9	132,6	229,8	311,5	372,0	407,3	435,9
Нёбная поверхность Palatal surface	вкладка inlay	29,8	29,9	53,7	73,8	88,9	98,5	109,9
	дентин dentin	12,6	10,6	19,6	27,4	33,3	37,0	41,1
	коронка crown	102,9	89,9	172,4	243,8	298,8	333,5	360,3
Ceramic		**0°**	**15°**	**30°**	**45°**	**60°**	**75°**	**90°**
Режущий кран Cutting edge	вкладка inlay	11,3	22,5	37,3	49,5	58,3	63,2	65,9
	дентин dentin	8,9	15,3	26,0	35,0	41,6	45,4	48,9
	коронка crown	82,1	131,1	228,3	309,9	370,6	406,0	439,9
Нёбная поверхность Palatal surface	вкладка inlay	15,2	16,7	29,3	40,2	48,3	53,1	56,3
	дентин dentin	12,5	10,4	19,3	27,1	33,0	36,7	40,1
	коронка crown	103,8	88,0	170,5	241,9	296,9	331,9	363,5

inlay at 75° load direction of the incisal edge of the crown. In ceramic crowns — irrespective of the pin inlay material — the stress is considerably reduced. At the same time, the stress in the tooth root increases: when the vertical load is displaced by 15°, the ultimate stress when the load is applied to both the incisal edge and the palatal surface is recorded: with chrome-cobalt inlay — 26.683 and 19.005 MPa respectively; with titanium inlay — 30.555 and 20.946 MPa respectively; with ceramic inlay — 38.355 and 25.351 MPa respectively.

Thus, tooth devitalization followed by the fabrication of a ceramic crown on a post support does not cause ultimate stress in the crown and post support regardless of its material — chrome-cobalt, titanium or ceramic; in dentin ultimate stress appears when the incisal edge is loaded at 30° and the palatal surface at 45°. The stress in inlays does not change with increasing time from tooth devitalization; it decreases 1.5-3 times in dentin — with a corresponding decrease in tooth strength and increases up to two times in a ceramic crown. Fracture of a devitalized tooth with an inlay on the crown margin, especially after a long period of time, significantly reduces the stress in the crown, but increases the stress in the inlays and — especially — in the dentin, in which the strength limit appears at 15-30° of the incisal edge and the palatal slope of the crown.

Conclusion

1. According to the data of mathematical modeling of functional load, the strength of the post-traumatic tooth defect replacement is sufficient when using both metal and ceramic post inlays; the change in the physical and

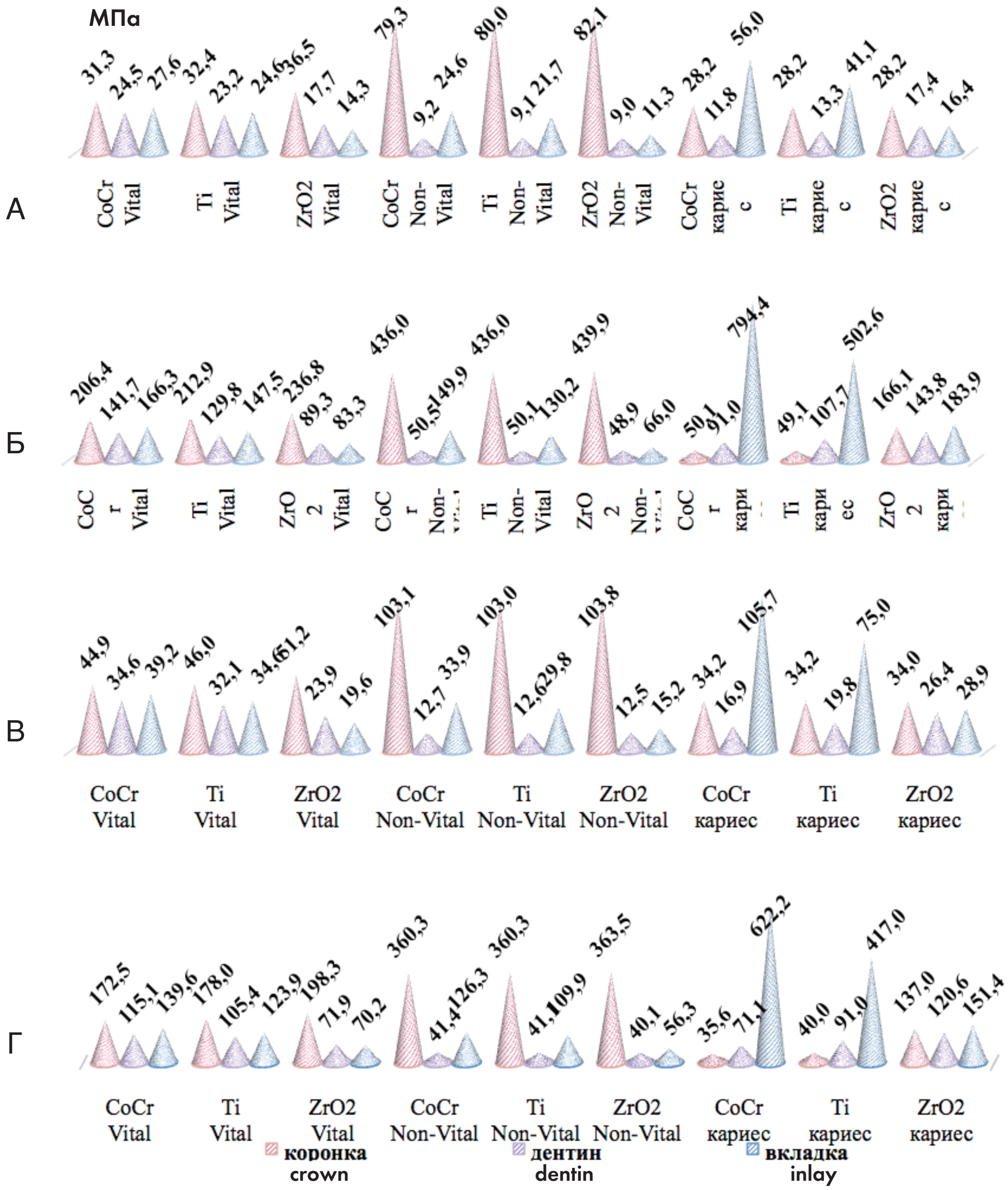

Рис. 3. Сравнение максимального напряжения в компонентах штифтовой конструкции в зависимости от материала штифтовой вкладки, сроков от момента девитализации зуба и целостности тканей корня: а – вертикальная нагрузка, режущий край; б – 90°, режущий край; в – вертикальная нагрузка, нёбная поверхность; г – 90°, нёбная поверхность

Fig. 3. Comparison of the maximum stresses in the components of the pin structure, depending on the material of the pin inlay, the timing of the devitalization of the tooth and the integrity of the root tissue: a) vertical load, cutting edge; b) 90°, cutting edge; c) vertical load, palatal surface; d) 90°, palatal surface

mechanical properties of the tooth with increasing time from the moment of devitalization increases the stress in the ceramic crown, and the root destruction along the edge of the crown causes a limit stress in it when the load direction is shifted horizontally.

2. In case of complete destruction of the crown part of the tooth the biomechanical justification allows to recommend milled post ceramic inlays as a support of metal-free artificial crowns. At the same time it is necessary to strictly observe the technology of their fixation in the root canal and fixation of crowns to the inlays. As the lifetime of the ceramic crown on a milled ceramic inlay increases, a strict follow-up examination is required to identify and eliminate tooth root caries. When fabricating a milled dowel-retained ceramic crown, the direction of the functional load must be within 30° of the axis of the tooth to be restored.

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