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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ИТТРИЙСОДЕРЖАЩИХ БЛОКОВ ДИОКСИДА ЦИРКОНИЯ

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Аннотация

Целью данного обзора является определение положительных и отрицательных качеств и свойств блоков из диоксида циркония разных поколений, а именно 3Y-TZP, 5Y-TZP, 4Y-TZP.

Материалы и методы. Проведен систематический обзор литературы в электронных базах Google Scholar и Pubmed. Рассмотрены статьи, содержание которых основано на изучении механо-оптических и физико-химических свойств блоков из диоксида циркония 1, 3 и 4 поколения, их применение в практике.

Результаты. В ходе анализа было рассмотрено 57 статей, из них выбрано 47 из Pubmed и 10 из Google Scholar. После отбора статей по критериям суммарное количество исследований составило 27. В исследованиях оценивались механические и оптические свойства разных поколений блоков из диоксида циркония.

Вывод. Применение в стоматологической практике керамики из диоксида циркония, стабилизированного иттрием, разных поколений дает возможности получения качественных результатов при изготовлении и установке коронок, протезов, виниров и других ортопедических конструкций. Говоря про физико-механические и оптические свойства, следует заметить, что каждое поколение имеет разные показатели. Специалисты должны быть осторожны при выборе керамики из диоксида циркония, так как оптические свойства не всегда являются решающим фактором при выборе материала для изготовления несъемных конструкций.

Ключевые слова: *диоксид циркония, 5-YTZ, 4-YTZ, прочность на изгиб, прозрачность, вязкость разрушения*

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COMPARATIVE ANALYSIS OF YTTRIUM CONTAINING ZIRCONIUM DIOXIDE BLOCKS

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Annotation

The aim of this review is to determine the positive and negative qualities and properties of zirconium dioxide blocks of different generations, namely 3Y-TZP, 5Y-TZP, 4Y-TZP.

Materials and methods. A systematic literature review in the electronic databases Google Scholar and Pubmed was conducted. The articles whose content was based on mechano-optical and physicochemical properties of zirconium dioxide blocks of 1, 3 and 4 generations and their application in practice were considered.

Results: 57 articles were reviewed during the analysis, of which 47 from Pubmed and 10 from Google Scholar were selected. After selecting the articles according to the criteria, the total number of studies was 27. The studies evaluated the mechanical and optical properties of different generations of zirconia blocks.

Conclusion: The use of yttrium-stabilized zirconium dioxide ceramics of different generations in dental practice provides opportunities to obtain quality results in the fabrication and placement of crowns, dentures, veneers and other prosthetic structures. Speaking about physical, mechanical and optical properties, it should be noted that each generation has different indicators. Specialists should be careful when choosing zirconium dioxide ceramics, as optical properties are not always a decisive factor when selecting a material for fabrication of fixed structures.

Keywords: *zirconium dioxide, 5-YTZ, 4-YTZ, flexural strength, transparency, fracture toughness*

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Introduction

Aesthetics and functionality make orthopedic dentistry constantly progress and look for ways to solve the problems associated with all-ceramic restorations. In recent years, zirconia has established itself as one of the best materials for prosthetic restorations due to its good mechanical and physicochemical properties.

The polycrystalline structure of zirconium dioxide (ZrO2) is arranged on cells that have the shape of three different phases: cubic, tetragonal and monoclinic. They are capable of changing from one phase to another under the influence of temperature, stress stimulus, or humidity [4]. In its pure form, zirconium dioxide (monoclinic phase) is stable up to 1170 °C. Modern dentistry uses zirconium dioxide stabilized with yttrium. The use of yttrium prevents the system from turning into a monoclinic phase at room temperature and increases mechanical and physical properties. There are other stabilizers such as CaO, MgO and CeO2, but only ZrO2-Y2O3 has its own ISO standard for orthopedic applications. Depending on the yttrium filling of the block, there are several generations: first generation 3 mol% Y2O3 0.25% Al2O3 (3Y-TZP); second generation 3 mol% Y2O3 0.05% Al2O3; third generation 5 mol% Y2O3 0.05% Al 2O3 53% cubic structure (5Y-TZP); fourth generation 4 mol% Y2O3 0.05% Al2O3 (4Y-TZP).

The first generation of yttrium-stabilized tri-molecular polycrystalline zirconia (3Y-TZP) was the first to appear on the market. Its composition was selected in such a way to improve the strength (more than 400MPa) and fracture toughness [3, 10]. Its main disadvantage is its low transparency, so often such crowns were covered with a vitrified cladding [24]. Because of the above properties, this material has been used for crown frameworks (mainly chewing group of teeth) and bridges, as well as implants and abutments [2, 18]. With the passage of time, the requirements for aesthetics among patients increased, so a new type of zirconia was developed in 2015. The third generation, 5Y-TZP, differs in composition from the previous ones by the amount of yttrium, which increased the cubic phase to 50% in proportion to the tetragonal phase [5, 9, 13]. However, the pursuit of high transparency resulted in lower bending strength and fracture toughness due to the stable cubic lattice. Therefore, the 3rd generation is used clinically for veneers, anterior bridges and crowns for the anterior group of teeth, with the volume of restorations ranging from 1 to 3 teeth [25]. It should be noted that a study [17, 25] showed a 2% failure rate of using 5Y-TZP for the anterior group of teeth due to reduced flexural strength and fracture toughness. Since the third generation did not have sufficient mechanical properties, a 4th generation (4Y-TZP) was developed. It is also a partially stabilized zirconium dioxide, but the cubic phase was reduced to 30% relative to the tetragonal phase[1, 9, 10]. This transformation slightly decreased the transparency but increased, relative to 3 generation, the bending strength and fracture toughness. In this regard, specialists were able to use 4Y-TZP for larger orthopedic constructions (more than 3 units) and not be afraid of poor aesthetics. In spite of this, today there is a large number of materials that are used for orthopedic constructions, so the question of choosing the most effective material is still open.

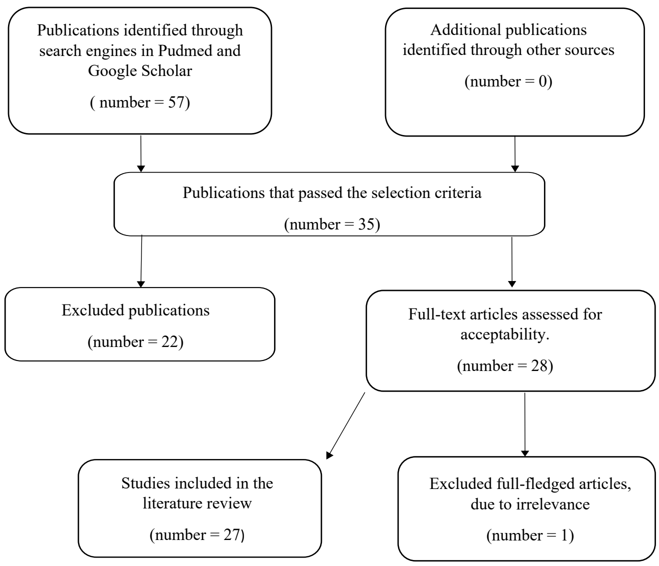
The purpose of this review was to conduct a comparative analysis of mechanical (bending strength, fracture toughness) and optical properties (transparency) of yttrium-stabilized zirconium dioxide blocks, namely 3Y-TZP, 5Y-TZP, 4Y-TZP.

Materials and Methods. This review was written with the help of literature retrieved by searching the electronic databases Google Scholar and Pubmed.

Table 1

Article selection process

Таблица 1. **Процесс отбора статей**



Criteria for article selection (research eligibility):

1. Studies no earlier than 2014 were included
2. Literature reviews were not included
3. Studies compared mechanical or optical or mechanical and optical properties of materials
4. Studies were selected based on keywords
5. Articles written in a foreign language (other than English) were not included in the review

As a result, 57 articles were reviewed, of which 47 from Pubmed and 10 from Google Scholar were selected. After selecting the articles according to the criteria, the total number of studies was 27. The studies evaluated the mechanical and optical properties of different generations of zirconia blocks.

Search terms included: *3Y-TZP, 5Y-TZP, 4Y-TZP, flexural strength, fracture toughness, zirconium dioxide*.

Discussion

Zirconium dioxide phases

In modern prosthetic dentistry, zirconium dioxide is one of the most popular materials for dentures, crowns and veneers.

There are three different phases of unstabilized zirconia: monoclinic (less than 1170), tetragonal (1170–2370), and cubic (greater than 2370). If unstabilized tetragonal zirconia is cooled (which will inevitably happen in the oral cavity), the t-grains (tetragonal grains) are converted into monoclinic grains, causing the material to undergo a volumetric fracture of 3–5%. As a result, cracks and chips appear in orthopedic structures. The monoclinic phase (m-phase) is inferior in its mechanical properties to the tetragonal phase, but the latter does not exist at room temperature. To solve this issue in zirconium dioxide began to add stabilizing substances – yttrium (YO) [5, 9].

In addition, the phases are characterized not only by different sintering temperatures, but also by grain size. Thus, the monoclinic phase has 3–5% more grains than the tetragonal phase. It should be noted that this parameter should be taken into account when assessing the transparency of the material. The smaller the grain, the better the optical properties of ceramics. The high content of cubic phase (c-phase) contributes to the improvement of aesthetic properties [1, 20]. To achieve an increase in this phase in ceramics, the stabilizing agent yttrium was again resorted to. Thus, in pursuit of high mechanical and optical properties, a new type of material was developed – yttrium stabilized tetragonal zirconia polycrystal (Y-TZP). Its main advantage is corrosion resistance and high strength, but the first generation has a significant disadvantage – low transparency [22]. The level of transparency, as already mentioned, can be corrected by adding yttrium, different sintering temperatures and grain sizes, so, several generations have been derived, which differ in their mechanical and optical properties. It is worth noting that in the composition of each generation in addition to yttrium, there is aluminum oxide. The point is that small amounts of Al2O3 are able to harden Y-TZP ceramics by increasing the adhesion of zirconium dioxide grain boundaries without a significant reduction in grain size [4]. This should be taken into account when evaluating the mechanical properties of ceramics.

Zirconia surface treatment

Ceramic surface treatment is necessary to increase the bond strength of zirconia to resin cements.

Kurtulmus-Yilmaz S (+3) in 2020 [12] conducted a study to determine the effect of zirconia surface treatment (3Y-TZP) on bending strength and optical properties. The materials were divided into 3 groups: pre-sintered, post-sintered and control. These groups were divided into subgroups according to the type of processing: APA (air particle abrasion), grinding, laser irradiation.

APA group: It was found that the use of abrasive particles of large size (110μm) promotes the transition of tetracycline phase to monoclinic phase (transformation t → m) in the near-surface layer, which reduces the bending strength (tendency to form chips, microcracks). The samples that were ground before sintering had a rougher surface due to the formation of pointed slits and deep recesses. On the samples polished after sintering, microcracks appeared, but they did not extend beyond the compressive layer because the phase transformation produced by APA was able to neutralize their propagation.

Grinding Group: During the study, the author found that grinding can induce reverse phase transformation on the surface of zirconia due to the heat generated during ceramic processing and stress, which ultimately leads to a decrease in mechanical properties. To avoid phase transformation it is necessary to use water cooling and diamond burs (to reduce stress). The control group and pre-sintered specimens showed similar results and no negative effect on bending strength. In the post-sintered group, grinding significantly increased the bending strength.

Laser irradiation group: The specimens that were treated after sintering showed an improvement in flexural strength. In contrast, the group of pre-fired specimens showed neither negative nor positive effects on flexural strength. The author attributed this phenomenon to the fact that the m-phase is preserved due to the minimal temperature increase resulting from the conducted laser irradiation with constant water cooling. It is worth noting that laser power also affects the strength characteristics of zirconium dioxide. Thus. For monolithic constructions it is recommended to use a power of 4–5.5 W, but it is mandatory to use water cooling. For two-layer zirconia restorations, use 2–3 watts. If too high a power is used, the structure of the zirconia will be disturbed and, as a consequence, the mechanical properties will be reduced.

Regarding the optical properties, the group treated before sintering showed an increase in transparency (TP) in all subgroups.

Thus, the author concluded that the pre-sintering group showed better mechanical and optical properties of all treatments except APA, but this problem can be solved by reducing the grain size, such as 5Y-TZP or 4Y-TZP.

First generation (3Y-TZP)

Yttrium stabilized 3 mol% tetragonal polycrystalline zirconium dioxide (3Y-TZP) is one of the strongest materials. According to studies [8–10, 13, 21] the bending strength ranges from 900 to 1251 MPa (however, other authors [4] had maximum values of 1556 MPa), fracture toughness 7.4–11.5 MPa m1/2. High mechanical properties were achieved due to the tetragonal phase, in 3Y-TZP it is ~90%, practically does not contain c-phase in its composition. On the other hand, Zhang in 2018 [25] reviewed the development of zirconia ceramics and found that 3Y-TZP is prone to accelerated aging (low temperature degradation – LTD) under oral conditions. LTD is caused by the ingress of water (saliva) into surface microcracks and cause spontaneous t-phase to m-phase transition, resulting in an increase in grain size, leading to further microcrack formation. Over time, this will lead to enlargement and interconnection of microcracks and grain delamination. As a result, the fracture strength and toughness of the ceramic will decrease [25]. The size of the restoration also affects the LTD [3, 5, 23]. Single crowns showed lower chipping rates, while multi-unit designs (3 units or more) showed higher chipping rates.

One of the negative properties of 3Y-TZP, according to studies [3, 23–26] is poor permeability. Yttrium stabilized tetragonal polycrystalline zirconium dioxide with 3 mol% contains almost no cubic phase (less than 10%), t-phase is dense and strong, however, due to anisotropy (tetragonal grains are birefringent) the material transmits light worse and as a consequence becomes opaque [1, 3, 26]. Transparency coefficient on average does not exceed 24–25, so 3Y-TZP is indicated as crowns, frameworks, bridges on the chewing group of teeth.

Strategies to improve the transparency of zirconia (3Y-TZP)

There are several ways to improve the optical properties of ceramics.

1. The transparency of the material is favorably affected by changes in sintering temperature [12], and it is important to note that the mechanical properties are not degraded in most cases [12].
2. Increasing the grain size also increased the transparency of zirconia. The larger the grains, the less reflection and scattering of light from grain boundaries. Grain size can be corrected by increasing sintering time and different sintering temperature [23].
3. On the contrary, decreasing the grain size will also lead to better transparency, as the fine structure will allow better light scattering [9, 14, 21].
4. Reducing sintering additives in the powder composition. For example, aluminum oxide. It is known that Al2O3 gives density to the material, but makes it less transparent. Reducing aluminum oxide to 0.25% can improve optical properties, but mechanical properties may suffer. This can be avoided by adding 0.2 mol% La2O3 to the powder composition. It increases the transparency, hydrothermal stability of 3Y-TZP, while maintaining the fracture toughness and strength of the first generation ceramics [23].
5. By increasing the cubic phase with the help of additive – yttrium. C-phase is the most stable and optically isotropic, due to which it does not scatter light at grain boundaries, resulting in improved optical properties. An example is 5Y-TZP. It has the best transparency, but the mechanical properties of the material are reduced due to the fact that the cubic phase predominates in this zirconia and it is very brittle [23, 25].

First and third generation

It is known that the third generation was created to improve the degree of transparency of the material compared to the first generation. Composition:

5Y-TZP: 5 mol% Y2O3 0.05% Al 2O3 ~53% cubic structure.

3Y-TZP: 3 mol% Y2O3 0.9% Al2O3 ~10% cubic structure.

Analyzing the composition of the two generations, we can observe the difference in the percentage of cubic phase, which increases in proportion to the yttrium content in the powder composition. The reduction of the tetragonal structure is accompanied by a decrease in the grain size of the material, which together leads to better light scattering and as a consequence, improved transparency of the ceramics. In addition, the cubic phase is stable and leads to the resistance of the material to hydrothermal aging [9, 13, 14, 23].

In one study [23], 3Y-TZP and 5Y-TZP were compared. The authors concluded that the degree of transparency of the third generation (30.1) was better than that of the first generation (19.5), which allows 5Y-TZP to be used for anterior restorations. On the other hand, clinical tests showed that the flexural strength of 3Y-TZP (3% yttrium stabilized zirconia) – 730MPa is higher than that of 5Y-TZP (5% yttrium stabilized zirconia) – 651MPa, and the fracture toughness of 5Y-TZP was 4.8MPa m1/2, while that of 3Y-TZP was 7.0MPa m1/2. This is explained by the increase in the cubic phase of the third generation (~54%) compared to the tetragonal phase (while the tetragonal phase of 3Y-TZP is ~90%) and the increase in grain size from 304nm to 713nm. These parameters increase the risk of chipping and microfracture formation of 5Y-TZP, which means that it is not suitable for fabrication of prostheses with more than 3 units and mounting of structures on masticatory groups, which is also confirmed by other studies [17, 25]. It is worth noting that in several other studies [10], the flexural strength of 3Y-TZP was ~1125 mPa and that of 5Y-TZP was 557 mPa. These results better show the difference in mechanical properties of different generations of ceramics.

Thus, the creation of the third generation solved the problem of aesthetics, but due to the excessive increase in the cubic phase, which is brittle, and the grain size of the powder composition, the mechanical properties: bending strength, fracture toughness, which is a key clinical drawback of 5Y-TZP, decreased.

Third and fourth generation

Fourth-generation materials were created to increase strength and preserve transparency. However, it was not possible to preserve transparency to the fullest extent, due to the increase in the tetragonal phase, which scatters light poorly [23].

Composition of 4Y-TZP: 4 mol% Y2O3 0.05% Al2O3, compared to the 3rd generation yttrium content decreased by 1%, aluminum oxide remained in the same amount, and compared to the first increased by Y2O3 3.75% and decreased by 0.2% Al2O3 content [1].

In 2017, Shaymaa E Elsaka conducted a study on the mechano-optical properties of 4Y-TZP and 5Y-TZP. The results of this study showed that the 4th generation stabilized zirconium oxide is more flexural strength (960.1mPa) compared to the 3rd generation (676mPa). The obtained values indicate superior structural reliability in 4% yttrium stabilized zirconia.

As for the fracture toughness, this parameter also varied and the best performance was with 4Y-TZP (4.7 mPa m1/2, 5Y-TZP – 3.7). According to ISO 6872, for the fabrication of dentures consisting of 4 units or more, the fracture toughness should be at least 5 mPa m1/2. Hence, 4Y-TZP can be used for structures of 3 units and 5Y-TZP can be used for single crowns[7]. The performance was similar in other researchers [1, 2, 9, 24].

Transparency evaluation showed the following results: 5Y-TZP – 19.41, 4Y-TZP – 15.88[7]. Materials of the 3rd generation have better aesthetic properties compared to the 4th generation, this is due to the different yttrium content in the composition (different percentage of yttrium affects the ratio of cubic and tetragonal phases), grain size (the smaller the grain, the better the transparency), in the different chemical ratio of chemical impurities. [9, 10, 17, 23]. It should be noted that the transparency coefficient of Shaymaa E Elsaka [7] differs from that of other studies, the results of which are presented in Table 4, this may be due to research error.

Thus, the 4th generation material solved the problem of low durability compared to the 3rd generation, but despite this, the issue of aesthetics remained open.

First, third and fourth generations

Based on clinical trials [9] conducted in 2021, the mechanical and optical properties of all three generations can be compared.

Thus, the bending strength of: 4Y-TZP – 846MPa, 5Y-TZP – 525 MPa, 3Y-TZP – 959MPa, fracture toughness: 4Y-TZP – 3.67 MPa m1/2, 5Y-TZP – 2.63 MPa m1/2, 3Y-TZP – 4.63 MPa m1/2. It can be seen from the results that the mechanical properties of the 4th generation have increased sufficiently to make structures for the chewing group of teeth, unlike the third generation. In spite of this, the strength and fracture toughness indices are still lower than those of the first generation and do not make it possible to create structures of more than 4 units [7, 9, 16]. This is due to the ratio of cubic and tetragonal phase in different grades of materials and the content of aluminum oxide, which provides strength. Recall that 4Y-TZP had a 0.2% decrease in Al2O3 content compared to 3Y-TZP.

The transparency coefficient of the generations was: 3Y-TZP – 28.6, 5Y-TZP – 35.4, 4Y-TZP – 33.1. Compared to the 4th generation, the transparency of the 3rd generation slightly decreased due to the change in the chemical composition of the material. However, the authors [24] claim that the decrease in transparency is not critical, so 4Y-TZP can be used as constructions for anterior teeth, especially the mechanical properties of this type of ceramics are quite good, which protects the constructions from chipping and microcracks. At the same time, the authors of another study [3] evaluate 3Y-TZP, 5Y-TZP and 4Y-TZP as "medium-semi-transparent" according to the classification introduced by Vichy et al [19] and consider the aesthetic performance to be insufficient for anterior teeth, which means that new materials with high optical and mechanical properties need to be developed. Thus, 4Y-TZP is borderline between 3Y-TZP and 5Y-TZP, with 3Y-TZP being the most durable and least esthetic, and 5Y-TZP being the most esthetic and least durable ceramic.

Results

The results of analyzing the studies where the authors compared different types of ceramics are presented in Tables 2, 3, 4. According to the tables, the average value for all three indicators was calculated (Tables 5, 6, 7). Analyzing the obtained values, we can conclude: when choosing prosthetic constructions with more than 4 units per chewing group of teeth, we should give our preference to the 1st generation (3Y-TZP), as it has the best indicators of strength and fracture toughness, which are clinically important parameters for the creation of a quality construction, but we should take into account the poor transparency.

If it is important for the patient to have an aesthetic appearance of the masticatory group of teeth, a 4th generation ceramic (5Y-TZP) should be chosen, but it is necessary to reduce the number of units included in the construction (at least 3), as the fracture toughness of this type of ceramic does not allow for extensive constructions (according to ISO6872 and study data [7]).

For the frontal group of teeth, specialists favor the 3rd generation (5Y-TZP), due to the high transparency and reduction of thermal aging of ceramics, but the key clinical disadvantage – low strength – should be taken into account when placing.

To summarize, we can say that the addition of yttrium to the structure of zirconium dioxide expectedly solved the problem of 1 generation (3Y-TZP) – aesthetics (5Y-TZP), but the strength characteristics decreased, so the 3rd generation is used exclusively for the anterior group of teeth (1–3 units), and 1 – for the chewing group of teeth (more than 4 units). In turn, the 4th generation (4Y- TZP) is a borderline material with good mechanical properties and satisfactory aesthetics (fabrication of constructions up to 3 units), so specialists should be careful when choosing zirconium dioxide ceramics, as optical properties are not always the decisive factor when choosing a material for fabrication of fixed constructions.

Table 2

Mechanical properties: Bending strength (mPA)

Таблица 2. **Механические свойства: Предел прочности на изгиб (мПА)**

Author	*3Y-TZP*	*5Y-TZP*	*4Y-TZP*
Nantawan Kolakarnprasert a, Marina R. Kaizer a b, Do Kyung Kim c, Yu Zhang a 2019 [10]	1125	557	748
Zhang F, Inokoshi M, Batuk M, Hadermann J, Naert I, Van Meerbeek B, Vleugels J. 2016 [23]	730	651	-
Jerman E, Lümkemann N, Eichberger M, Zoller C, Nothelfer S, Kienle A, Stawarczyk B. 2021 [9]	959	525	846
Zhang F, Spies BC, Vleugels J, Reveron H, Wesemann C, Müller WD, van Meerbeek B, Chevalier J2019 [24]	908	534	928
Kwon SJ, Lawson NC, McLaren EE, Nejat AH, Burgess JO. 2018[13]	1194	688	-
Elsaka SE. 2017 [7]	-	676	960.1
Jansen JU, Lümkemann N, Letz I, Pfefferle R, Sener B, Stawarczyk B. [8]	1023-1251	-	1126-1257
Vardhaman S, Borba M, Kaizer MR, Kim D, Zhang Y. Wear 2020 [18]	851	-	-
Kou W 2019 [11]	-	678	998
Yan J., Kaizer M., Zhang Y 2018 [21]	904	593	749
Yu N.-K., Mi-Gyoung P 2019 [22]	-	424-461	-
Cokic S. 2022 [4]	1556	606	928
Vieira Cardoso K., Adabo G.L., Mariscal-Muñoz E., Gutierres Antonio S., Neudenir Arioli Filho J.	-	542.9-577,5	-
De Araújo-Junior E.N.S., Bérgamo E.T.P., Bastos T.M.C., Benalcázar Jalkh E.B., Lopes A.C.O., Monteiro K.N., Cesar P.F., Tognolo F.C., Migliati R., Tanaka R. 2020 [5]	-	618	-

Table 3

Fracture toughness (MPa m1/2)

Таблица 3. **Вязкость разрушения (МПа·м1/2)**

Author	*3Y-TZP*	*5Y-TZP*	*4Y-TZP*
Zhang F, Inokoshi M, Batuk M, Hadermann J, Naert I, Van Meerbeek B, Vleugels J. 2016 [23]	7.0	4,8	-
Jerman E, Lümkemann N, Eichberger M, Zoller C, Nothelfer S, Kienle A, Stawarczyk B. 2021 [9]	4.36	2.63	3.67
Zhang F, Spies BC, Vleugels J, Reveron H, Wesemann C, Müller WD, van Meerbeek B, Chevalier J 2019 [24]	5,1 ± 0,3	4,1 ± 0,2	3,2 ± 0,2
Elsaka SE. 2017 [7]	-	3.7	4.7
Vardhaman S, Borba M, Kaizer MR, Kim D, Zhang Y. Wear 2020 [18]	5,0	-	-
Cokic S. 2022 [4]	4.2	2.4	3.7
De Araújo-Junior E.N.S., Bérgamo E.T.P., Bastos T.M.C., Benalcázar Jalkh E.B., Lopes A.C.O., Monteiro K.N., Cesar P.F., Tognolo F.C., Migliati R., Tanaka R. 2020 [5]	-	3.8	-

Table 4

Transparency coefficient

Таблица 4. **Коэффициент прозрачности**

Author	*3Y-TZP*	*5Y-TZP*	*4Y-TZP*
Nantawan Kolakarnprasert a, Marina R. Kaizer a b, Do Kyung Kim c, Yu Zhang a 2019 [10]	-	33.7	31.7
Zhang F, Inokoshi M, Batuk M, Hadermann J, Naert I, Van Meerbeek B, Vleugels J. 2016 [23]	19.5	30.1	
Jerman E, Lümkemann N, Eichberger M, Zoller C, Nothelfer S, Kienle A, Stawarczyk B.2021 [9]	28.6	35.4	33.1
Kwon SJ, Lawson NC, McLaren EE, Nejat AH, Burgess JO. 2018 [13]	28.37	34.22	-
Elsaka SE. 2017 [7]	-	19.41	15,88
Vardhaman S, Borba M, Kaizer MR, Kim D, Zhang Y. Wear 2020 [18]	26.3	-	-
Yan J., Kaizer M., Zhang Y 2018 [21]	24.0	29.2	24.2
Cokic S. 2022 [4]	25.0	33.0	27.0

Table 5

Flexural strength mPa (average values)

Таблица 5. **Прочность на изгиб, мПа (средние значения)**

3Y-TZP	5Y-TZP	4Y-TZP
1053 ± 86	597 ± 36	926 ± 51

Table 6

Fracture toughness in MPa m1/2 (average values)

Таблица 6. **Вязкость разрушения, МПа м1/2 (средние значения)**

3Y-TZP	*5Y-TZP*	*4Y-TZP*
5.4 ± 1.0	3.8 ± 0.8	3.9 ± 0.54

Table 7

Transparency coefficient (TP)

Таблица 7. **Коэфициент прозрачности**

3Y-TZP	*5Y-TZP*	*4Y-TZP*
25.4 ± 4.5	30.3 ± 6.1	26.2 ± 4.7

Conclusion

The use of yttrium-stabilized zirconium dioxide ceramics of different generations in dental practice allows obtaining quality results in the production and placement of crowns, dentures, veneers and other orthopedic constructions. Speaking about physical, mechanical and optical properties, it should be noted that each generation has different indicators.

3Y-TZP: has the best strength and fracture toughness among other generations due to the high percentage of tetragonal phase (90%). Negative properties: low transparency, tendency to low-temperature degradation. Indications: constructions on masticatory teeth.

5Y-TZP: high esthetics, due to increased amount of yttrium and as a consequence cubic phase, reduced LTD. Negative properties: low mechanical properties. Indications: single crowns or veneers on anterior teeth (not more than 3 units).

4Y-TZP: satisfactory esthetics (inferior to 5Y-TZP, better than 3Y-TZP), good flexural strength and fracture toughness (inferior to 3Y-TZP, but better than 5Y-TZP). Indications: orthopedic constructions on the masticatory and anterior group of teeth, but not more than 4 units.

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