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DENTAL CERAMIC MATERIALS, PART I: TECHNOLOGICAL DEVELOPMENT OF ALL-CERAMIC DENTAL MATERIALS

ДЕНТАЛНИ КЕРАМИЧКИ МАТЕРИЈАЛИ, ДЕЛ I: ТЕХНОЛОШКИ РАЗВОЈ НА ЦЕЛОСНО КЕРАМИЧКИТЕ МАТЕРИЈАЛИ

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Abstract

All-ceramic fixed restorations, because of their excellent aesthetic characteristics, are made more and more often. On the other hand, the discontinuity of the dental arches in the posterior regions could be solved by the restorations/bridges made out of the stabilized zirconium dioxide because of its great strength. This article reviews the current literature covering all-ceramic materials and systems. A history regarding the development of these materials is presented, starting with the first all-porcelain "jacket" crown, all the way to recently introduced all-zirconia and resin-matrix ceramic materials. The machinable materials fabricated for the CAD/CAM technology are also presented. **Keywords**:dental ceramics, CAD/CAM, glass ceramic, zirconia, hybrid ceramic.

Апстракт

Фиксните реставрации сѐ почесто се изработуваат целосно од керамички материјали поради нивните извонредни естетски карактеристики. Од друга страна пак, јачината на циркониум диоксидот овозможувапротетичко реставрирање на дисконтинуитетот во забните низи и во постериорните регии. Овој ревијален труд ги сублимира податоците од литературата кои се однесуваат на целосно керамичките материјали и системи. Во првиот дел е презентиран технолошкиот развој на овие материјали, почнувајќи од т.н. џекет коронка, па сѐ до најновите материјали, кога реставрациите целосно се изработуваат од стабилизиран циркониум диоксид или пак од керамиките со смолеста матрица. Посебен осврт е направен на материјалите за машинска - CAD/CAM обработка. **Клучни зборови**: дентална керамика, CAD/CAM, стакло керамики, циркониум диоксид, хибридни керамики.

Introduction

Contemporary fixed prosthodontics is based on using all-ceramic restorations. Impeccable esthetics and functionality offered by ceramic materials have put porcelain-fused-to-metal (PFM) system in the background[1].

For a long time the disadvantage of ceramic materials was their insufficient strength. For fabrication of crowns and bridge structures especially in the posterior region where a great masticatory load is generated (and thus possibility of breakage of the substructure), PFM systems had priority when selecting. Today, due to the qualitative development of ceramic materials, in such clinical cases, restorations can completely be ceramic made[2].

Contemporary ceramic materials "cover" all indications for fixed prosthetic rehabilitation: single tooth restorations such as veneers, inlays, onlays, crowns and posts, as well as multi-unit bridges. Zirconium posts have priority over those made of metal alloys, because all-ceramic crowns could be made with desirable esthetic effect afterwards[3]. The fabrication of veneers and crowns in the frontal region should primarily meet the priorities of esthetic and phonetic aspects; inlays, onlays and crowns in premolar and molar region should meet the requirements in terms of strength, esthetics and durability; multi-unit bridges made of ceramic material should be characterized by high strength and fracture toughness, uniform distribution of masticatory load as well as esthetics[2]. Ceramic material that is used for the fabrication of crowns over the implants should possess ability to absorb masticatory forces and to distribute pressure throughout the whole structure of the crown, to be resilient and reduce stress to the implant[4]. Technological developments in the dental industry in the field of ceramic materials provide prosthetic solution in all of the above mentioned cases.

According to Zarone et al.[5] "Since the early introduction of the porcelain jacket single crowns into the dental practice, dental ceramics have been considered among the most promising restorative materials because of noticeable prosthetic advantages: esthetic appearance, chromatic stability, biocompatibility, low plaque retention and fluids absorption, high hardness, wear resistance, low thermal conductivity, and chemical inertness". An ideal all-ceramic material should possess excellent esthetic characteristics, including translucency, light transmission, and natural tooth color, and, at the same time, optimal mechanical properties such as high flexural strength and fracture toughness, as well as limitation of crack propagation that may occur in terms of the functional and parafunctional load conditions; all these features are important for the longevity and reliability of all-ceramic restorations[5].

However, despite the large number of all-ceramic materials for clinical use, the analysis of Conrad et al.[6] showed that there is still no universal material or system that could be used in each clinical situation. The successful use of various ceramic systems depends entirely on the clinician's ability to propose an appropriate treatment plan for each patient individually, to select an appropriate ceramic material and manufacturing technique and to choose appropriate luting material and procedure[6]. But, whether ceramic restoration will meet the expectations of the patient and the dentist depends on the dental technician's knowledge, skill, creativity and dedication[7].

This paper reviews the current literature covering all-ceramic materials and systems, with a overview of the technological qualitative development of these materials, starting with the first all-porcelain "jacket" crown, all the way to recently introduced all-zirconia and resin-matrix ceramic materials.

Technological development of dental ceramics

The usage of ceramic materials in dentistry dates back as far as 1889 when Charles H. Land patented the first all-porcelain "jacket" crown – PJC[8]. It was so-called, as this restoration rebuilds the missing tooth structures with porcelain covering as a jacket. This kind of restoration was extensively used (until the 1950s) after improvements made by E.B. Spaulding[9].

The failure rate of the "jacket" crowns, which was very high because of the internal micro-cracks that appeared during the cooling phase of fabrication, resulted in the development of the porcelain-fused-to-metal (PFM) system innovated by Abraham Weinstein in the late 1950s[10]. Despite the good reliability that this system has, the appearance of PFM restorations doesn't fulfill the patients' high esthetic demands.

First successful attempt to strengthen the feldspathic porcelain was made by W. Mc Lean and T.H. Hughes in 1965. They reinforced dental feldspathic porcelain with an addition of up to 50% aluminium oxide powder during the manufacturing[11]. Although it had twice the strength of the traditional PJC, it could've been used in the anterior region only (due to its lower strength). Its higher opacity was also a major drawback[12].

Another development in the 1950s by Corning Glass Works led to the creation of the castable Dicor® crown system in which the glass was strengthened with various forms of mica. A glass restoration (using the lost-wax casting technique) underwent through the "ceramming" process that provided a controlled crystallization of the glass. Such glass ceramics, had different crystalline formations depended on the feldspathic formulation used, such as leucite, fluoromica glass, lithium disilicate, and apatite[13]. Numerous small crystals that were evenly distributed into the glassy matrix increased the strength and toughness of the ceramic. The processing difficulties (time and temperature controlling) and high incidence of fracture were factors that led to the abandonment of this system[14].

The idea for the first pressable ceramic was primarily developed at the University of Zürich, Zürich, Switzerland, in 1983. Later on (1986), Ivoclar Vivadent took over the development project and after some improvements that have been made, in 1990 the IPS Empress system was introduced[15]. IPS Empress® 1 was high leucite-containing ceramic in which the leucite crystals, incorporated in the material, increased the coefficient of thermal expansion. The leucite crystals improved flexural strength and fracture resistance through so-called dispersion strengthening, slowing down the micro-crack propagation that easily could happen into the feldspathic porcelain. This process of pressing the heated ceramic ingots became very popular due to the good esthetics and easy usage in the laboratory.

Later on, Ivoclar Vivadent introduced the second generation of heat-pressed dental ceramic material, IPS

Empress® 2, containing about 65 vol % lithium disilicate, which strength was more than twice than that of first generation – the leucite-reinforced IPS Empress® 1. In late '90s, IPS Empress 2 contained 70 vol% lithium disilicate that made material suitable for production not only a single unit restorations but for the 3 unit FPD in the frontal region as well. A 5-year clinical study revealed a 70% success rate when used as a fixed partial denture framework[16].

Since 2004, Ivoclar Vivadent's leucite-based and lithium disilicate ceramic materials for heat-pressed technique are fabricated as IPS Empress Esthetic and IPS e.max Press respectively.

In 1983, Matts Andersson in cooperation with Nobel Biocare developed the Procera method for high-precision industrial manufacturing of dental crowns. In 1989, the first ceramic computer-aided designed and computer-aided manufactured (CAD/CAM) coping, the Procera® AllCeram, was introduced. The Procera® AllCeram crown consisted of a densely sintered alumina core that contained more than 99.9% aluminum oxide to which feldspathic porcelain was fired as a veneering material[17].

When VITA In-Ceram was introduced to the dental market in 1989, a new era of all-ceramic restorations has begun. The slip-casting technique developed by Sadoun allowed the production of restorations with an excellent long-term prognosis including a three-unit anterior bridge without metal substructure[18]. The aluminum oxide content of In-Ceram® Alumina has been increased to 80% and, by using the infiltration technique with special lanthanum glass (12% La_2O_3, 4.5% SiO_2), a flexural strength value of approximately 500 MPa was reached for the first time. By using industrially sintered, highly homogeneous aluminum oxide blocks for the CELAY system in 1993 and for the CEREC system in 1997, In-Ceram® Alumina BLANKS gained increased strength and excellent machine processability. In 1994, VITA introduced In-Ceram® Spinel ($MgAl_2O_4$) with better translucency and esthetics, but lower flexural strength of 250–400 MPa. In-Ceram® Zirconia is considered as a modification of In-Ceram® Alumina, in which, for the first time, zirconium oxide was used as in a dental ceramic. Alumina core was strengthened with 33 wt.% of 12 mol% cerium-partially stabilized zirconium oxide, which increased the flexural strength to 620–700 MPa19. Until then, many problems regarding stability of zirconia used as biomedical material have been already solved.

Since 1969, zirconia has been considered as a material for production of surgical implants[20]. In 1985, yttria-stabilized zirconia was used for the first time to replace femoral heads in the hip joint arthroplasy[21]. Between 2000 and 2002, a series of premature failures (fractures)of ceramic heads made of Y-TZP in such prostheses were reported[22,23], that resulted in reduced use of zirconia in orthopedic surgery by more than 90%[24]. The reason for such fractures was changed processing procedure during the production, which resulted in increased monoclinic content[23,25]. These episodes increased awareness of phase transformation of a zirconia used as biomaterial and imposed caution during processing of the material and production of prosthesis.

In 2001, the Cercon all-ceramic CAM system was introduced, using for the first time dental zirconia for the production of crowns and bridges. Two years later, colored Cercon bases were introduced, offering not only a material with high flexural strength but a material with natural, tooth-like shades that meets aesthetic demands[26].

In the last 20 years, most of the ceramic manufacturers have started a production of an already established and proven all-ceramic materials, as milling blocks for a CAD/CAM fabrication, but with improved chemical composition and mechanical features. The first commercially available all-ceramic CAD/CAM material was VITABLOCS Mark I (1985), feldspar ceramic that in 1991 was replaced by Mark II. Ivoclar Vivadent's leucite-reinforced and lithium disilicate ceramics (known as IPS Empress Esthetic and IPS e.max Pressfor heat-press technique) were introduced (2006) as IPS Empress CAD and IPS e.max CAD respectively. As a replacement for the glass infiltrated Vita In-Ceram® Alumina and Vita In-Ceram® Zirconia, VITAZahnfabrik offered densely sintered alumina and zirconia CAD/CAM blocks -In-Ceram® Al and In-Ceram® YZ.

The use of CAD/CAM technology spurred a whole new generation of zirconium dioxide-based materials used for manufacturing of substructures with superior mechanical properties. They are characterized with sufficient flexural strength of 900 MPa to 1300 MPa, allowing to be used for fabrication of multi-unit posterior bridges. Final esthetic appearance of the restorations is achieved by veneering the substructure with feldspar porcelain.

Several manufacturers introduced crown- and bridge-frameworks (Lava, 3M ESPE; Procera Forte, Nobel Biocare; Vita In-Ceram YZ, VITA; and Cercon, DENTSPLY) milled from blocks of pre-sintered yttrium-stabilized zirconium dioxide ceramic. The oversized milled frameworks are then sintered (with shrinking of the structure by 20–25%) providing an excellent fit[27]. Other manufacturers mill fully sintered zirconium dioxide blocks(Everest, KaVo; DC-Zirkon and DC-Zirkon col., DCS Bien-Air Dental), known as HIP-ed (hot isostatic pressing) zirconia, to avoid the shrinkage factor, thus providing a superior marginal fit[28]. However, there are several undesirable effects in milling dense sintered ceramic blanks: possibility of unwanted surface and structural defects in the ceramic restoration that minimize overall restoration strength and reliability, longer milling time and increased wear of the milling tools[29].

Further improvements in the composition and chroma features, led to introduction of a new era of zirconia materials that can be used for production of all-zirconia restorations without need of veneering, thus preventing failures due to porcelain chipping[30]. At the same time, these materials are found to have less abrasive effect to enamel of the opposite dentition compared to veneering porcelain and a pressed glass ceramic[31] or even natural enamel[32]: Lava™ Plus HT Zirconia (2012) of 3M ESPE, Zenostar® Full Contour Zirconia (2013) inovated in close cooperation between Wieland Dental and Ivoclar Vivadent, as well as Dentsply's Cercon® ht True Color (2015), zirconia discs with 16 different shades[26].

In collaboration with Fraunhofer Institute for Silicate Research ISC, Dentsply and VITA have used a new lithium compound to create a glass ceramic with higher flexural strength than lithium disilicate ceramic. After breaking up the partnership, Dentsplyand VITA continued with their own research which resulted in the introduction of zirconia-reinforced lithium silicate ceramics - Celtra Duo and VITA Suprinity® (2013).

Humans' striving to mimic the features of the human tissues has led to the creation of a new type of dental materials, so-called 'hybrid' ceramics. In 2011, 3M ESPE have introduced the first 'resin nano ceramic', Lava™ Ultimate CAD/CAM Restorative, which consists of a ceramic particles with nano-dimensions incorporated into the resin matrix.

Taking into consideration specific structure and composition of the dentin and spongy bone that consist of inorganic and organic interconnected phases, the development of hybrid materials took another direction. The inorganic constituents of biological tissues are weak by themselves, but together with the organic matrix and specific structural distribution, materials with superior mechanical properties are built [33].

The idea for developing the novel kind of interpenetrating phase material was discussed by Dr. Norbert Thiel (VITA Zahnfabrik) and Prof. Russell Giordano (Boston University) 20 years ago. Finally, in 2013, VITA has introduced VITA Enamic®, retaining the ceramic structure of Mark II and adding a polymer. A porous feldspar glass ceramic was infiltrated with a polymer that closes the gaps between already existing ceramic material. In this way, VITA Enamic® imitates the properties of dentin, with respect to the elastic modulus and density[34].

These are the first attempts, ceramic materials to get features similar to the human enamel and dentin in terms of wear characteristics and modulus of elasticity and yet to have properties as those of glass ceramics, i.e. similar optical features, flexural strength and fracture resistance in order to withstand the masticatory load[4].

The newest one, Cerasmart™ from GC, introduced in 2014 features the highest flexural strength (in this category of hybrid materials) of 230 MPa, and in the same time offers a high flexibility (breaking energy) of 2.2 N/cm to buffer the masticatory pressure[35].

Conclusion

Starting from the first "jacket" crown, all the way to the newest ceramic materials, the fast and versatile technological development of the dental industry, in this field, is easily noticeable.

Glass ceramics, because of their optical characteristics, are still considered the best material when it comes to esthetics. The stabilized zirconia, as a material with astounding mechanical characteristics and strength, is used for the production of dental bridges, as a replacement for the metal substructure. Biomimetics, as a science with a very fast development rate, resulted in the innovation of the hybrid ceramics, which come closer and closer to the human tissues.

In the future, perfecting the development is expected not only for the technological processing, but for the ceramic materials as well, with maximizing their potential abilities, while minimizing their weaknesses.

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