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บทคัดย่อ

บทความนี้นำเสนอเกี่ยวกับประวัติของเซรามิกทางทันตกรรม ความเป็นมาต้นกำเนิด ส่วนประกอบ และลักษณะเฉพาะของเซรามิกทางทันตกรรมที่ใช้อยู่ในปัจจุบัน รวมถึงวิจารณ์โดยละเอียดถึงส่วนประกอบที่ใช้ในการผลิตเซรามิกทางทันตกรรมที่ได้รับความนิยมอย่างแพร่หลาย ซึ่งประกอบด้วย เฟลดสปาติกกลาส ลูไซต์ และอะพาไทท์

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Ceramics in Dentistry

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Abstract

This article is intended to present a brief history of ceramic in dentistry and to demonstrate background knowledge including the origin, composition and characteristic of current dental ceramics. Attention is paid to review of the composition of commercial dental ceramics which consists of feldpathic glass, leucite and/or apatite.

Keywords: Ceramics, Dentistry, History, Feldpathic Glass, Leucite, Apatite

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1. History

The first ceramic tooth material was used to produce denture teeth and was patented in 1789 and introduced soon afterwards by a French dentist called de Chemant [1]. The product was in fact an improved version of "mineral paste teeth" that was produced in 1774 by Duchateau. This baked compound was not used to produce individual teeth at the time because there was no effective way of attaching the teeth to denture base materials. The first ceramic crown arrived in 1903 and was made by Dr. Charles Land [2]. These crowns employed a technique using a platinum foil matrix and high–fusing feldspathic porcelain. These crowns exhibited excellent aesthetics but the low flexural strength of porcelain resulted in a high incidence of failure [2]. Unfortunately, feldspathic porcelains have been too weak to use reliably in the construction of all ceramic crowns (those without a cast-metal core or metal-foil coping). Furthermore, their firing shrinkage causes significant discrepancies in fit and adaptation of margins unless correcting bakes are made [1]. Two of the most important breakthroughs responsible for the long standing superb aesthetic performance and clinical longevity of metal-ceramic restoration are the patents of Weinstein et al in 1962 and 1963 [3], [4]. They developed a new porcelain-metal system for crowns and bridges termed "metal-ceramic prostheses" or porcelain fused to metal (PFM) restorations. Such high expansion porcelains for veneering metal frameworks are partially crystallized feldspathic glasses (glass ceramics) with the addition of undissolved stains and opacifying crystals. Each porcelain crown is composed of several ceramic layers of different translucencies. One is called the enamel or incisal porcelain. The dentine body or gingival porcelain comprises the majority of the crown and has a lower translucency and the inner layer is opaque porcelain which covers the underlying metal surface. These patents described the formulation of feldspathic porcelain that allowed systematic control of the sintering temperature and thermal expansion coefficient. The other patent described the components that could be used to produce alloys that bonded chemically to and were thermally compatible with feldspathic porcelain. Since then, feldspathic porcelains with reliable chemical bonding have been used in metal-ceramic prostheses [1]. The first commercial ceramic was developed by Vita Zahnfabrik in 1963 [1]. Although the first Vita ceramic products were known for their aesthetic properties, they still had limited use with all varieties of alloy due to their incompatible the coefficient of thermal expansion (CTE). Recent developments in metal ceramics such as opalescence, specialized internal staining techniques, greening-resistant ceramics and ceramic shoulder margins have significantly enhanced the overall appearance of metal ceramic crowns and bridges and the clinical longevity of these prostheses.

2. Origin, Composition and Characteristic of Dental Ceramics

The dental ceramic consists of a glass matrix with crystalline minerals [5], [6]. It is referred to as a glass-ceramic material. Most commercial dental ceramics consist of feldpathic glass and a crystalline phase which are leucite and/or apatite [7].

Glass-ceramic materials are polycrystalline solids containing a residual glass phase and are prepared by melting glass and forming it into products that are subjected to controlled crystallisation. The concept of controlled crystallisation of glass is based on the separation of a crystalline phase from the glassy parent phase in the form of tiny crystals, where the number of crystals, their growth rate and thus also their final size are controlled by suitable heat treatments. The initial glasses for the preparation of the glass-ceramic materials usually start from inorganic raw materials (known as raw materials) for glass melting such as silicon dioxide, potassium carbonate and magnesium silicate [8]. Therefore the glass ceramic may demonstrate special morphologies related to their particular structures as well as considerable differences in appearance depending on their mode of growth. All these different ways of forming microstructures involve controlled nucleation and crystallisation as well as the choice of parent glass composition [9].

The formulation of the dental ceramic uses the basic silicon-oxygen network as the glass-forming matrix but additional properties, such as low-fusing temperature, high viscosity and the resistance to devitrification, are built in by the addition of other oxides to the glass forming lattice. These oxides generally consist of potassium, sodium, calcium, aluminium and boric oxides [10], [11]. Glass modifiers such as the oxides of potassium (K), sodium (Na) and calcium (Ca), also act as fluxes to increase CTE of the ceramic. The disadvantage of excessive sodium though is its tendency to produce a less abrasion resistant surface with an increased solubility in acid [12]. Calcium oxide (CaO) will also help to strengthen the glass phase and reduce the solubility in the presence of a high potassium oxide content. MgO is desirable because it appears to function synergistically with the CaO in strengthening the glass in relation to either on their own [13].

It has been described that dental ceramic should have the following characteristics [14], [15]:

1. Simple processing technique required
2. Precise reproduction of the wax model and high stability of form during further firings (staining, glazing etc)
3. Adequate strength, including a built in safety factor to withstand functional loading
4. Minimal shrinkage
5. Chemical stability under intraoral conditions
6. First-rate bonding with all current clinically proven alloys (whether they be precious, palladium-silver, palladium-copper or non precious) and all high strength ceramic core materials
7. Natural looking, vital colouring under all lighting conditions through natural fluorescence and perfect colour stability even after many firings
8. Be possible to correct work that has already been completed and fired
9. A fine texture that presents no problems for grinding and polishing

From the clinical success point of view, the material used for dental ceramic restorations must meet the following requirements:

1. High flexural strength
2. High fracture toughness
3. Homogeneity of the microstructure (absence of microcracks, pores, etc)
4. Processing formable
5. Non toxic / allergenic
6. Very low solubility
7. High stability in the oral environment; high resistance to acidic foods and solutions
8. Low tendency for plaque formation
9. No undesired interaction with other dental materials
10. No chemical decomposition involving the release of decomposition products

3. Feldspathic Glasses

The feldspathic glasses are compounds containing oxides of aluminium and silicon in combination with potassium, sodium or calcium (e.g. $NaAlSi_3O_8$) [16].

Feldspar is the ingredient primarily responsible for forming the glass matrix [1]. It has been used to make dental ceramics for a number of decades due to the ease at which it can be fritted and coloured to produce high fusing dental ceramics [5]. Naturally occurring feldspar does not exist in a pure form but is a mix of two substances: potassium aluminium silicate (K_2O-Al_2O_3-$6SiO_2$, also called orthoclase or potash feldspar) and sodium aluminium silicate (Na_2O-Al_2O_3-$6SiO_2$, also referred to as albite or sodium feldspar) with free crystalline quartz [1]. The ratio of potash to sodium feldspar differs in a given batch of material. This is important to dental ceramic manufacturers because the two types of feldspar impart quite different handling characteristics to the ceramic [11], in that soda tends to lower the fusion temperature while the potash increases the viscosity of the molten glass [16]. This is because potash feldspars have an extremely high viscosity and this viscosity decreases only relatively slowly with a rise in temperature [5]. The potash form of feldspar not only increases the viscosity of the molten glass but also aids in the control of the ceramic's pyroplastic flow (slumping) during sintering (firing) [11]. Sodium feldspar lowers the fusion temperature of the ceramic causing it to be more susceptible to pyroplastic flow [1]. Sodium feldspar does not contribute to the optical quality of translucency [11]. When feldspar is melted, the alkalis (Na_2O and K_2O) unite with the alumina and silica to form sodium or potassium aluminium silicates. A glassy phase is formed with a free crystalline silica phase [5].

4. Leucite

Leucite is a potassium alumina-silicate ($KAlSi_2O_6$) and undergoes a crystallographic transformation from tetragonal to cubic at 625°C [1], [29]. Most traditional dental ceramics are derived from the K_2O-AL_2O_3-SiO_2 system. As shown by the phase diagram by Levin et al in 1964 [17], potash feldspar (K_2O-Al_2O_3-$6SiO_2$) and leucite (K_2O-Al_2O_3-$4SiO_2$) are important crystal phase of this system.

The leucite based veneering ceramic has been used in the manufacture of metal ceramic restorations since the early 1960s. The high CTE of leucite raises the CTE of veneering ceramic to a level where it is compatible with metal alloys such as gold and platinum. Nowadays, leucite is also popular for use in high strength ceramic core materials. Leucite can be added to by means of two methods : the incongruent melting of potash feldspar or by adding synthetic powder [18]. In early leucite ceramics, it was formed by incongruent melting with potash feldspathic glasses having a K_2O content higher than approximately 12 wt%. More recently, the synthetic leucite has been added in significantly higher concentrations (40-50 wt%) as a dispersion strengthening phase and still retains acceptable translucency because of the relatively close match in index of refraction between leucite and feldspathic glasses [5], [10].

Leucite occurs in both the isometric (cubic) and tetragonal form. In nature, it is generally found in particular types of igneous rocks that are low in salicylic acid content. Leucite can also occur in a spheroidal form and the colouring of its crystals varies from white to grey [19].

Leucite has a very high CTE (24-26 ppm/°C) and its crystallisation in dental ceramics may be brought about by suitable formulation coupled with an appropriate heat treatment. Increasing the K_2O (potash) content of the ceramic will move the composition into the leucite field and increase the tendency to crystallise, particularly in the presence of nucleating agents such as TiO_2. The major crystalline component of dental ceramics rely on a tetragonal leucite containing frit to provide the high expansion needed in the leucite content of selected dental ceramics [20]. At room temperature, the frit consists of crystalline tetragonal leucite embedded in a feldspar-based glass matrix. Any thermally induced reaction which would lower the volume fraction of tetragonal leucite (CTE=20-25 ppm/°C), would lower its average CTE. Leucite is not an equilibrium phase at this composition though and together with the fact that the tetragonal leucite undergoes a displacive transformation to cubic leucite at approximately 600°C to 625°C, indicates that dental ceramics containing leucite may have the potential for significant alterations in thermal behaviour when subjected to repeated firings. The displacive transformation of tetragonal leucite to cubic leucite could have significant ramifications. Because of the reversible nature of this type of transformation, it is probable that it occurs every time a leucite containing dental porcelain is subjected to a normal firing in the dental laboratory furnace. The transformation is complete below 600°C, which is below the glass transition temperature for most dental ceramics. The abrupt change in CTE and the volumetric change which accompanies this transformation occur while the leucite particles are embedded in a rigid glass matrix.

5. Apatite

Apatite is a group of crystalline compounds. The most important compound is calcium hydroxyapatite. The apatite can consist as a number of structure such as fluorapatite (F-apatite), chloroapatite (Cl-apatite) and carbonate apatite (CO_3-apatite). The ion substitution in hydroxyapatite primarily influences the morphology of the crystals and the different properties of the various types of apatite. Biological apatite is classified as carbonate apatite. These substances also illustrate different levels of solubility because of their various degrees of crystallinity. Thus, enamel carbonate apatite is more chemically stable than the dentine carbonate apatite because of a higher degree of crystallinity. However, carbonate apatite demonstrates higher chemical solubility than fluorapatite [9].

As early as the 1970s, the development of apatite glass ceramic was successful in producing bioactive glass for replacement of bone in human medicine [21]. Apatite glass ceramic is a silicophosphate, mainly consisting of SiO_2-CaO-Na_2O-P_2O_5 [22]. Since then, many bioactive apatite glass ceramics have been used for many medical applications such as human body implants and middle-ear devices [9].

In dentistry, the apatite glass ceramic was introduced for use as a veneering ceramic in the fluorapatite ($Ca_{10}(PO_4)_6F_2$) system. Fluorapatite is a form of apatite where the hydroxyl groups (OH) are substituted by fluoride ions, which increase the compressive strength [23]. The microstructure is characterised by needle like fluorapatite crystals. The special properties of this dental ceramic are chemical durability and abrasion behaviour. The dental ceramic exhibits low chemical solubility. The abrasion characteristics of sintered dental ceramic is very good and has shown to be highly compatible with natural antagonistic teeth [24].

6. Summary

Aesthetic dental ceramic are widely used in dentistry. It becomes increasingly popular due to greater insistent of patient for esthetic and public scare about allegedly adverse side effects of metal alloy. However, the recent dental ceramic still have a tendency to chip and fracture in clinical use due to their lack of strength and toughness [1]. Therefore, the future ceramic in dentistry is clearly open to new material and technologies to improve the strength as well as esthetic.

Reference

[1] KJ. Anusavice, *Phillips' Science of Dental Materials,* 11th ed, Saunders, Philadelphia, 2003.

[2] C. Land, "Porcelain Dental Arts," *Dent Cosmos*, vol. 45, pp. 615-620, 1903.

[3] M. Weinstein, S. Katz, and AB.Weinstein, "Fused porcelain to metal teeth," U.S. patent 3 052 928, 1962.

[4] M. Weinstein and AB.Weinstein, "Porcelain-covered metal reinforced teeth," U.S. patent 3 052 983, 1962.

[5] JW. McLean, *The science and Art of dental ceramics Volume I: The nature of Dental ceramics and their clinical use*, Quintessence, Chicago, 1979.

[6] MN. Aboushelib, de Jager N, CJ. Kleverlaan, and AJ.Feilzer, "Microtensile bond strength of different components of core veneered all-ceramic restorations," *Dent Mater*, vol. 21, pp. 984-991, 2005.

[7] MM. Barreiro, O. Riesgo, and EE. Vicente, "Phase identification in dental porcelains for ceramo-metallic restorations," *Dent Mater*, vol. 5, pp. 51-57, 1989.

[8] Z. Strnad, "Glass-ceramic materials," *ELSEVIER*, Amsterdam, 1986.

[9] W. Höland and G. Beall, *Glass-ceramic Technology*, American Ceramics Society, Columbus, Ohio, 2002.

[10] JW. Mclean, *Dental ceramics proceedings of the first international symposium on ceramics. Quintessence*, Chicago, 1983.

[11] WP. Naylor, *Introduction to metal ceramic technology*, Quitessence, Chicago, 1992.

[12] JD. Preston, *Prespectives in Dental Ceramic Proceedings of the Forth International Symposium on Ceramics*, Quintessence, Chicago, 1988.

[13] S. Katz, "High strength feldspathic dental porcelain containing crystalline leucite," U.S. patent 4 798 536, 1989.

[14] Ivoclar Vivadent, *Instructions for use IPS Inline*, Ivoclar Vivadent AG, Schaan, Liechtenstein, 2005.

[15] JR. Kelly, "Ceramics in restorative and prosthetic dentistry," *Annu Rev Mater Sci.*, vol. 27, pp. 443-468, 1997.

[16] R. van Noort, *Introduction to dental materials*, 3rd ed. Mosby, London, 2007.

[17] EM. Levin, CR. Robbins, and HF. McMurdie, *Phase diagrams for ceramists*, American Ceramic Society, Columbus, Ohio, 1964.

[18] PF. Cesar, HN. Yoshimura, WG. Miranda Júnior, and CY. Okada, "Correlation between fracture toughness and leucite content in dental porcelains," *J Dent*, vol. 33, pp. 721-729, 2005.

[19] CD. Heinz, *Dental magazine*, 1981, pp. 6.

[20] PW. Piché, WJ. O'Brien, CL. Groh, and KM. Boenke, "Leucite content of selected dental porcelains," *J Biomed Mater Res*, vol. 28, pp. 603-609, 1994.

[21] CG. jr. Pantano, AE. jr. Clark, and LL. Hench, "Multilayer corrosion films on bioglass surfaces," *J Am Ceram Soc*, vol. 57, pp. 412-413, 1974.

[22] LL. Hench, "Bioceramic: From concept to clinic," *J Am Ceram Soc*, vol. 74, pp. 1487-510, 1991.

[23] BI. Bogdanov, P. Pashev, JH. Hristov, and IG. Markovska, "Bioactive fluorapatite-containing glass ceramics," *Ceram Int*, vol. 35, pp. 1651-1655, 2009.

[24] JA. Sorensen, E. Sultan, and JR. Condon, "Three-body in-vitro wear of enamel antagonist dental ceramic," *J Dent Res*, vol.78, pp. 219, 1999.