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Review Article

CERAMICS - FROM EVOLUTION TO REVOLUTION: A REVIEW

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ABSTRACT:

As new materials and processing techniques are steadily being introduced, the technological evolution of ceramics for dental applications has been remarkable. The interest of dental research in metal-free restorations has been rising following the introduction of innovative all-ceramic materials in the daily practice. In particular, high strength ceramics and related CAD/CAM techniques have widely increased the clinical indications of metal-free prostheses, showing more favourable mechanical characteristics compared to the early ceramic materials. The purpose of the present paper is providing a brief review on the all-ceramic dental materials from their evolution to their revolution.

Key words: Dentistry; ceramic, porcelain fused to metal, zirconia, aesthetics.

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INTRODUCTION:

Since the development of porcelain-fused-to-metal (PFM) procedures in the early sixties, metal–ceramic restorations have represented the *"gold standard"* for years in prosthetic dentistry. They hold up well; they're easy to prescribe and place; and they're predictable. At the same time, the PFM has always had one limitation, and that's esthetics.[1,2] Validated by long-term scientific evidence, the predictability and consistency of positive clinical results, the ease and accuracy of the conventional casting procedures, as well as the findings of rare adverse reactions to precious alloys have made PFM crowns and bridges more and more popular and widespread over time.[2]

In the last 5 years, the dental industry has changed significantly with the advent of CAD/CAM and zirconia substructures. "What's happened is that as the opportunity to create better-looking restorations and prosthetics developed, dentists jumped on it.[1] For many years, gold was the only realistic option when crowning molar and premolar teeth, and restorations of this type continue to provide superb long-lasting service for many patients.

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"DENTISTRY is an evolving profession". "We are becoming much more of a profession for which aesthetics is tied directly into our work, and is not considered as an adjunct to it." Today full coverage crowns are commonly being used for the restoration of heavily filled, fractured, worn or congenitally malformed teeth. Similar restorations are used as the abutments for conventional fixed bridgework and so it is easy to see why they have become the most widely prescribed of all indirect restorations. The desire for an aesthetic solution led firstly to the development of the porcelain-fused-to-metal (PFM) restoration and ultimately to the various all-ceramic types that are available today.[3]

Discussion:PFM restorations were introduced in 1962 following the development of porcelains thermally compatible with dental alloys during firing. It was now possible for porcelains to be fired successfully onto metal substructures, so successfully in fact that, around the world, PFM restorations still comprise over three-quarters of all indirect restorations.[3] History says that their use dates back to 10,000 yrs. ago, during the stone age. Pierre Fauchard did enameling of metal denture. De Chemant – introduced porcelain denture tooth. Charles Land – introduced first Ceramic crown.[4]

Veneering ceramics for metal-ceramic restorations -commonly named feldspathic porcelains- are usually leucite-based. Feldspar-derived glass alone exhibits a low coefficient of thermal expansion, around 8.6 × 10-6/°K. The addition of leucite to feldspar glass led to the production of veneering ceramics with a coefficient of thermal expansion compatible with that of the metal substructure. Considering that metal-ceramic dental restorations have been used in dentistry for more than four decades, their overall performance can be considered as quite successful. This is mainly due to sustained efforts by manufacturers to improve the quality of the materials offered, particularly in terms of crystal size and optical properties, such as opalescence. Metal-ceramic technology is challenging, and optimal aesthetics can only be achieved by skilled technicians. Nevertheless, it was estimated in 2005 that more than 50% of all dental restorations fabricated were metal-ceramics.[5]

All ceramic systems:

Driven by a debatable need for metal-free restorations, the evolution of all-ceramic systems for dental restorations has been remarkable in last three decades. Processing techniques novel to dentistry have been developed, such as heat-pressing, slip-casting, and Computer Aided Design-Computer- Aided Machining (CAD-CAM). Concurrently, all-ceramic materials have been developed to match dental requirements, offering increasingly greater performance from a mechanical standpoint.[5]

Heat pressed ceramics: The popularity of heat-pressed ceramics relies on the ability to use the lost-wax technique to produce dental ceramic restorations. Dental technicians are usually familiar with this technique, commonly used to cast dental alloys. In addition, the equipment needed to heat-press dental ceramics is relatively inexpensive. The first generation of heat-pressed dental ceramics contains leucite as reinforcing crystalline phase. The second generation is lithium disilicate-based.[2,5] Due to their low values of flexural strength (~100–120MPa)-, leucite-reinforced ceramics are only indicated in the anterior region, where aesthetic is paramount, both for single crowns (SCs) and laminate veneers. In a long-term study (11 years), a remarkable survival rate of 98.9%was evidenced with IPS Empress anterior SCs, however such a value dropped to 84.4% in the posterior region [7]. With respect to the veneers, IPS Empress yielded a success rate of 98.8% after 6 years [8], equivalent to the positive results reported for the veneers made of feldspathic ceramics (91–94% at 12 years) [9,10]. A significant improvement in clinical performance was introduced by lithium disilicate glass–ceramics, veneered with fluoroapatite-based ceramics, like IPS Empress 2 (Ivoclar Vivadent, Lichtenstein), showing higher flexural strength (~350MPa) than the precedent ones and, at the same time, very appealing translucency, much more suitable than in zirconia-based ceramics [11]. For such promising characteristics, lithium disilicate glass–ceramics have been advised for clinical use in SCs (molar region excluded) and 3-units fixed partial dentures (FPDs) in the anterior region; in the last years, moreover, both their mechanical and optical properties have been enhanced, with the development of IPS e.max Press (Ivoclar Vivadent, Lichtenstein), thanks to some technical improvements in the production process. [2] Overall, lithium disilicate glass-ceramics for all-ceramic restorations have performed well. Their strength is more than twice that of first generation leucite-reinforced all-ceramics and their good performance has led to their expanded use to restorations produced by machining.[5]

Dry-pressed and sintered ceramics: Densely sintered alumina-based ceramics produced by dry pressing, followed by sintering have been available since the early 1990s and are still currently used. The technique involves computer aided production of an enlarged die in order to compensate for sintering shrinkage (12 to 20%). Dry pressing and sintering of a high purity alumina-based core ceramic is then performed at high temperature (1550 °C). This leads to a highly crystalline ceramic with a mean grain size of about 4 micrometers and a measured flexural strength of 601 ± 73 MPa [12,13]. All production steps are carefully controlled by the manufacturer. The high-strength core is then veneered with translucent porcelain to achieve adequate aesthetics. Clinical results have demonstrated an excellent *in vivo* performance at 15 years [14]. The same technology is also available for zirconia-based core ceramics.[5]

Slip-cast ceramics: Another noticeable improvement in the mechanical properties of all-ceramic restorations was offered by the so-called “glass-infiltrated high-strength ceramic core systems”, developed for the first time in the late eighties with In-Ceram Alumina, followed, after some years, by In-Ceram Spinell and In-Ceram Zirconia (VITA Zahnfabrik, Germany). All of these oxide-ceramics allow the realization of highly stable frameworks for SCs or three-unit bridges with one pontic, based on the so-called "slip-casting technique": a semi-liquid mixture containing up to 80wt% of metal-oxides, like Al_2O_3 (In-Ceram Alumina), $MgAl_2O_4$ (In-Ceram Spinell) or $Al_2O_3 + ZrO_2$ (In- Ceram Zirconia), is sintered to a refractory die, so creating a porous, oxide-ceramic core that undergoes a further firing cycle for lanthanum glass infiltration. Thanks to such a process, the framework flexural strength and load-bearing capacity are remarkably enhanced: the infiltrated glass fills the minute spaces and voids that might initiate cracks and induce excessive stress concentrations in the core structure [15]. Eventually, the aesthetic veneering material (i.e. a feldspathic ceramic) is layered on the core surface.[2] The dual crystalline reinforcement in this system allows two types of strengthening mechanisms:

(1) The stress-induced transformation in zirconia grains produces compressive stresses within the transformed grains and surrounding glassy matrix, as well as circumferential tensile stresses around the grains, accompanied by microcrack nucleation. Keeping in mind that transgranular fracture is difficult in zirconia, this represents an efficient strengthening mechanism.

(2) Crack deflection, contact shielding and crack bridging are expected from the presence of large alumina grains [16].

The combination of these two strengthening mechanisms explains why alumina-zirconia slip-cast ceramics offer the highest flexural strength and fracture toughness of all slip-cast ceramics. [5,17]

Machined ceramics: Computer Aided Design/Computer Aided Design (CAD/CAM) technology was introduced in dentistry by Duret in the early 70's [18]. The technology was originally intended for fully sintered ceramic blocs (hard machining), it has now been expanded to partially sintered ceramics (soft machining), that are later fully heat treated to ensure adequate sintering.[5] CAD/CAM industrial manufacturing of densely sintered, high-purity alumina (Procera AllCeram, Nobel Biocare AB, Goteborg Sweden) introduced in the early nineties and extensively utilized for both single unit restorations and 3-unit anterior FPDs so far. The Procera AllCeram core is realized by compacting, with an industrial process performed at a centralized manufacturing plant in Sweden, high purity aluminium oxide against an enlarged, refractory die of the prepared tooth obtained through a scansion by the dental technician; eventually, the coping is milled in the outer aspect and then sintered to full density. In the end, the resulting, leucite-free porcelain framework, containing about 99.9% alumina in a polycrystalline state, is veneered with low-fusing feldspathic ceramic. AllCeram cores are characterized by a higher flexural strength than glass infiltrated pre-sintered alumina [19] that, in addition to the pure and homogeneous structure of aluminium oxide and to the accuracy of the sinterization process, can explain the very good mechanical performance and resistance to fracture, still maintaining a fair translucency and opalescence [20]. As to the marginal fit, gaps ranging between 60 and 80 micrometers were detected, demonstrating a suitable prosthetic precision of fit [21,22] and also from the clinical standpoint marginal integrity was reported to be excellent or acceptable.[23,24]

Soft-machining of partially sintered zirconia ceramic blocs by CAD/CAM technology, to produce dental restorations was proposed in 2001 after intensive research work [25,26]. The design compensates for the volume shrinkage that will later occur during sintering of the zirconia blocs (about 25%). The partially sintered blocs are easy to mill, which leads to substantial savings in time and tool wear. The type of zirconia used in this technology is biomedical grade tetragonal zirconia stabilized with 3 mol % yttria (3Y-TZP) [27]. Unalloyed zirconia is monoclinic at room temperature and tetragonal above 1170 °C [28]. The tetragonal to monoclinic transformation (t→m) is associated with a substantial volume increase (~4.5%). The high temperature tetragonal form can be stabilized at room temperature by addition of various oxides, including yttria, ceria, calcia or magnesia [28,29]. Partially stabilized tetragonal zirconia exhibits phase transformation toughening, which involves the transformation from tetragonal to monoclinic phase at the crack tip, associated with a volume increase, thereby creating compressive stresses. This mechanism is efficient in preventing further crack propagation and is responsible for the outstanding mechanical properties of partially stabilized zirconia [30]. Of interest is the fact that the stability and therefore the mechanical properties of 3Y-TZP strongly depend on its grain size [31,32]. Above a critical grain size, 3Y-TZP is less stable and more susceptible to spontaneous transformation while smaller grain sizes are associated with a lower transformation rate [33,34]. Grain size is determined by the sintering conditions and particularly the sintering temperature and duration. Higher temperatures and longer durations lead to larger grain sizes. Currently available 3Y-TZP ceramics for soft machining of dental restorations require sintering temperatures varying from 1350 to 1550 °C and durations from 2 to 6 hours, depending on the manufacturer. Since its introduction to dentistry, almost a decade ago, the soft machining technique has been extremely successful. The extensive number of dental publications on zirconia, combined with the large amount of literature published on the various types of zirconia prior to its introduction in dentistry, now provides a large database of information. Several review articles provide state of the art information on zirconia ceramics for biomedical applications.[35,36,37]

From evolution to revolution:

Whether the restoration is a fully pressed all-ceramic porcelain veneer or a zirconia-based all-ceramic restoration, clinicians choose all-ceramics for aesthetic reasons because there is no metal involved. When faced with the decision to select a PFM or an all-ceramic restoration, prescribe a material or restoration based on its indications. Pressable ceramics typically are indicated only for the anterior region for single units only (eg, laminate veneers). When bridges are required—regardless of whether anterior or posterior—then zirconia would be the all-ceramic material of choice. If we are comparing conventional ceramics, feldspathics, and pressables directly to a PFM, then there are definite limitations because these materials don't demonstrate the strength requirements that the new glass-free all-ceramics do. With polycrystalline zirconium oxide materials, that limitation has been significantly reduced. However, there are clinical circumstances for which choosing a PFM may be a matter of selecting the most appropriate restorative option for the indication. Dentists select the best solution for the clinical problem. When it comes to PFMs or all-ceramics, the decision is between a long-standing, very well-proven, and established methodology and a newer, proven, and established methodology. [1,2]

CONCLUSION:

After the development era, dental ceramics introduced in the last 20 years exhibit different, favorable and promising aesthetic and mechanical properties. At the moment, there is no one ceramic material that equally excels in all of these characteristics. The choice of one specific typology of ceramic, rather than on the latest fashion, should be based on a careful evaluation of the very advantages and disadvantages of the material related to the specific dental application, always referring to clinical data with a proper level of scientific evidence and paying attention to the real aesthetic needs of the patient. When it comes to deciding between PFMs and higher-strength, all-ceramic restorations, clinicians are no longer faced with as many limitations as in years past. In fact, all things being equal, clinicians can look at either type and confidently select the high-strength, all-ceramic alternative. With the high-strength zirconia, clinicians have the flexibility to use conventional cementation using glass ionomers, resin-modified glass ionomers, or resin cements. They have a lot of flexibility, and they really don't have the limiting factors any more.

We are an evolving profession. "We are becoming much more of a profession for which aesthetics is tied directly into our work, not considered as an adjunct to it."

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