Dental Ceramics: From Science and Technology to Clinical Application

STATE OF THE ART

Dental ceramics have been around in various forms for over two centuries. Up to the 1960s they were limited to use for denture teeth, inlays and onlays, and porcelain jacket crowns for anterior teeth.[1] Ceramics bring esthetics, but are traditionally limited by their brittleness, as they are susceptible to short-term (fracture) and long-term (fatigue) failures.[2] The role of modern ceramics in dentistry began to become more prominent with the development of resilient metal copings or strong ceramic cores to support weak porcelain veneers.[1] Subsequently, new high-strength ceramics, specifically aluminas, zirconias, and lithia-based glass-ceramics, have expanded their usage to more demanding dental prostheses, such as crowns and fixed dental prostheses (FDPs). The challenge has always been to improve high structural durability while maintaining esthetic qualities. Over the last few decades, dental companies and researchers have strived to meet this challenge. With a burgeoning number of new ceramics entering the market, today's clinician has a wide range of material choices for restorative procedures.

The most commonly used ceramics for the less demanding restorations remain the classical feldspathic ceramics, leucite-reinforced ceramics, and ceramic-polymer interpenetrating networks. For the more stringent prostheses (crowns, bridges), lithia glass-ceramics with compositional and microstructural variants and zirconias with various amounts of yttria stabilizer are primary candidates. All of these ceramics come with a wide range of shades and degrees of translucency. The zirconias are stronger and tougher than the lithia glass-ceramics, but less esthetic. Efforts continue to develop more translucent zirconias by adjusting the yttria content and by grading the microstructure[3] and to enhance the strength of glass-ceramics by manipulating the base glass composition and heat treatment protocol. Again, it is a balancing act.

Tooth restorations need to provide structural support for repetitive mouth motions associated with normal dental function—chewing, swallowing, clenching, and grinding. Bite forces can be substantial, exceeding several hundreds of Newtons. This is exacerbated by the fact that such forces can be concentrated over small occlusal contact areas, so that local stresses can sometimes be sufficient to cause irreversible deformation or fracture.[4] As mentioned, ceramics are inherently brittle, so efforts need to be made to optimize material strength (S, resistance to catastrophic crack initiation) and toughness (T, resistance to crack propagation) properties. Strength is important to prevent crack generation in the first place, and toughness is important to inhibit continued growth of cracks once they start. These properties do not always go in the same direction—measures that improve strength may simultaneously diminish toughness, and vice versa.[5] In addition, ceramics are notoriously susceptible to degradation in cyclic loading; ie, fatigue.[2] Consequently, "standard" laboratory tests that simply measure S and T values may not provide a significant indicator of restorative failure resistance or longevity.

It is instructive to view the latest "strong" dental ceramics in this light of competing mechanical properties. The microstructures of lithia glass-ceramics come in various forms, depending on crystal content (typically

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ranging from 40% to 80%), crystallite size (0.1 µm to 10 µm), and morphology (equiaxed or elongate).[6] Measured strengths vary between 200 and 800 MPa, which is adequate to resist mastication for crowns and 3-unit FDPs up to the second premolar. Marketed zirconias have different yttria contents (3Y/4Y/5Y) and can be processed with different grain sizes.[7] Their strengths tend to be higher (typically 500 up to 1,000 MPa or more with decreasing Y content). The strengths of these ceramics can degrade by up to a factor of 3 over a million loading cycles.[8]

Shaping and finishing techniques, adjustment of the restoration during fitting onto the die and remnant tooth, and geometrical design can all play a decisive role in the ultimate performance of ceramic restorations.[9] With advancements in digital technology, the speed and accuracy of the dental workflow are ever improving. Fabrication processes available to the dental technician are diverse: from lost-wax heat pressing to CAD/CAM machining, high-speed sintering, crystallization or glazing, and even 3D printing. The potential detrimental effects of CAD/CAM machining and other grinding or sandblasting procedures on strength properties have not been fully addressed. Postfabrication heat treatments may only partially heal ensuing microcracks. While zirconia sintering time has been reduced from 8–12 hours to 15–60 minutes, the influence of speed firing on ceramic mechanical and optical properties remains elusive. Three-dimensional printing promises greater ease in fabrication while reducing material waste, but porosity issues may have a deleterious effect on mechanical integrity and optical translucency. Plenty of room remains for the research scientist to explore the fundamentals of shaping and finishing processes in relation to ceramic composition and microstructural flaw distribution.

FUTURE IMPROVEMENTS

What is on the horizon for next-generation ceramic restorative materials and their associated fabrication and finishing technologies? So far, most attention has focused on development of strong and esthetic ceramic materials. CAD/CAM shaping and diamond bur grinding methodologies have not kept pace. Current milling and grinding protocols can compromise ceramic strength and thus need to be optimized.[10] Novel ‘ductile’ grinding technologies that effectively remove the material without introducing strength-limiting subsurface microcracks would appear to be a holy grail for maximizing longevity of ceramic prostheses. The cost benefits of any such improved shaping and finishing techniques promise to be enormous. To date, ductile grinding technology has only been applied to the manufacture of semiconductors and amorphous optical glasses.[11,12] There is an urgent need to develop novel milling and grinding protocols for glass-ceramics and zirconias.

On the next ceramic front, optimization of material composition and microstructure for superior mechanical and esthetic properties appear to be called for in order to circumvent the need for veneering. With the development of functionally graded materials and surface modifications, new ceramics will likely have enhanced esthetics, strength, and adhesive bonding properties. They may also have the capacity to stimulate beneficial biologic responses for better tissue integration and to facilitate repair of defects in both natural and synthetic teeth.[1]

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