Technology update: the clinical-laboratory interface Part two – ceramic selection

David Reaney, David Penn and Philip Newsome explain the structures of the various dental ceramics available today and highlight the importance of making the correct selection for any given clinical situation

There exists today a plethora of different ceramic systems. An understanding of the basic structure of these various dental ceramics is important because their physical properties are a result of their underlying composition and this, accordingly, dictates the most appropriate choice for any given clinical situation. There is, however, considerable confusion among many dentists concerning ceramic choice. We have found it helpful to think about any particular dental ceramic as a composite material sitting at some point on a spectrum comprising, at one end, an unfilled glassy matrix and, at the other, a virtually wholly crystalline structure with little or no matrix at all. Conceptually, this is very similar to the more familiar resin-based composite restorative materials but with a glass matrix as opposed to one comprised of resin.

Predominantly glassy materials — **Particle-filled glasses** — **Polycrystalline ceramics**

Predominantly glassy ceramics

At one end of this spectrum are largely vitreous, or glass, ceramics, three-dimensional networks of atoms having no regular pattern to the spacing and characterised by an amorphous structure.

Dental ceramics in this category come from a group of mined minerals called feldspar and are based on silica (silicon oxide) and alumina (aluminium oxide), and hence belong to a family called aluminosilicate glasses. Such feldspathic ceramics (for example, Vita Alpha and Degudent Allceram) exhibit low opacity and high translucency, low heat conductivity, are hard, chemically inert and biocompatible. While this high degree of translucency means they are unsuitable for masking dark teeth, their main drawbacks are their poor mechanical properties (flexural strength of 56MPa) and the high degree of shrinkage that occurs during firing, with the result that they are nowadays never used as the sole porcelain component of the restoration but rather as a veneer over a stronger underlying core material.

Filler particles

As one moves further along the continuum, filler particles are added in increasing amounts to the base glass matrix to improve mechanical properties and to control optical effects such as opalescence, colour and opacity. The introduction of the particles into the glass matrix can be achieved in a number of different ways, and the particular process used will affect the properties of the material and hence influence material choice.

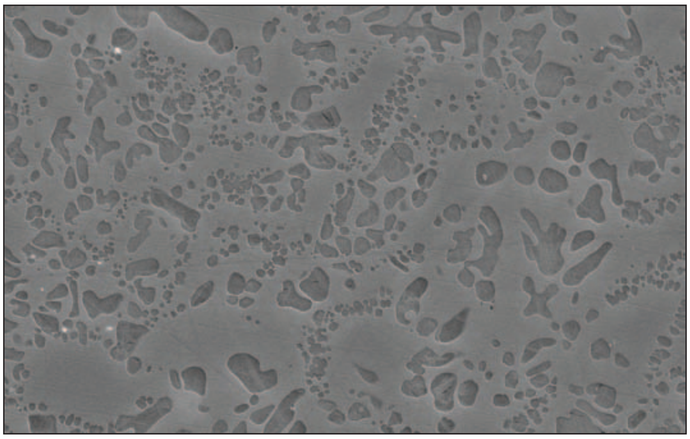

Figure 1: SEM view of Empress Esthetic ceramic

Particle-filled glasses

The first fillers to be used in dental ceramics contained particles of a crystalline mineral called leucite. This was added by simply mixing in the filler ceramic (between 17% to 25% mass). The porcelains created in this way are thermally compatible during firing with dental alloys and therefore can be fired successfully onto metal substructures. Such porcelain-fused-to-metal (PFM) systems, first developed in 1962 (Weinstein), have been so successful that they still comprise over three-quarters of all indirect restorations.

Shortly after the development of leucite-filled porcelain, the search was on for a ceramic core that could act as a more aesthetic alternative to metal, primarily as all-ceramic substructures transmit some light whereas metals do not. The first successful strengthened substructure ceramic (McLean, 1965) was made of feldspathic glass reinforced with particles (55% mass) of aluminium oxide, and so, for the first time, durable all-ceramic restorations were available to the profession – for example Vitadur-N (Vita).

In the 1980s, leucite was used at much higher concentrations (40-55% mass) than those needed for metal-ceramics, and in a system in which the ceramic is pressed into a mould at high temperatures (Wohlwend, 1989), resulting in reduced porosity and excellent fit, e.g. Empress I, now marketed as Empress Esthetic (Ivoclar Vivadent) (Figure 1), OPC (Pentron) and Finesse All-Ceramic (Dentsply). There are two major benefits to using leucite as a filler in dental ceramics (Kelly, 2004). Firstly, leucite's index of refraction is close to that of feldspathic

David Reaney is in private practice in Moy, Co Tyrone, and is managing director of Southern Cross Dental Laboratories (Ireland).

David Penn is in private practice in Sydney, Australia, and is managing director of Southern Cross Dental Laboratories (Australia).

Philip Newsome is associate professor at the Faculty of Dentistry, University of Hong Kong.

porcelain, thus maintaining some translucency and secondly, leucite etches at a much faster rate than the base glass, and it is this 'selective etching' that creates a multitude of tiny features for resin cements to enter and create a strong micro-mechanical bond. Restorations of this type exhibit much improved flexural strength as compared to basic feldspathic porcelain (160-300MPa) as a result of the almost perfect distribution of the leucite crystals within the glass matrix. This is achieved without any significant reduction in translucency.

Glass ceramics
The filler particles just described tend to be added mechanically to the glass, for example by mixing together with the glass powder before firing. An alternative approach is where the filler particles are grown inside the basic glass restoration after it has been formed. In one approach the glass is given a special heat treatment (ceraming), causing the precipitation and growth of the crystals within the glass. The fillers are derived chemically from atoms of the glass itself.

The first such glass-ceramics, as they are referred to, was Dentsply's Dicor (Grossman, 1985). This was followed by a glass-ceramic containing 70% crystalline lithium disilicate, Empress II, now marketed as e.max press (Ivoclar Vivadent). The structure of these porcelains increases flexure resistance to 320-450MPa as result of the densely distributed elongated crystals, which increase in size after pressing. Such porcelains are used to make the restoration's inner coping, which is then covered with a more aesthetic porcelain.

A similar approach involves the use of aluminium oxide as a means of strengthening the underlying ceramic core. Some way was needed of increasing the aluminium oxide filler content above the original 55% achieved by McLean in the 1960s. This was achieved by lightly firing packed alumina powder and then infiltrating this still porous alumina framework with a low-viscosity glass (Hornberger, 1995). The resulting material was put on the market as In-Ceram Alumina (Vita), a material exhibiting high levels of strength and fracture toughness.

Polycrystalline ceramics

At the other end of the spectrum to the predominantly glassy ceramics are the polycrystalline ceramics, which contain densely packed atoms with little or no vitreous glassy 'matrix' phase. This arrangement results in restorations that are more difficult to drive a crack through in comparison to the less dense and irregular linkages found in glass structures. As a consequence, polycrystalline ceramics are generally much tougher and stronger than glassy ceramics. They are, however, much more opaque and more difficult to process into complex shapes than glass ceramics. It was only with the introduction of computer-aided manufacturing (CAM) that well-fitting prostheses made from polycrystalline ceramics became possible. In general these systems use a three-dimensional data set representing the prepared tooth or a wax model of the desired substructure. There are two basic types of polycrystalline dental ceramics currently available based upon their component crystals:

1. Aluminium oxide
With an aluminium oxide content as high as 99%, these materials offer extremely high flexural strength – 680MPa in the case of Procera Alumina (Nobel Biocare). The Procera system was developed by Andersson and Oden (1993), and provides a solution when restorations need to exhibit high strength and aesthetic concerns are not paramount. The manufacture of these restorations uses a scanning process to machine the densely-sintered ceramics and demands very careful tooth preparation if errors in scanning are to be avoided.

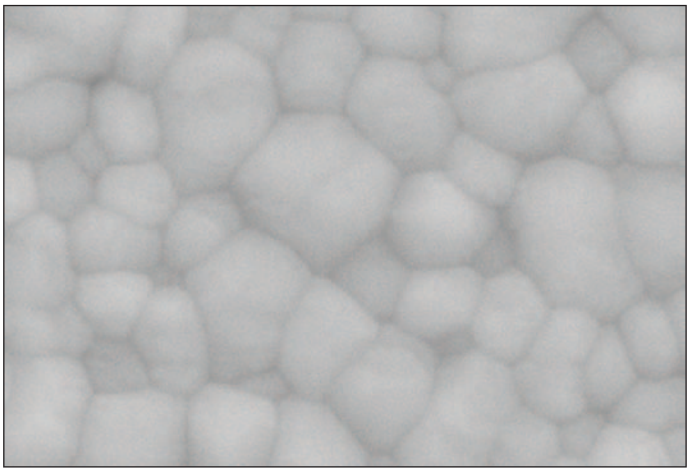

Figure 2: SEM view of zirconium polycrystalline dental ceramic

Figures 3a and 3b: Matching a natural contra-lateral central incisor is often said to be one of the most difficult tasks in everyday clinical dentistry. In this case, highly aesthetic Empress Esthetic has been used to replace a previously placed porcelain-fused-to-metal (PFM) crown

2. Zirconium oxide
Zirconium oxide is a polycrystalline material with a tetragonal structure partially stabilised with yttrium oxide yielding an almost total absence of structural porosities (Figure 2). The result is great strength and fracture resistance (900MPa) and, once again, as a consequence of its high opacity this material is used primarily

Table 1: A guide to ceramic selection

Ceramic system	Restoration type	Indications	Contra-indications	Comments
Zirconium Cercon Procera Zirconia Lava	Crowns and bridges	Premolars and molars where metal-free option is preferred	Inlays Onlays Veneers Anterior teeth	Great strength for posterior teeth but aesthetics not as good as e.max or Procera Alumina. Can be cemented without risks of bonding procedures
Alumina Procera Alumina	Simple anterior bridges Crowns Inlays Onlays Veneers	All restorations where more strength than, say, e.max (Empress II) is required and underlying abutment colour may be a problem	Sharp line angles and uneven thickness of ceramic can lead to restoration fracture	Stronger than e.max (Empress II) and more aesthetic than zirconium-based ceramics. Excellent for masking non-vital teeth. Models are scanned so any undercuts present in the preparation cause problems
Lithium disilicate filler e.max (Empress II)	Simple anterior bridges Crowns Inlays Onlays Veneers	Favourable cases, e.g. moderate occlusal forces, minimal discolouration to be masked	• Insufficient occlusal clearance • Short clinical crowns • Parafunctional habits • Deep discolouration of underlying abutment, root-filled or metallic post and core • Uneven thickness of ceramic • Subgingival margins	Excellent aesthetics although translucency can cause problems if abutment is dark, but can be overcome in some situations by using opaque ingots and opaquers to mask discolouration
Leucite filler Empress Esthetic (Empress I)	Crowns Inlays Onlays Veneers	As above, only more so!	As above	Superb life-like aesthetics, highly translucent

as an internal coping for crowns and bridgework. Examples include Cercon (Dentsply), Lava (3M) and Procera Zirconia (Nobel Biocare). Unfortunately, as a result of its densely-packed crystalline structure, the fitting surface of a zirconium restoration cannot be etched in the same manner as materials such Empress or Procera Alumina and so cannot rely on micro-mechanical retention. Zirconium restorations cannot therefore be used for restorations relying purely on bonding for retention and require the same degree of retention form as conventional, non-bonded restorations.

Aesthetic versus substructure ceramics

From the preceding discussion it can be seen that any given ceramic is primarily suitable for use either as an underlying core material or as an overlying aesthetic veneering material. The predominantly glassy ceramics, i.e. the feldspathic porcelains, are suitable for use as veneers over ceramic substructures. Similarly, the moderately-filled glasses, i.e. between 17% to 25% mass, are for use primarily as veneers over metal substructures. At the other extreme, the polycrystalline ceramics (e.g. Lava, Cercon, Procera Zirconia and Alumina) and highly filled glasses such as In-Ceram and Empress II are extremely strong but so opaque that they are only to be used for substructures. Such high strength ceramics have also been recommended for the creation of substructures for three-unit bridges.

There are, however, some materials that can act as both substructure ceramic and aesthetic veneering ceramic in appropriate clinical situations. These are the highly filled glassy ceramics such as Empress I (Empress Esthetic), Finesse and OPC, which are highly aesthetic and yet still strong enough to produce durable single-unit crowns, inlays, onlays and veneers (Figures 3a and 3b). Consideration of prevailing clinical factors is essential in order to arrive at the correct choice of material.

Choosing the right porcelain

In order to make a rational decision as to which material to use in which clinical situation (see Table 1), one needs to ask the following types of question:

- Does the restoration need to mask tooth discolouration? If so, how severe is this discolouration?
- Will retention of the restoration rely solely on resin-bonding (e.g. veneers) or will conventional retention form be available?
- What is the functional loading on the new restoration? For example, is the restoration a single-unit or a multi-unit bridge?
- Does the patient exhibit signs of tooth wear or parafunctional habits?

Single-unit restorations

By balancing the requirements for aesthetics, strength and avoidance of further tooth wear, one can start to choose a porcelain that is most suitable for any given clinical scenario. Fundamentally, the rationale driving this choice is based upon an assessment of the need for translucency versus opacity, and on the demands on the strength of the restoration/tooth unit. A further consideration is the abrasiveness of the particular ceramic against natural tooth structure. Ideally, this should match that of natural tooth enamel. It is this interplay between light transmission, strength and clinical requirements that must be considered when choosing the type of porcelain to be used (Fons-Font et al, 2006). For example, in many clinical situations there is a need to mask deep discolourations and therefore a highly opaque porcelain is desirable, as is the ability to deliver this level of opacity while still maintaining a thin cross-section and hence the porcelain should also be very strong. In this case, an aluminium oxide ceramic such as Procera Alumina would be appropriate. In other clinical situations, there is less need for such a high degree of opacity and, in fact, this can be highly undesirable when no change of tooth colour is required and a porcelain such as Empress Esthetic would be suitable.

Where strength is the prime concern, as in cases where occlusal loading is high, then clearly a high-strength ceramic is required and the accompanying higher opacity means that aesthetics may have to be compromised.

As far as abrasiveness is concerned, low-fusing ceramic (Empress II, Finesse, Procera) has been shown to cause less wear of opposing teeth than conventional porcelain (Christenson, 2000). It is also well documented that rough, abraded porcelain is extremely damaging to opposing unrestored teeth. One recent study compared various ceramic materials with gold (Elmaria, 2006). While gold, unsurprisingly, proved to be the least abrasive, polished low-fusing porcelains also resulted in minimal tooth wear. This suggests that should intra-oral adjustment be required, thorough polishing will lead to an acceptably smooth surface.

Multiple-unit restorations

The manufacturers of In-Ceram Alumina and Empress 2 have recommended their products for anterior three-unit bridges, while In-Ceram Zirconia, Lava and Cercon have been advocated for posterior three-unit prostheses (Figures 4a and b). Patient selection is critical in such cases and one must ensure that there is adequate available height for the framework material and veneering ceramic. Raigrodski (2004), for example, has suggested that a minimum of 4mm from the interproximal papilla to the marginal ridge of the prospective abutment is adequate clearance for most contemporary systems. With this in mind, the same author (2002) highlighted the following clinical scenarios as

Figures 4a and 4b: The opacity and great strength of zirconium-based ceramics make them ideal for use as internal copings in posterior crowns and bridges in conjunction with a weaker, more aesthetic, ceramic

been unsuitable for the use of ceramic bridges:

1. A deep vertical overlap with a reduced horizontal overlap leading to a deep bite in the anterior maxillary segment that may not allow sufficient labiolingual connector width
2. An opposing tooth that is supra-erupted into the edentulous space that cannot be corrected with minor enameloplasty only and that may be accompanied by mesial drift of a prospective molar abutment tooth into the edentulous space
3. Prospective abutment teeth with short clinical crowns that may restrict the height of the connector.

Other contra-indications include cantilever designs and heavy bruxers – use of a more conventional porcelain fused to metal design is recommended.

Conclusion

All-ceramic restorations have transformed the way we deliver cosmetic dental care to many of our patients. An understanding of the structure and composition of these ceramics is essential to get the most out of them. In a future article we will consider the specific tooth-preparation requirements for such systems, as these are different to those recommended for 'conventional' crown and bridge restorations and have a significant impact on their long-term success.

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