Dental Ceramics: What's New?

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Abstract: **The advances in dental ceramic materials and systems continue to be related to improvements in strength, fitting accuracy and aimed towards avoidance of the use of metal substructures both in posterior and anterior teeth. Many of the changes seen within the last few years have been associated with modifications to, and improvements of, existing techniques. These are considered in this paper, and ceramic post systems are also reviewed.**

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Clinical Relevance: **Modifications in existing dental ceramic materials and new systems continue to be introduced to the dental profession, so clinical and laboratory performance must be considered by the clinician prior to use.**

Ceramic materials now have a firmly established role in many aspects of clinical dentistry. The success of recently introduced ceramic materials and systems may be attributed to several factors, including technological advances and an increasing move towards the avoidance of the use of metals in the mouth and their replacement with tooth-coloured materials whenever possible. The past ten years have seen significant changes, and it is likely that the next decade will continue to herald both innovations and fine-tuning of existing techniques.

As for all restorative materials, improvements in strength, clinical performance and longevity continue to drive the search for the ideal ceramic material. It is also essential that selection of newer systems and materials is based on the best evidence – which may, indeed, be limited.

The traditional problems associated with processing shrinkage and consequent production of accurately fitting restorations has, to some extent, been overcome by other fabrication methods which reduce 'technique sensitivity'. The traditionally inherently brittle nature of ceramics has similarly been addressed by the introduction of stronger materials and by reliable bonding to tooth structure. However, the fit of restorations of some indirect systems still gives cause for concern and their long-term performance is generally unknown. Many changes in the field of dental ceramics technology within the last few years have been evolutions of existing techniques. Other approaches have adopted technologies developed for engineering applications. There have also been completely new innovations such as the use of electronic data transmission to enable remote fabrication at a central facility. Access to complex technology is therefore a possibility for many practitioners when relatively costly equipment is required.

All-ceramic restorations may be categorized according to material composition and fabrication into four groups:

- castable ceramics;
- hot pressed ceramics;
- ceramic powders fired onto a refractory model (applied as a slurry or flame sprayed); and
- machined materials (CAD-CAM, or copy milling).

To date, those ceramic materials which appear to have the strength for use in posterior teeth as full and partial coverage restorations include InCeram (Vita Zahnfabrik, Bad Säckingen, Germany), Procera (Nobel Biocare, Göteborg, Sweden) and Empress (Ivoclar Vivadent, Schaän, Liechtenstein). Irrespective of material, clinical and laboratory studies indicate that tooth preparation should always preserve as much dentine as possible as this will determine the strength of the restored unit. All preparations should be smooth with rounded internal line angles to minimize stress concentrations. Occlusal reduction of 1.5 mm for non-functional and 2 mm for functional cusps are recommended. Traditionally, a shoulder finish line was considered to be essential, but it is now acknowledged that a chamfer or

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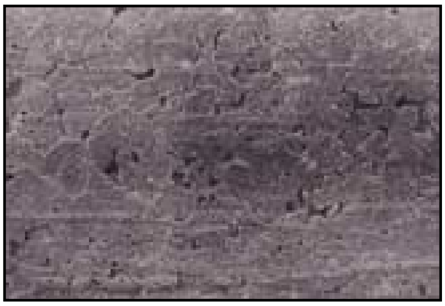

Figure 1. *Microstructure of the fitting surface of a Techceram restoration.*

a shoulder is appropriate. Inlay preparations may be used for small to moderate proximal cavities with enamel margins. Onlay preparations can provide cuspal coverage in situations in which there is a mesio-occluso-distal cavity with intact buccal and lingual walls.

The introduction of strong alumina cores (InCeram and Procera AllCeram) has resulted in restorations that are not susceptible to acid etching and which do not easily form silane bonds due to their low silica content. Bonding of such restorations requires alternative approaches. If successful bonding is to be achieved then the fine sensitivity of the technique to create the link between ceramic fitting surface, luting agent and tooth tissue must be respected.

The marginal performance of inlay/onlay and crown restorations is dependent on factors such as the restorative material itself, the behaviour of the luting material in clinical function and over time, the design of the margins of the restoration and operator ability. Clinical factors are especially significant: fracture in the occluso-proximal contact region of restorations may be related to the site of occlusal contact or to localized occlusal adjustment, for example. Another relevant factor which may be related to the performance of all ceramic crowns is the choice of core and/or post material that serves as support for the overlying structure.

This paper is not intended as a comprehensive overview of all ceramic materials and systems currently available. It should, however, furnish the reader with an update on certain recent developments which may become a part of our future restorative armamentarium.

TECHCERAM

Techceram all-ceramic restorations (Techceram Ltd, Shipley, UK) rely on a patented flame spray process and subsequent sintering to create a uniform alumina base layer 0.1–1.0 mm thick. For crowns, a layer of 0.5 mm is typically used. There are five base layer shades compatible with Vita Classic shade systems; this facility for shade selection permits extension of the base layer to the margin of the restoration. Creation of the final anatomic and aesthetic form is achieved by building up with Vita Alpha opalescent porcelains and subsequent firing.

The flame spray process enables production of base layers that do not shrink during sintering, hence trimming to the gingival margin may be carried out. The sintered fitting surface is rough, which facilitates mechanical retention of the dual-cure resin composite luting agent (Figure 1).

It is recommended that axial reduction of 0.7-1.00 mm is created and that there should be at least 2 mm occlusal clearance. Margins should be rounded and there should be no sharp edges or excessive tapers within the preparation. Tooth preparation and the completed Techceram restorations are illustrated in Figures 2 and 3.

CERAMIC INSERTS

These may be used to reduce the volume of unpolymerized composite resin required to restore a tooth cavity, thereby decreasing overall polymerization shrinkage. In a study to evaluate the effects of glass ceramic inserts and different application techniques of resin composite on marginal leakage, three groups of teeth were compared using Class V cavities on the buccal aspect of all teeth:[1] group 1 received resin composite restorations placed in one increment, group 2 received restorations placed in two increments and group 3 received resin composite restorations with beta quartz inserts. There was no difference between the restorations placed with the incremental technique and those with beta quartz inserts, although the restorations placed with the bulk technique had significantly more leakage. However, Coli *et al*. found increased microleakage when glass-ceramic inserts were used in combination with *All Bond 2* bonding agent.[2]

Worm and Meiers[3] investigated the effect of insert contamination on the resin–insert interface. Latex gloves, bare fingers and saliva all had a detrimental effect and could compromise longevity of a restoration.

Use of a sonic preparation technique in conjunction with ceramic inserts has been described by Koczarski and Mitchell.[4]

Cerana Inlays

Cerana inlays (Nordiska Dental AB, Helsingborg, Sweden) are pre-manufactured translucent leucite-

Figure 2. *Tooth preparation for Techceram restorations.*

Figure 3. *Techceram crowns have been provided to restore the four upper anterior teeth illustrated in Figure 2.*

Figure 4. (a) *The cavity is rendered caries free.* **(b)** *A suitably sized preparation diamond is used to modify the cavity.* **(c)** *A dentine-bonding agent is applied to the completed cavity.* **(d)** *A light-curing composite is placed into the cavity to a level just above the dentine–enamel junction.* **(e)** *An inlay corresponding to the size of the preparation diamond is selected. A bonding agent is applied to the inlay, which is then gently inserted into the cavity before light curing.* **(f)** *Final contouring of the occlusal surface is achieved by finishing with fine diamond burs.*

reinforced glass ceramic inlays of four different shapes:

- Class 1 (standard inlays);
- Class 2 (proxi-primary inlays);
- Class 2 (proxi-replacement inlays);
- Crown sealing (endo inlays) for restoration of ceramic crowns following endodontic treatment.

Accessory products include five diamond preparation burs of different size, contour burs and curing cones. Initial *in vitro* findings indicate that there is favourable marginal adaptation following thermocycling of teeth restored with four ceramic insert systems.[5] Clinical procedures involve tooth preparation with inlay burs. Pulp protection is placed as necessary. The prepared surfaces are etched and bonded and the cavity filled with a light-curing resin composite to just above the dentine-enamel junction. An inlay (pre-etched and silanized) corresponding to the size of the inlay bur is selected and bonding resin applied to the fitting surface. The resin layer is air thinned, the inlay placed into the cavity, excess composite is removed and light cured for 40 seconds. Figure 4 illustrates the clinical procedure involved in restoration of an occlusal cavity with a Cerana inlay. An *in vitro* study carried out by Hahn *et al*. to evaluate the marginal microleakage of Cerana inlays in combination with two different composite luting materials and a polyacid modified composite compared Empress inlays luted with a highly viscous resin composite as a control group.[6] The use of Cerana inlays with a polyacid-modified composite resin did not result in good marginal adaptation. However, both Cerana and Empress inlays with the highly viscous composite exhibited comparable marginal fit.

CAD–CAM

The first chairside-produced ceramic inlay based on a CAD-CAM unit (Cerec, Siemens, Bensheim, Germany) was placed in 1985, since when there have been several related developments, including introduction of the second generation in 1994 – and in 2000 Cerec 3 made its debut. There have been several reports related to the clinical performance of Cerec restorations, the results of which are variable.[7–10] In a 12-year study of 299 patients,[7] 1010 Cerec restorations were placed over 39 months, and reviews were carried out up to 9–12 years after placement. Kaplan-Meier analysis indicated that the probability of survival decreased to 90% (s = 0.018) after 10 years and 84.9% after 11.8 years, with no further loss by the final observation at 12 years. Size and outline form did not appear to affect the success rate. Premolars rated better than molars and vital teeth provided better results than non-vital teeth. The use of a dentine adhesive significantly improved success. Over this period, 81 failures were recorded, the most frequent cause for which was fracture of restoration or tooth.[7] Recurrent caries was the cause for failure in 12 cases, despite previous reporting of alteration in the adhesive interface of Cerec inlays, suggesting that such changes do not necessarily result in recurrent caries.

In a systematic review of the performance of Cerec restorations, Martin and Jedynakiewicz identified 15 suitable clinical reports.[8] They concluded that such a system provides a useful restoration with a high success rate. However, wear of the luting composite on the occlusal surfaces led to submargination. In an *in vitro* study, wear of Vita Mk 2 machinable ceramic itself was less than that of conventional and low fusing porcelains and in turn produced less wear of opposing enamel.[9] Similar rankings were determined in the presence of carbonated beverage Vita Mk2 samples.[10] Ceramic fracture, wear at the interface and postoperative hypersensitivity remained a problem which required further investigation.

Cerec 3

Cerec 3 comprises both an acquisition and a milling unit which enables concurrent design and production of restorations. The software can be supplemented with ‘Cerec 3 Crown’, which contains a tooth library and is said to be suitable for the manufacture of all posterior restorations and anterior crowns. Another option is the Cerec 3 Veneer software for producing anterior partial crowns and veneers. The Cerec 3 milling unit has been separated from the acquisition unit to enable simultaneous design and milling. The milling wheel has been replaced with a tapered diamond bur, reducing the machining process time by 3–5 minutes. The milling element is designed to accommodate the future option of fabricating three-unit bridges. Another feature is the Cerec Scan option for production of a restoration by the indirect approach, in which a conventional model of the preparation and adjacent teeth is cast. This is scanned with an integrated laser scanner, the model is then replaced with a ceramic block and the milling procedure commences.

PROCERA

Procera crowns (Nobel Biocare, Goteberg, Sweden) combine the advantages of a metal coping with high-precision processing techniques. The substructure is fabricated from titanium (a metal used widely in dental implants and with a proven high degree of biocompatibility) using a combination of copy milling and spark erosion. The aesthetic porcelain that overlays the metal core is of a low fusing composition to minimize excess oxidation of the titanium during firing. As with conventional ceramometallic crowns, the integrity of the metal–porcelain interface is critical to the success of the restoration in terms of fracture resistance and colour stability.

In clinical trials over 5–6.5 years, three out of a total of 44 crowns failed due to fracture;[11] loss of colour stability was also noted.

Procera AllCeram

This innovative ceramic was first described by Andersson and Ogen in 1993.[12] It comprises a high-strength, densely sintered alumina core veneered with porcelain. A die, constructed from an impression of the prepared tooth, is scanned to allow remote production of a densely sintered alumina core which is returned to the original laboratory for porcelain build-up of the final crown. To date, there is a lack of long-term clinical data related to the performance of these ceramic restorations, although several studies report relatively good short-term results. For example, a 5-year clinical study of 100 Procera crowns indicated that there was a 94% success rate.[13] Five failures resulted from fracture of the ceramic. However, the success rates may not be directly comparable with other ceramic systems as Procera restorations require preparations of adequate resistance and retention form and some crowns produced by other methods may not. An *in vitro* determination of the compressive strength of Procera AllCeram crowns found them to be slightly weaker than InCeram and IPS Empress restorations, but not significantly so.[14]

Fracture resistance of ceramic restorations is dependent not only on the intrinsic strength and toughness of the material itself: overall fitting accuracy also contributes to the ability of the restoration to withstand biting forces, as a uniform lute space will enable better load distribution. In a laboratory study, May *et al*.[15] determined the luting space to be less than 70 microns for AllCeram crowns, and recorded a similar figure for marginal fitting accuracy. This was in close agreement with the results of Sulaiman *et al*., who determined the mean marginal opening to be 83 microns.[16] Sulaiman *et al.* compared the marginal fit of Procera AllCeram with that of InCeram (161 microns) and IPS Empress (63 microns).

However, traditionally, the fit of an indirect restoration refers to the gap between its inner surface and the prepared tooth, although it is the fit following cementation that is said to be most relevant to long-term clinical performance,[17] and there is no general consensus of opinion as to what constitutes a biologically acceptable marginal gap. Christensen[18] stated that a marginal gap of 25–30 microns would give a cement width with minimal likelihood of microleakage. However, Leinfelder *et al.*[19] noted that the smallest detectable ledge is 100 microns. The problem of measurement of three-dimensional fit has not been practically solved, although several studies have adopted the successful, non-destructive method described by McLean and von Fraunhofer,[20] using an elastomeric wash of the space between tooth and restoration. The marginal fit does not necessarily reflect the accuracy of overall three-dimensional fit which may, in turn, be more significant.

IPS EMPRESS 2 (IVOCLAR VIVADENT, SCHAAN, LIECHTENSTEIN)

Hot-pressed, leucite-reinforced ceramics were introduced some 10 years ago,[21] the leucite crystals serving to reinforce the glassy matrix and prevent crack propagation. In one clinical study, a 97.4% success rate was reported for Empress crowns after 3 years.[22] Although the crystals serve to strengthen the ceramic, the more crystallinity present the more opaque is the framework or core – hence the limiting factor is determined by aesthetics.

With IPS Empress, 30-40% crystal content can be introduced before the aesthetics of the core and resulting restoration are compromised. In IPS Empress 2, controlled crystallization production of a lithium disilicate glass ceramic enables the creation of a 60% crystal content (by volume) without loss of translucency as the refractive index of the crystals is similar to that of the glassy matrix. Furthermore, the strength of the resultant material is reported to be three times that of the original Empress, with a flexural strength of almost 200 MPa.[23]

IPS Empress 2 ingots are processed in the same furnace as IPS Empress glass ceramic but the pressing temperature is 920°C and the pressing procedure takes 5-15 minutes. The lithium disilicate glass ceramic serves as the underlying framework for IPS Empress 2 restorations and the manufacturers indicate that the strength of the material is sufficient to withstand masticatory forces and to support edentulous areas up to 9 mm in the premolar area and 11 mm in the anterior region. The veneering material is a new type of sintered glass ceramic. This powdered overlay is applied to the pressed framework. Fluorapatite crystals are formed through controlled crystallization and are reported to be similar in shape and composition to those in natural tooth structure, providing similar wear compatibility and optical properties.[23] It is also claimed that the fine grain structure and high crystallinity of the glass ceramic reduce the potential for

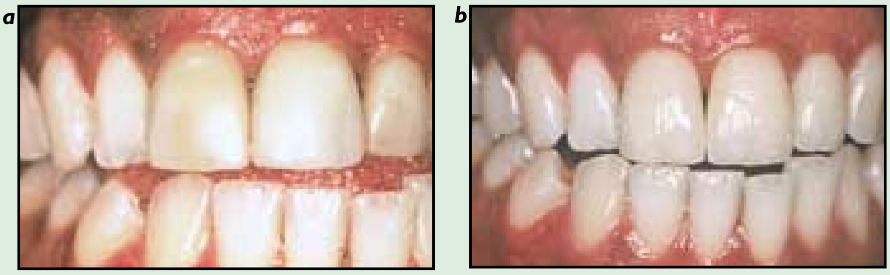

Figure 5. (a) *The preoperative appearance of 1|12 before preparation for Empress 2 crowns.* **(b)** *Empress 2 crowns used to restore the teeth.*

wear of the opposing dentition.

There are definite clinical advantages to using Empress 2. While 1.5 mm axial tooth reduction is usually recommended for metal ceramics, only 1 mm is needed for IPS Empress 2. Another potential application is fixed bridges using inlay and onlay abutments. Figure 5 illustrates the pre- and postoperative appearance of three upper anterior teeth restored with Empress 2 full-coverage restorations.

IPS design (Ivoclar, Amherst, NY)

IPS design is a glass ceramic fused to metal system ceramic featuring a fluorapatite glass ceramic with six matched alloys. As with Empress 2, the fine crystalline structure, said to closely match that of enamel, enhancing aesthetics and minimizing the potential to wear opposing tooth structure, is a glass ceramic with two distinct crystalline components: fluorapatite and leucite.

INCERAM

InCeram core material is primarily crystalline in nature, whereas other forms of ceramics used in dentistry are largely composed of a glass matrix with a secondary crystalline phase. InCeram is said to possess sufficient strength and toughness to be used for anterior and posterior all-ceramic restorations and fixed partial denture bridgework[24] (Figures 6 and 7). The three types of InCeram are based on alumina, spinel (a mixture of alumina and magnesia) or zirconia, which makes possible the fabrication of frameworks of different translucencies by the use of different processing techniques.

The flexural strength and fracture toughness of InCeram alumina are 2.5–3.5 times greater than those of conventional or high-leucite ceramics and it has been reported that this

Figure 6. Final contouring to the framework for a three-unit InCeram bridge.

material can be used for three-unit anterior bridgework in specific, non-load-bearing situations.[25] The introduction of InCeram zirconia makes the provision of posterior bridges a future possibility. Zirconia itself imparts a high degree of toughness to the core material, owing to its ability to undergo a process of shear transformation at a growing crack tip, thus inhibiting crack propagation. Another application of the InCeram technique is in the production of alumina cores for all-ceramic crowns by copy milling.[26]

Marginal adaptation of InCeram has been reported to be inferior to that of IPS Empress and Procera AllCeram,[16] although Neiva *et al*. (1998) found the fracture resistance of InCeram to be better than that of IPS Empress and Procera Allceram.[14] In addition, both glass-infiltrated alumina and yttria-stabilized tetragonal zirconia samples have be shown to exhibit greater resistance to fatigue loading than porcelain and micaceous glass ceramic.[27]

Figure 7. Completed full-coverage InCeram restorations.

Because of the high alumina or zirconia content of InCeram core materials, it is more difficult to create a chemically bonded restoration. The low siliceous glass content limits the possibilities for silane bonding and the acid etch resistance of the fitting surface prevents creation of a micromechanically retentive surface by this method. Blasting the surface with diamond particles improves shear bond strength of InCeram samples[28] and Wood *et al*.[29] reported that the Bateman retention system, which relies on the incorporation of plastic chips burnt out to create a pitted fitting surface, improves the shear bond strength of samples contaminated with saliva (although no differences were observed for uncontaminated surfaces). Furthermore, application of the Bateman technique reduced the flexural strength of InCeram and InCeram Spinel.

MISCELLANEOUS PORCELAINS

The reinforcement of glassy matrices (namely dispersion strengthening[30]) has been the key to improvement of a range of aluminous and feldspathic porcelains.

With aluminous core porcelains, increasing the volume of reinforcing phase to over 50% destroyed the handling characteristics of the slurry and increased the opacity of the fired crown. HiCeram (Vita Zahnfabrik, Bad Säckingen, Germany) is a dispersion-strengthened dental porcelain in which over 50% alumina crystals are employed as the reinforcing phase. The volume of reinforcing phase was increased by means of a specific particle size distribution without sacrificing the aesthetics of the restoration or the ease of manipulation of the powder slurry.[31] The increase in alumina content also raised the tensile strength.[32]

Zirconia fibres were added to Mirage 2 (Myron International, Kansas City) feldspathic porcelain. Toughening may be achieved by inhibition of cracks due to shear transformation of the crystalline zirconia, or by increasing the tortuosity of the crack path. Translucency is reduced, which may be advantageous if masking of discoloured tooth substance is required.

Figure 8. An InCeram alumina sintered all-ceramic post and core.

Feldspathic porcelain with a high leucite content has been marketed (Optec HSP, Jeneric/Pentron Inc., Wallingford, CT, USA). The leucite phase leads to an improvement in strength and toughness as the high expansion coefficient crystals create a network of compressive tangential stresses in the surrounding glassy matrix.[33]

An experimental magnesia-based porcelain has been described. The reinforcing phase, forsterite, is believed to be responsible for the high flexural strength.[34]

Matchmaker ALX (Schottlander, Letchworth, UK) is a leucite-free veneering porcelain specially formulated for bonding to aluminium oxide copings such as Procera and InCeram.

ALL-CERAMIC POSTS AND CORES

All-ceramic posts and cores can be used in conjunction with all-ceramic crowns in an attempt to avoid problems associated with metal posts, including corrosion and discoloration.[35] The clinical application of such systems was reported as early as 1989.[36] Further development of this technique resulted in the introduction of posts and cores made of glass-infiltrated aluminium oxide ceramic,[37] a monobloc technique for the fabrication of a post, core and crown constructed from a glass ceramic material[38] and prefabricated zirconia ceramic endodontic posts[39,40] (Figure 8). A review paper by Koutayas and Kern described four different techniques of all-ceramic post and core construction with high toughness materials[35] and concluded that of slip casting, copy milling, the two-piece technique and the heat press methods, the two-piece system appeared to be the most promising. They also noted that use of all-ceramic posts and cores made of alumina ceramic for canals of less than ISO 110 should be avoided. Long-term clinical data are required before such systems can be considered as favourable alternatives to conventional methods for the indirect restoration of broken down, endodontically treated teeth.

DISCUSSION AND CONCLUSIONS

The diversity and range of applications for the use of ceramics in dental restorations continues to expand. There are still limitations with respect to financial considerations and the exacting laboratory procedures – and, as yet, long-term clinical studies are lacking. However, when selected and used correctly, ceramic restorations can have excellent aesthetic, biological, mechanical and physical properties. The operator and patient also have the benefit of the knowledge that the longevity of restorations of several ceramic systems may equal, if not exceed, that of alternative materials.

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