

# Material Testing and Layering Techniques of a New Two-Phase All-Glass Veneering Porcelain for Bonded Porcelain and High-Alumina Frameworks

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**E**xciting new developments in all-ceramic technology have led to the development of ceramic systems durable enough to be used for full-coverage crowns anywhere in the mouth.<sup>1-4</sup> The advent of CAD/CAM technology in dentistry, specifically for the generation of solid sintered zirconia and alumina frameworks, is being touted as a sure replacement for metal-ceramics. As with metal-ceramics, all of these ceramic systems require veneering with porcelain for an es-

thetic result. There have been significant esthetic improvements in veneering materials for metal-ceramic restorations in recent years. As technologies for CAD/CAM-generated solid-sintered alumina or zirconia, and infiltration ceramics like In-Ceram, are relatively new, less development has taken place in creating esthetic veneering materials for these ceramic coping systems. Thus, some early core/porcelain systems were less esthetic than what was available at the time in metal-ceramic technologies. Many problems with veneering materials have only been dealt with recently.

Problems with veneering porcelains over the years have included poor color stability, abrasiveness, and devitrification with multiple firings.<sup>5,6</sup> Many of these problems are created by the crystalline phase that is contained within the glassy phase of most ceramics. The crystalline phase is included in many materials to impart necessary properties in the material.<sup>6</sup> For instance, leucite is incorporated in metal-ceramic porcelains and certain all-ceramic materials to increase the coefficient of thermal expansion (CTE) of the material so it can be used on metals that have higher CTEs than the base glass. It is also done as a strength-

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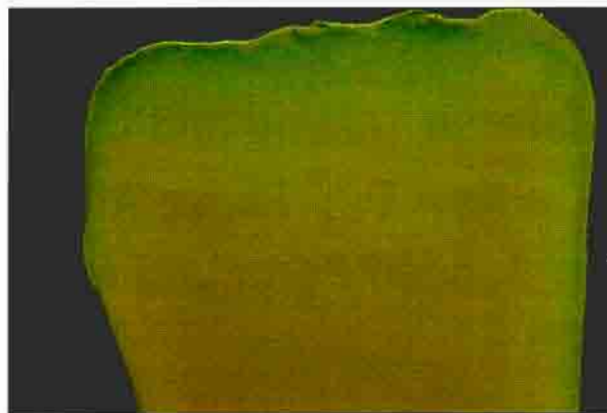
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**Fig 1** Opal porcelain demonstrating a bluish reflection due to scattering of shorter wavelengths of visible light as the longer wavelengths are transmitted. Once the longer wavelengths (orange/red) hit a reflective surface (as in the white background or dentin), they are reflected back, giving an orange appearance. Some of the orange/red color we see in natural teeth is a result of this effect.



**Fig 2** Transilluminated sample of a VM7 opal translucent porcelain. Note the orange appearance from the transmission of orange and the blue spectrum reflected back at the light source.

ening mechanism for the base glass. The leucite phase can be problematic in that it is not stable over multiple firings, as leucite can precipitate or dissolve within the glassy matrix.<sup>6</sup> The net effect is that the CTE of the material changes. This can cause thermal mismatches with either metals or ceramic cores that can lead to catastrophic fracture. Crystalline phases can cause devitrification of the material, which literally means to be less glasslike. In effect, the material gets more opaque, thus losing its vital appearance. This process occurs when the crystals grow in size over multiple firings. One of the benefits of a glassy phase and a separate crystalline phase is optical in nature. If the crystals are the correct size and of different refractive index from the glass, they will scatter or refract light similar to enamel, giving a more natural appearance. Newer materials have incorporated within the enamel crystals on the order of 0.7 microns, which are similar in size to enamel rods. These smaller particles create a scattering pattern of light where only the shorter wavelengths (eg, blue) are reflected and the longer wavelengths (red/orange) are transmitted. This phenomenon, termed the "opalescent effect,"<sup>7</sup> will give a bluish effect in thinner sections and an orange effect if the longer wavelengths

pass through a thicker material and are eventually reflected back at the observer (Figs 1 and 2). Again, the problem with previous materials was that the small particles were not stable after firing and either dissolved or caused devitrification.

Material manufacturers have looked for ways to make the crystalline phase and the added opalescing agents more stable, especially over multiple firings. Techniques to do this are easier for materials that are made for lower-expansion core systems, like alumina and zirconia, as no leucite needs to be added or created in the porcelain to raise the CTE of the parent glass for use on metals. Ideally, some secondary phase needs to be added to the base glass to impart natural toothlike optical properties. One strategy was to develop a material with two glass phases, which are different in size and refractive index, to create diffraction properties similar to materials with a crystalline and glassy phase. The purpose of this article is to discuss initial material testing and the specialized layering techniques of a new material tentatively called VM7 (Vita, Bad Säckingen, Germany), designed for use on high-alumina core systems and for bonded porcelain (veneers, inlays, and onlays), that uses this two-glass phase technology.



## MATERIAL TESTING: ABRASIVENESS AND FLEXURAL STRENGTH

One of the main problems and lingering concerns over the use of porcelains is their abrasive potential or wear of the opposing tooth structure. Wear in the oral cavity is a complex process dependent upon the load applied to the teeth, the food ingested, the bathing solution (saliva), and whatever else may be imbibed. These environmental factors interact with the specific restorative material and the patient's enamel, which varies from person to person. Two major determinants of "enamel wear kindness" are surface finish and microstructure. At a microstructural level, previous-generation materials have had crystalline phases with leucite crystals that have an average size greater than 30  $\mu\text{m}$ . These large particles left microscopically rough surfaces that abrade opposing enamel, thus increasing the wear rate. Porcelain manufacturers have known this for a while and have introduced materials with finer grain structure. A porcelain with a refined structure, such as a small leucite phase on the order of microns or a crystal-free material with fine glass particles, should produce a wear-kind surface that is easily polished or glazed. The preliminary data on these new-generation porcelains do indeed show these materials to be significantly less abrasive than previous materials.

A number of studies have been carried out to examine wear kindness; they have used chewing machines, simulated "oral" conditions, or have been simpler pin-on-disc-type studies.<sup>8-11</sup> A number of studies have tested wear of a limited number of materials opposed to human and bovine enamel with varying results. A part of our testing involved a large number of porcelain and composite resin materials to examine the issue of wear kindness.

Various restorative materials were fabricated into rectangular sections  $2 \times 10 \times 16$  mm. Enamel pieces were sectioned from freshly extracted teeth and loaded into a holder to create an overall size equivalent to the restorative samples. Enamel pins were trephined from freshly extracted teeth. A modified toothbrush abrasion sys-

tem was used to mount the pins on a brass rod. The enamel pins contacted the test materials. A load of 400 g was applied to the pin. The system was run at 160 cycles/min for 60,000 cycles under continuous water flow. Ten samples per group were measured before and after cycling. The load and cycling parameters represent a common value determined from an extensive literature search on wear testing of dental restorative materials. Restorative samples were polished to 1 micron using a series of diamond wheels and pastes.

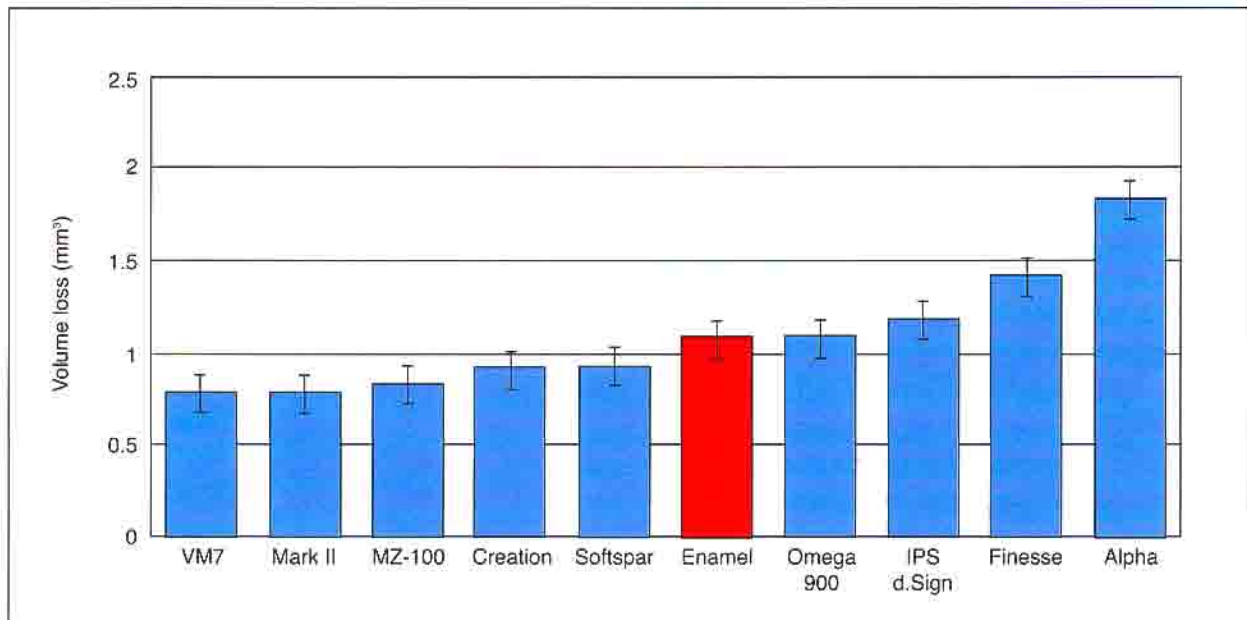
The results shown in Table 1 and Fig 3 demonstrate the low enamel wear for the new veneering material, VM7. Also note the wear kindness of materials with small crystal structure. As expected, composite resin exhibits low enamel wear but higher material wear. In Fig 4, the data displayed have been normalized with respect to enamel. Enamel is made to equal a value of 1. The wear ratio attempts to include both material and enamel loss and to compensate for differences in enamel samples. Wear ratios closest to 1 indicate wear that most simulates that of opposing enamel. Of all the materials tested, VM7 comes closest to that of enamel opposing enamel with respect to material loss and enamel loss. In addition to measuring volume loss of material and enamel, the surface roughness was measured using a profilometer. The average roughness values for each material were measured before and after wear testing (Fig 5). Roughness may be important with respect to gingival health. Increased plaque accumulation may occur as the restoration surface becomes rougher during clinical service.

Figure 6 is a scanning electron micrograph (SEM) of acid-etched VM7, and Fig 7 is an SEM of the old Vitadur Alpha (Vita) material. The structure of the VM7 is a refined two-phase glass of much finer particle size than the Alpha material, which helps explain the good wear kindness of this material. This porcelain, as is the case with other alumina veneering porcelains, does not contain a crystal phase. As part of the analysis of new materials, strength testing of VM7 was conducted and compared to other veneering materials. Porcelains were mixed using a standard water-powder ratio

**Table 1** Enamel Wear Test: Material/Enamel Volume Loss

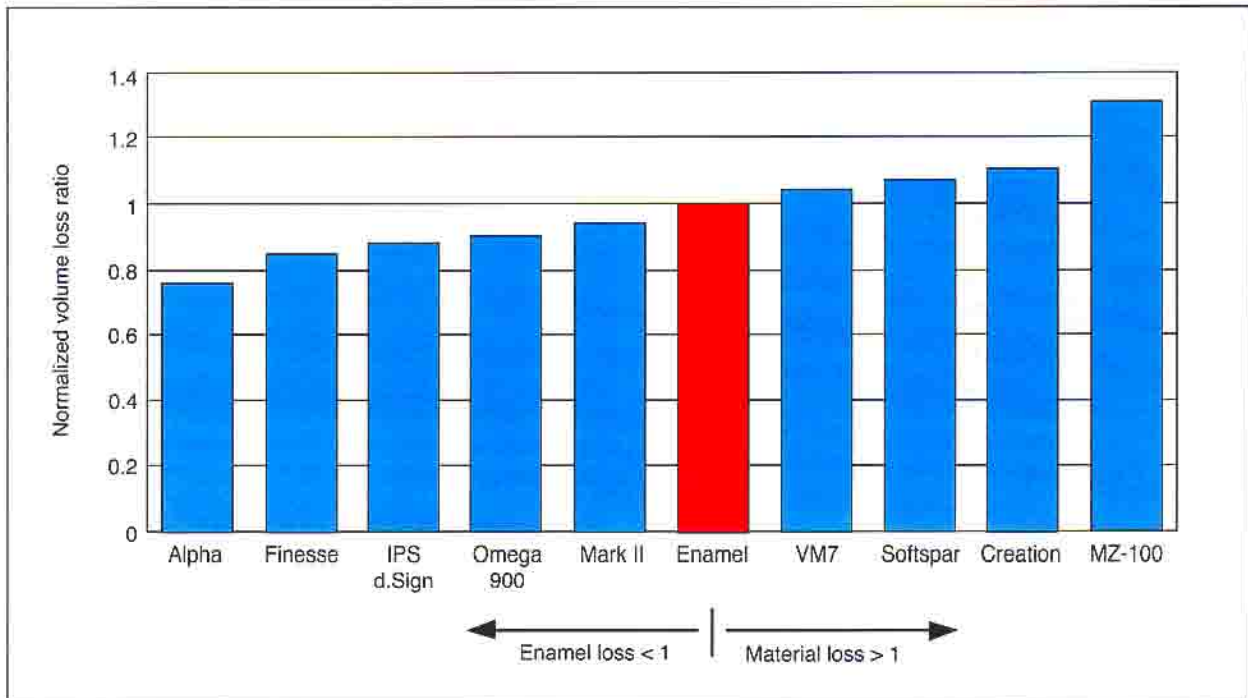
| Material               | Manufacturer                      | Material volume loss (mm <sup>3</sup> ) | Enamel volume loss (mm <sup>3</sup> ) | Wear ratio normalized relative to enamel | SD |
|------------------------|-----------------------------------|---|---------------------------------------|--|----|
| Enamel                 | —                                 | 1.09 ± 0.04                             | 1.19 ± 0.25                           | 1.0                                      | A  |
| VM7                    | Vita (Bad Säckingen, Germany)     | 0.77 ± 0.22                             | 0.8 ± 0.1                             | 1.04                                     | A  |
| Mark II                | Vita (Bad Säckingen, Germany)     | 0.68 ± 0.17                             | 0.8 ± 0.1                             | 0.94                                     | B  |
| Creation               | Jensen Industries (Northaven, CT) | 0.94 ± 0.21                             | 0.93 ± 0.12                           | 0.94                                     | B  |
| Softspar               | Jeneric/Pentron (Wallingford, CT) | 0.93 ± 0.11                             | 0.95 ± 0.18                           | 1.07                                     | B  |
| Omega 900              | Vita (Bad Säckingen, Germany)     | 0.91 ± 0.25                             | 1.1 ± 0.32                            | 0.90                                     | B  |
| IPS d.Sign             | Ivoclar (Amherst, NY)             | 0.97 ± 0.14                             | 1.2 ± 0.27                            | 0.88                                     | C  |
| Finesse                | Dentsply/Ceramco (Burlington, NJ) | 1.09 ± 0.21                             | 1.41 ± 0.23                           | 0.84                                     | C  |
| Alpha                  | Vita (Bad Säckingen, Germany)     | 1.27 ± 0.21                             | 1.83 ± 0.09                           | 0.75                                     | D  |
| MZ-100 composite resin | 3M/ESPE (St Paul, MN)             | 1.0 ± 0.13                              | 0.85 ± 0.14                           | 1.3                                      | E  |
| Temporary bridge resin | —                                 | 3.11 ± 0.74                             | 0.36 ± 0.1                            | 9.4                                      | F  |

Wear ratio: Values > 1 indicate material loss. Values < 1 indicate enamel loss. Ideal values are closest to 1. SD: Materials with the same letter are statistically equivalent.

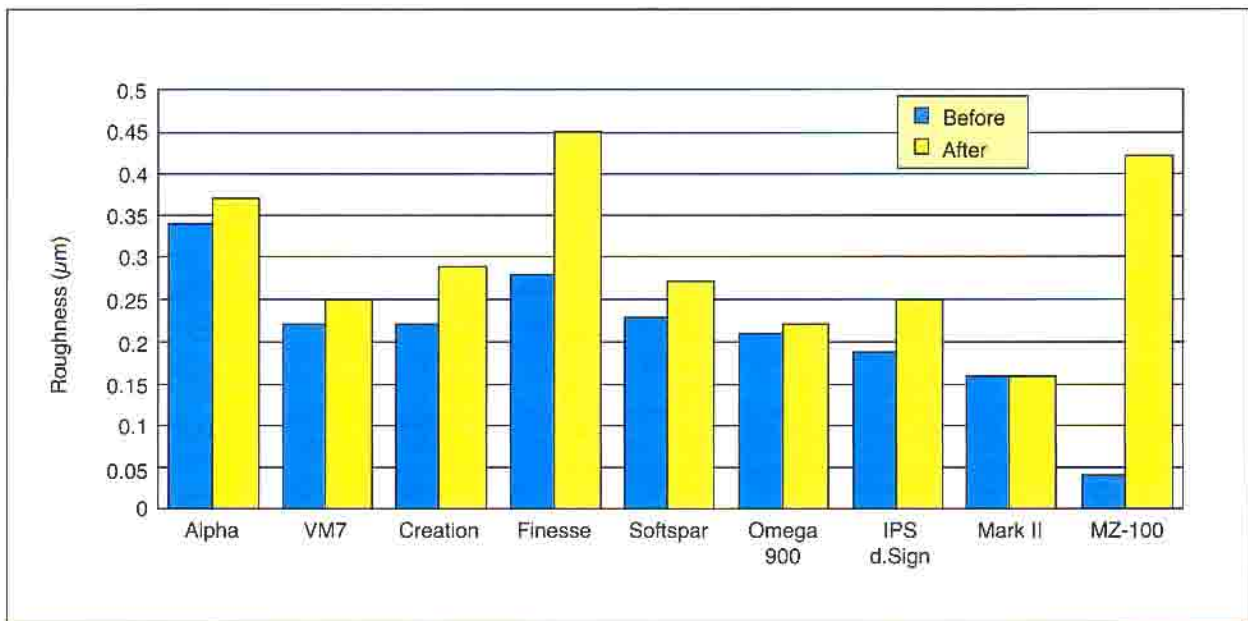


**Fig 3** Graph demonstrating the wear of the opposing enamel from the various test materials. The red bar represents enamel wear against enamel. The VM7 material demonstrated the least wear of the enamel.

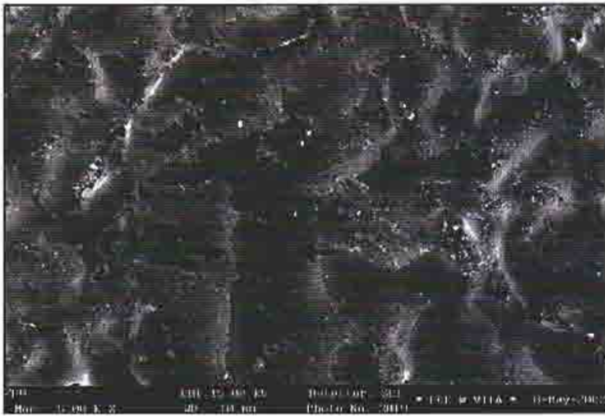




**Fig 4** The left half of the graph represents increasing abrasiveness (loss) of enamel and less attrition (loss) of the test material relative to enamel. The right half of the graph represents increasing attrition and less abrasiveness of the test material relative to enamel.



**Fig 5** Graph of roughness data of test materials before and after testing. There is a close correlation between roughness and abrasiveness.



**Fig 6** SEM of the VM7 material demonstrating the fine structure. The two separate glass phases can be clearly seen.



**Fig 7** SEM of the previous Alpha material, which has a significantly coarser structure than the new material. This coarseness contributes to its increased abrasiveness relative to finer-structure materials.

**Table 2** Flexural Strength of Porcelain Materials

| Material           | Manufacturer                             | Flexural strength (MPa) | SD |
|--------------------|--|-------------------------|----|
| Omega 900          | Vita (Bad Säckingen, Germany)            | 128.8 ± 7.9             | A  |
| VM7                | Vita (Bad Säckingen, Germany)            | 104.1 ± 8.4             | B  |
| IPS d.Sign         | Ivoclar (Amherst, NY)                    | 88.9 ± 4.6              | C  |
| Finesse            | Dentsply/Ceramco (Burlington, NJ)        | 88.5 ± 10               | C  |
| Creation           | Jensen Industries (Northaven, CT)        | 82.8 ± 5.4              | C  |
| Alpha              | Vita (Bad Säckingen, Germany)            | 78.3 ± 7.6              | C  |
| All-Ceram          | Procera/Nobel Biocare (Göteborg, Sweden) | 78.9 ± 10.3             | C  |
| Low-fusing ceramic | —  | 77 ± 27.9               | C  |
| Ceramco II         | Dentsply/Ceramco (Burlington, NJ)        | 76 ± 15                 | C  |
| Softspar           | Jeneric/Pentron (Wallingford, CT)        | 73.5 ± 9.3              | C  |

SD: Materials with the same letter are statistically equivalent.

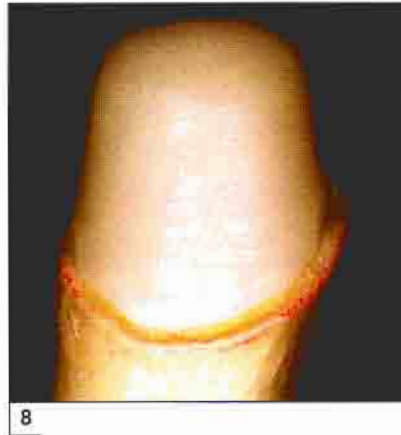
and vibrated into silicone molds to form standardized bars 2 × 4 × 25 mm. The bars were condensed and fired according to the manufacturer's recommendations. Ten bars per group were tested in three-point flexure using an Instron Universal Testing Machine with a crosshead speed of 0.5 mm/min, and strength values were automatically calculated using the standard formula for three-point bending contained in the Instron software. VM7 has a strength of 104.1 ± 8.4 MPa as compared to 78.3 ± 7.6 MPa for Vitadur Alpha and 78.9 ± 10.3 MPa for All-Ceram. Omega 900, which

has leucite crystals in the 3- to 5- $\mu$ m range, has a flexural strength of 128.8 ± 7.9 MPa as compared to 88.9 ± 4.6 MPa for d.Sign and 76 ± 15 MPa for Ceramco II (Table 2). In addition to improved wear kindness with a refined microstructure, mechanical properties are also improved. The VM7 material is significantly stronger than the original Alpha porcelain designed for use with alumina core materials as well as a number of porcelains used for metal frameworks. Only Omega 900 is significantly stronger. Correlation between flexural strength and smaller crystal size is also seen with these values.



**Fig 8** Procera core with the margin cutback on the facial to allow for a porcelain margin.

**Fig 9** Application of liner porcelain as a margin material. In this case the direct lift technique was used.



### LAYERING WITH THE SKELETON BUILDUP TECHNIQUE

There have been several techniques described over the years for building porcelain. Space limitations render it impossible to discuss all of them here; the reader is referred to several excellent sources that discuss these techniques in detail.<sup>12-17</sup> This new material is different enough from previous materials to require a slightly altered building technique to maximize the esthetic results. Several years ago, a simplified porcelain building technique, called the "skeleton buildup technique" was described for building the Alpha porcelain.<sup>5</sup> This technique was adapted for use with the new material. The skeleton buildup technique is a compilation of many techniques broken down further into distinct manageable and easily correctable steps. It is so named to create an image of a structure that is built from the skeleton outward one layer at a time, each of which is individually completed (fired) prior to veneering the skin (enamel surface), thus allowing maximum control of both shape and shade.

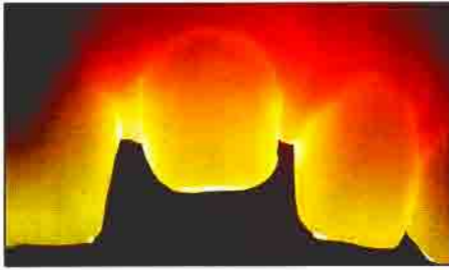
#### Core System and Design

The first material of this kind to be marketed is designed to be used with In-Ceram, Spinell, and Procera alumina cores. Subsequent materials are being developed for zirconia-based ceramics.

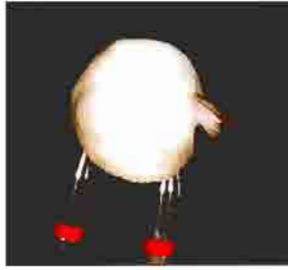
More translucent core systems, especially in situations where masking is not indicated, are ideal. We have found the Cerec in-lab system using the Vita Spinell material or the new translucent Procera densely sintered alumina core systems to have the best available combination of physical properties and translucency for anterior crown situations. While the translucency of the core is favorable, the marginal region can still be problematic, as the core rarely has the same chroma and translucency of cervical dentin. The recommended solution for this problem is to design the cores with a slight labial cutback (Fig 8) of about 0.5 mm and use the liner porcelain from the system as a porcelain margin material (Fig 9). These cores can be safely trimmed to 0.3 mm on the facial aspects if additional space is required.<sup>18</sup>

#### Liner Porcelain

Liner porcelain can be used as a margin material, as previously stated, to improve the optics in this region. The material has fluorescence similar to that of natural dentin, which is most important at the margin or gingival area and less important in other areas of the restoration. Fluorescence adds about 3% of the light we see reflected off natural teeth, thus having minimal effect on optics in the middle and incisal regions of the crown, but in the gingival area fluorescent materials act as light carriers much like a fiberoptic. Light is carried from



**Fig 10** Transilluminated coping with the fluorescent liner material used as a margin material and covering the core. The fluorescent material acts like a fiberoptic carrying light, which helps illuminate the surrounding gingiva.



**Fig 11a** Application of the liner.



**Fig 11b** The liner layer fired.

the marginal area, helping to illuminate the marginal gingiva, which gives the restoration and the gingiva in this area a more natural appearance (Fig 10). The liner is applied in a thin layer (about 0.2 mm) and fired (Figs 11a and 11b). The liner gives a little chroma and brightness to the core while still maintaining translucency.

### Base Dentins

Base dentins are new materials replacing the traditional opacous dentins. They have improved chroma and opacity, such that the material could be used without dentin in thin areas where chroma is needed but little space is available for the dentin layer. Examples are veneer situations where it is necessary to create chroma and ideal opacity but minimal space is available (Figs 12a and 12b). The base dentins of the desired shade are built to mimic dentin that needs to be replaced. In building base dentin materials, some contrasting elements need to be placed (ie, color zones). Even in bleached teeth there are at least three distinct contrast zones. As a general guide, the chosen base shade is placed in the middle third, a shade slightly higher in chroma and lower in value in the gingival third, and a shade slightly lower in chroma and lower in value in the incisal third. This layer should be slightly overbuilt at this point and then fired (Fig 13). Slight overcontouring can be easily contoured with a bur after firing.

### Dentins

The dentins in the new system have better chromas and hues that are closer to natural tooth structure than the previous material. Dentin materials are placed over the fired base dentin layer using the same color or contrast scheme as the base dentins. Again, it is best to slightly overbuild the dentins, which can be adjusted after firing (Figs 14a and 14b).

### Incisal Framing

The next step in the process is to build the lingual incisal edge out of enamel and translucent materials, termed "incisal framing." With the internal structure (skeleton) of the base dentins and dentins fired, it is easier to control the position and dimensions of the enamel materials. The lingual wall of the incisal edge (incisal frame) is built up with a 50/50 mixture of enamel light and the light-blue translucent effect enamel (EE8 in the beta test kit) for light shades, and with a 50/50 mixture of enamel dark and EE8 for shade 3 value (A3 with the old shade system) and darker. This is then fired. Due to the small volume of porcelain, firing shrinkage is minimal, thus affording maximum positional control of the incisal edge. Slight overbuilding can be adjusted after firing, and slight underbuilding can be corrected by adding more porcelain and refiring prior to going to the next layer (Figs 15a and 15b).

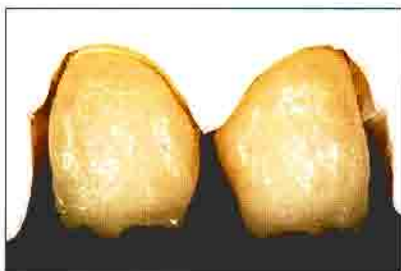




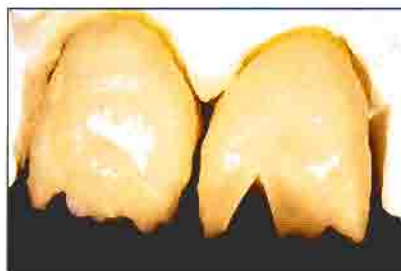
**Fig 12a** Preoperative view of the temporary bonding of a Class IV fracture.



**Fig 12b** Postoperative view of a thin veneer that primarily used the base dentins for the internal structures.



**Fig 13** The base dentins were built up and fired to establish the color contrast zones described in the text.



**Fig 14a** Buildup of the dentins following the same scheme as for base dentins.



**Fig 14b** The dentin layer fired.



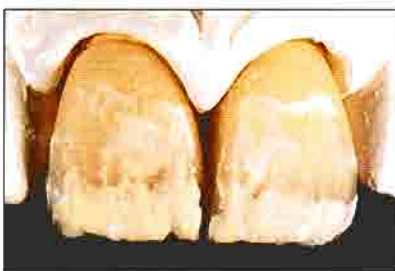
**Fig 15a** Buildup of the incisal frame, which is the lingual half of the incisal edge.



**Fig 15b** The incisal frame after firing.



**Fig 16** Internal (mamelon) effects applied with a glaze liquid so the effects can be visualized before firing.



**Fig 17** Effect powders air fired to 800°C. They are chalky in appearance at this point. The powders can be rewet with stain liquid to visualize the fully sintered effect.

### *Internal Effects*

Mamelon or other internal effects are created at this point. Special high-chroma porcelains called mamelon powders were developed for this purpose. The colors of these new mamelon powders are not realistic, so we use the intensives from the Vitadur Alpha porcelain system for mamelon effects. The disadvantage of using the intensives from the old system is that they are not as color stable as the new material; if an extra firing or two is needed, the colors will burn out somewhat. Mamelon and other high-chroma effects can be created with fluorescent stains, which do not burn out with repeated firings. Vita Internos and the internal live stains for Cerebein (Noritake, Aichi, Japan) work well for this. It is important to layer these very thinly, as they are intense and could be easily overdone in the final result.

The intensives are layered on top of the fired dentin using a stain-type liquid to create mamelon effects (Fig 16). Other effects are created in the same manner. These are then air fired to only 800°C to set them on the surface. Firing to 800°C will not affect the internal microstructure of the fired dentins and enamels, thus minimizing the potential devitrifying effect of multiple firings. After firing, the applied effect powders will appear chalky as they are incompletely sintered at this point (Fig 17). Wetting the surface with a glycerin-type liquid will alter the refractive index to allow viewing of the fired effects. This step can be repeated as many times as necessary until the desired effects are obtained. If the effects are excessive, they can be easily removed prior to proceeding to the next layer. With a full-contour buildup technique, effects cannot be viewed until after complete sintering. If undesired effects are created, complete stripping of the crown may become necessary.

### *Enamel Skin*

The enamel or translucent layer ("the skin layer") is placed next. The new material has 11 different translucent materials called "effect enamels." There

are also three translucent pearly enamels that are useful to recreate a bleached tooth effect (Figs 18a and 18b) as well as three translucent highly opal porcelains for cases that require a bluish or whitish opal effect. Because of the two-glass phase of this new material, the translucent materials are more color stable over multiple firings and resist devitrification. In our experience, the colors, translucencies, and opalescent effects have shown to mimic nature more closely than the Alpha material.

For bright cases, Opal Translucent 1 built at the incisal edge with Effect Pearl 1 used in the middle third gives a believable bright result. Generally, for the gingival third the light-yellow/orange effect enamel used about 0.2 mm thick gives a slight warmth to this region (Fig 19). Because of the exacting control of the internal layers (skeleton), the precise control of the enamel/translucent layer (skin) is fairly easy. Overbuilding is preferred to allow slight contouring of the porcelain after firing, rather than a second addition of translucent porcelains to complete contour. If an incisal halo effect is desired, it is created by placing a thin bead of a mixture of dentin and enamel porcelain at the incisal edge of the facial translucent layer. Any slight corrections of form can be completed by the addition of small amounts of translucent porcelains. This is then fired to complete the buildup (Fig 20). If after the skin bake the contour is insufficient, a correction bake is completed by adding the necessary material to full contour and firing.

### *Contouring and Glazing*

Contouring and surface texture are completed as necessary using diamonds and stones. It is not possible to cover all the steps involved in contouring and glazing, as this is beyond the scope of this article. QDT 2004 is scheduled to include our step-by-step process for finishing a restoration, called "the final touch." It is important to note that natural teeth, even very old teeth, have some surface texture. Proper contour and texture are a prerequisite for natural-looking restorations. Figures 21 and 22 show two cases in which the new VM7 material was used as described.





**Fig 18a** Final preparation and shade taking of a single central veneer to be matched to adjacent bleached teeth. Note the relatively dark dentin shade and that the unprepared teeth are higher in value than the 1M1 shade guide.



**Fig 18b** Postoperative view. The maxillary right central is veneered using the new pearlescent VM7 material to match adjacent bleached teeth.



**Fig 19** Layering the enamel skin layer. Generally opal blue is used at the incisal corners, Opal Translucent 1 is used in the rest of the incisal two thirds, and an effect enamel with a slight warm chroma is used in the gingival third.



**Fig 20** The all-ceramic crowns after firing the enamel skin layer.

## CONCLUSION

Material testing of this new material has demonstrated flexural strength similar to or better than previous-generation materials. Within the constraints of this study, the material demonstrates abrasive and wear potential similar to enamel, which is ultimately what is desired from a restorative material.

A simplified porcelain building technique, called the skeleton buildup technique, was de-

scribed for use with this new material. This technique might seem time intensive, but in reality the time spent building porcelain is the same as for other techniques. The only difference is the oven time; if the ceramist can do other work while the restoration is baking, there is no actual increase in labor time. The benefit of this technique is complete control of each buildup step with the ability to view each fired layer and adjust it as necessary prior to proceeding. It is also a great teaching tool.



**Fig 21** Postoperative view after restoration of two old all-ceramic crowns (inset). The maxillary left central incisor was discolored due to previous root canal therapy and a metal post and core.



**Fig 22** Postoperative view of a tooth that had discolored subsequent to trauma and root canal therapy (inset). Note the excellent optics of this new material that matches closely to natural tooth structure.





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