

Zirconia-Based Ceramics: Material Properties, Esthetics, and Layering Techniques of a New Veneering Porcelain, VM9

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In the search for the ultimate esthetic restorative material, many new all-ceramic systems have been introduced to the market¹⁻³; the use of all-ceramic materials is increasing at almost an exponential rate. Ceramics offer the potential for excellent esthetics, biocompatibility, and long-term stability.¹⁻³ One material currently of great interest is zirconia. Zirconia is the strongest and toughest ceramic material available for use in dentistry today.⁴ Zirconia has the potential to allow for the use of reliable, multiunit all-ceramic restorations for high-stress areas, such as the posterior region of the mouth.

Although still too new to have generated 5- and 10-year studies, in 2 years of using zirconia

frameworks for single crowns and some short fixed partial dentures (FPD) at the UCLA School of Dentistry and Boston University, the authors have yet to encounter a single failure. Three-year data from studies in Germany and Switzerland, where zirconium-core technology was developed, are now emerging; these report no fractures of the zirconia frameworks.⁵

Zirconia frameworks are available from several computer-aided design/manufacturing (CAD/CAM) systems, such as Vita YZ from CEREC inLab (Sirona, Bensheim, Germany), Lava (3M/ESPE, Seefeld, Germany), Cercon (Dentsply/Degussa, York, PA, USA), and Procera Zirkon (Nobel Biocare, Göteborg, Sweden). In addition to new framework materials, veneering porcelains are being engineered with fine microstructures to improve the clinical benefits for the patient. Concomitantly, the microstructures create improved optical properties that more closely mimic the properties of natural teeth (Figs 1 and 2). The understanding of color science relative to teeth has improved in recent years, as some manufacturers have improved shading to be able to more closely replicate the shades of natural teeth.⁶

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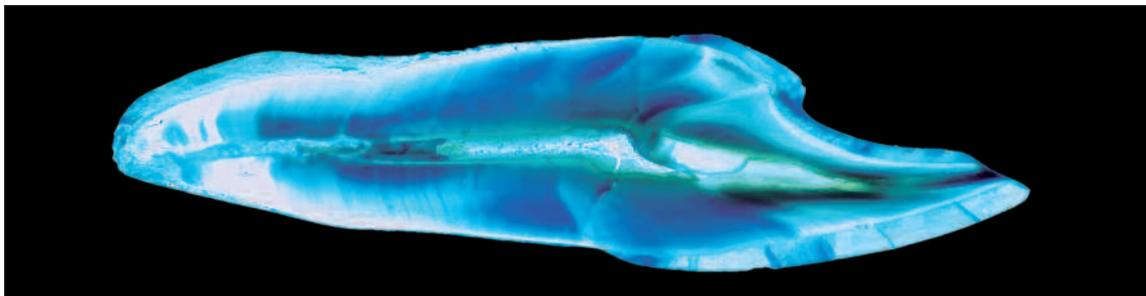


Fig 1 Section of natural tooth displays opalescence, fluorescence, and iridescence under specialized light.

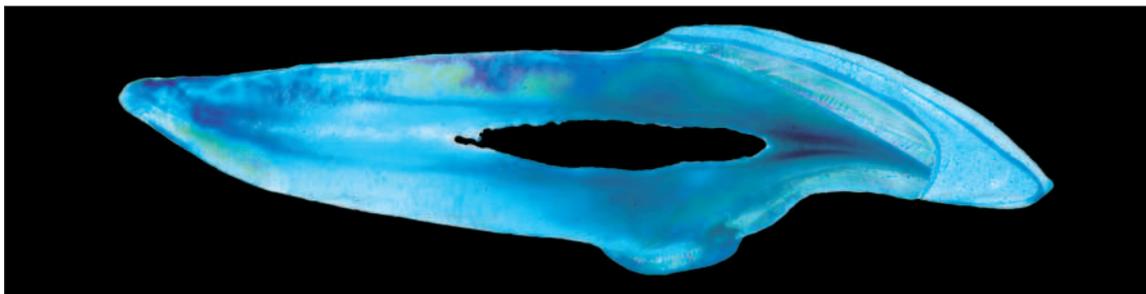


Fig 2 Section of veneered natural tooth with VM9 displays similar natural tooth optics.

VM9 (Vident/Vita, Brea, CA) is one such material with a fine microstructure and improved optics; it is specifically designed to be used on Vita YZ zirconia but has a thermal expansion coefficient to match other zirconia materials such as Lava, Cercon, and Zirkon. The purpose of this article is to discuss the material properties of the new zirconia core systems, esthetic optimization of core design and use of core bonding agents, and the material properties and specialized esthetic veneering technique of a new porcelain specifically designed for solid-sintered zirconia frameworks.

MATERIAL PROPERTIES AND FABRICATION TECHNIQUES

Zirconia (ZrO_2) is an oxidized form of the zirconium metal, just as alumina (Al_2O_3) is an oxidized form of aluminum metal. Zirconia may exist in several crystal types (phases), depending on the addition of minor components such as calcia (CaO), magnesia (MgO), yttria (Y_2O_3), or ceria (CeO_2). These phases are said to be stabilized at room temperature

by the minor components. If the right amount of component is added, one can produce a fully stabilized cubic phase—the infamous cubic zirconia jewelry. If smaller amounts are added, 3 wt% to 5 wt%, a partially stabilized zirconia is produced. The tetragonal zirconia phase is stabilized, but under stress, the phase may change to monoclinic, with a subsequent 3% volumetric size increase. This dimensional change takes energy away from the crack and can stop it in its tracks. This is called “transformation toughening” (Fig 3). Also, the volume change creates compressive stress around the particle, which further inhibits crack growth.

Natural teeth often contain many cracks in the enamel, which do not propagate through the entire tooth. These cracks can be stopped by the unique interface at the enamel-dentin junction.⁷ The ability to stop the cracks as they enter the zirconia core structure mimics the effect seen in natural teeth. Furthermore, the core may be able to resist high-stress areas internally, such as sharp line angles in the tooth preparation, grinding damage during internal adjustment, and stresses generated by chewing or thermal changes in the mouth.

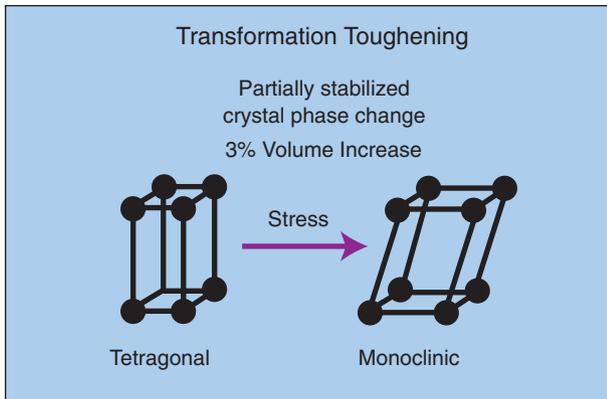


Fig 3a Phase change from a tetragonal-shaped crystal to a monoclinic form of crystal.

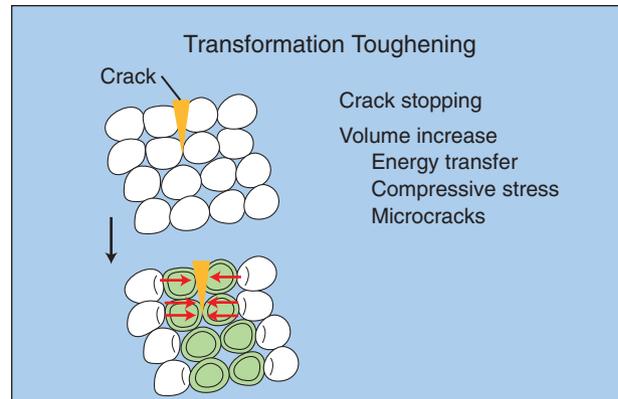


Fig 3b Closing of microcracks because of the crystal volume increase caused by the phase change.

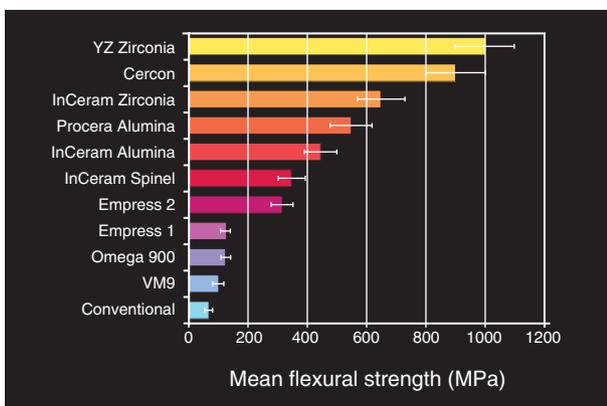


Fig 4 Flexural strengths of various ceramic core systems. Note the high strength of the two zirconia systems tested.



Fig 5 CEREC inLab, Cercon, and Lava systems.

Transformation toughening helps give zirconia its excellent mechanical properties: high flexural strength—900 MPa to 1.2 GPa—and toughness—7 to 8 $\text{MPa}\cdot\text{m}^{-0.5}$ (Fig 4). Other beneficial properties include good biocompatibility.^{8,9} The mechanical properties may allow for decreased coping thickness and connector sizes, helpful because tooth reduction is often less than desired. Also, it may be possible to make longer-span FPD frameworks of four, five, or six units.

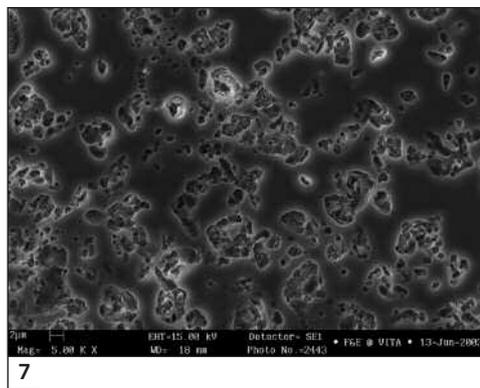
Several dental laboratory milling systems (Fig 5) are designed to fabricate frameworks from a zirconia-containing material. There are two basic approaches to using near 100% zirconia. One is to mill 100% dense, sintered zirconia directly. This approach requires a rigid milling unit, which translates to a large, heavy machine, as it is difficult to machine dense zirconia. Mill times for a coping

range from about 2 to 4 hours. This approach has an advantage in that no post-milling sintering is required. There is no shrinkage; what you see is what you get. The obvious drawback is the extended milling time and wear of the milling bars.

Another approach is to mill a partially fired zirconia block. The blocks are about 50% dense. Because they are only partially fired, the blocks are weak but easy to mill. However, the milled framework must be fired for 6 to 8 hours to increase the density of the restoration. A large amount of shrinkage occurs, and this must be compensated for during the milling process (Fig 6). Oversized frameworks are fabricated, relying on a computer to enlarge the pattern correctly to compensate for shrinkage and provide a reliable fit. Each block has a barcode containing the density for that block. The milling system then computes the proper de-



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7

Fig 6 Vita YZ block after machining but before complete sintering (top), and the same framework after complete sintering. Note the significant shrinkage.

Fig 7 Scanning electron micrograph of the VM9 material demonstrates the fine grain structure. Fine microstructures correlate directly to greatly reduced abrasion potential of these types of materials.

degree of oversizing needed to compensate for the shrinkage to full density. Thus, the homogeneity of the block and density measurement is a key to the success of this approach. Vita YZ, Cercon, and Lava take this approach, which is somewhat similar to the Procera technique in that compensation for shrinkage of the oversized framework must be performed. All of these materials are about 95% zirconia, with the rest made up of yttria and some natural impurities.

MATERIAL TESTING, VM9 VENEERING PORCELAIN

VM9 is a newly released veneering porcelain designed for these zirconia frameworks. VM9 is the latest in a series of Vita veneering materials with a refined particle size (Fig 7). Ceramics processing literature shows that reduction of particle size in a ceramic generally increases the strength and toughness of the material.¹⁰ There are other clinical benefits as well; these include improved wear kindness and polishability.¹¹ Research on the properties of veneering porcelains, ceramics, and resin composites is ongoing in the laboratory of one of the authors as part of a comprehensive analysis of mechanical properties, surface finish, polishability, and wear of various restorative materials.

Wear in the oral cavity is a complex process dependent on the load applied to the teeth and environmental factors that 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.¹² Porcelain with a refined structure should produce a wear-kind surface, which is easily polished or glazed. Older-style porcelains with coarse structures may produce rougher surfaces, which might wear opposing enamel at an accelerated rate. It is also important to properly sinter (fire) the veneering porcelain, as even fine-grained but underfired porcelain is rougher and thus more abrasive.¹³

In the authors' tests, restorative materials were fabricated into rectangular sections 2 mm × 10 mm × 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 system 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 water. 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 using a series of diamond wheels and pastes.

The results shown in Fig 8 demonstrate the low enamel wear for the refined new veneering porcelains—VM7, VM9, and materials with fine crystal structures, such as Omega 900 (Vita) and MkII CEREC blocks. In Fig 9, the data displayed have been normalized with respect to enamel. The wear ratio attempts to include both material and enamel loss and compensate for differences in enamel

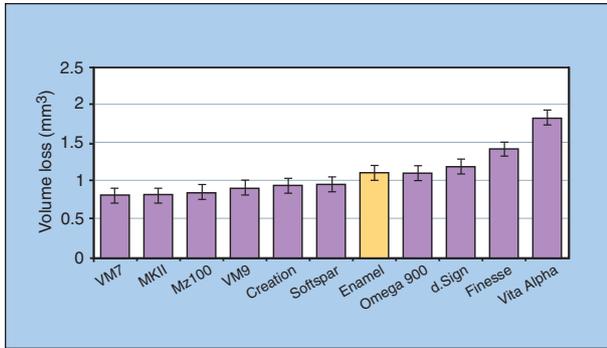


Fig 8 Wear of the opposing enamel from the various test materials. The red bar represents enamel wear against enamel. Everything to the left of the red bar represents enamel worn less than enamel wore enamel.

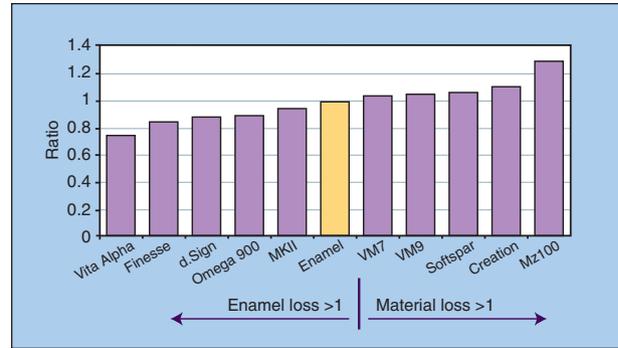


Fig 9 Normalized wear values of the various veneer materials. The left half of the graph represents increasing abrasiveness of enamel and less attrition of the test material relative to enamel. The right half of the graph represents increasing attrition of the test material and less abrasiveness of enamel.

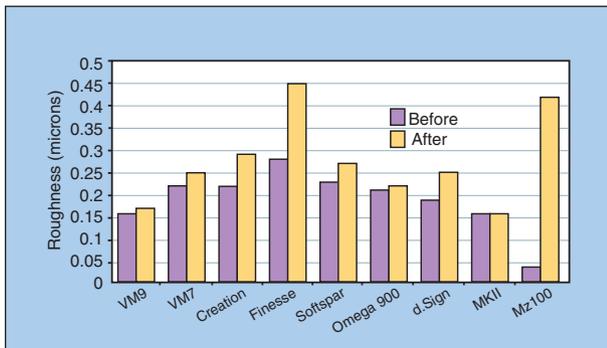


Fig 10 Mean roughness data of test materials before and after testing. There is a close correlation between roughness and abrasiveness.

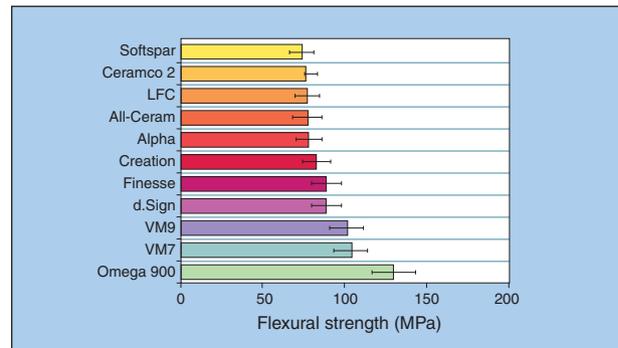


Fig 11 Flexural strength of the various veneering porcelains.

samples. Wear ratios closest to 1 indicate wear that most simulates enamel versus enamel. Again, fine-structured porcelains have values close to that achieved with natural human tooth enamel against enamel. The mean roughness value for each material was measured before and after wear testing (Fig 10). The roughness data describe both the smoothness of the surface that may be achieved during polishing as well as material resistance to surface abrasion during clinical service. Increased plaque accumulation may occur as the restoration surface becomes rougher during clinical service. Roughness values also correlate well with materials with a fine microstructure.

As part of the analysis of new materials, strength testing of VM9 was conducted and compared to

other veneering materials. Porcelains were mixed using a standard water:powder ratio and vibrated into silicone molds to form standardized bars 2 mm × 4 mm × 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 (Canton, MA, USA) with a cross-head 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 (Fig 11). Compared to other veneering materials, those with a refined particle size, such as VM9, VM7, and Omega 900, have values significantly higher than those of other porcelains in a similar class.

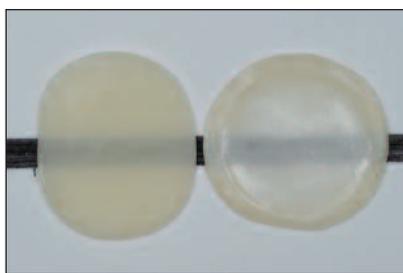


12a



12b

Figs 12a and 12b Before and after views of a PFM restoration with a Captek substrate (Captek/Precious Chemicals, Altamonte Springs, FL).



13

Fig 13 Comparison of 0.3-mm zirconia core sample against 0.8-mm Empress veneer (Ivoclar Vivadent, Amherst, NY) demonstrates similar or greater translucency in the dimensions that are actually used. Note: the black line and white background show through more on the Lava sample on the right than on the pressed-glass sample on the left.

OPTIMIZING ZIRCONIA ESTHETICS

Exciting as the new developments in zirconia milling technology are, little attention has been paid to the optical behavior of the various zirconia core systems relative to core design to optimize esthetics. Zirconia, while somewhat translucent, is as opaque as metal if used at certain core thicknesses and with certain cement combinations. Also, if the core is thicker than it needs to be, opacity is increased, and room for the veneering porcelain is used up. This would in fact be worse esthetically than a properly designed porcelain-fused-to-metal (PFM) restoration with a thin metal framework used in the same situation, because there would be more space for the veneering porcelain for the PFM (Figs 12a and 12b). Thus, core design (ie, facial thickness) in the esthetic zone will have a detrimental effect on esthetics.

Typically, cores have been recommended to be 0.5 mm thick on the facial aspect, with 0.6 mm the only option at this time for the Procera zirconia copings. The authors have found 0.5 mm of the

zirconia (especially the white material) to be too opaque for incisors in most clinical situations. The CEREC system, which uses the Vita YZ material, and the Lava system allow for thinner frameworks to be fabricated for incisors. These systems allow for the framework to be fabricated with a facial thickness of 0.3 mm (Fig 13), which is as translucent as 0.8-mm-thick pressed glass of the same shade. If absolutely necessary for a single incisor, the authors will thin the coping to 0.2 mm on the facial aspect to allow maximum translucency. The best technique found was to use the Noritake Meister diamond-impregnated knife-edged wheel (Noritake Dental Supply, Aichi, Japan) (Fig 14). This wheel generates little heat and has not created cracking problems with the core. After treatment with the wheel, the core is aluminum oxide air abraded with 50- μ m Al_2O_3 at 50 psi to clean the contaminants.

Most manufacturers use an achromatic or white form of zirconia for the cores. For high-value shades, eg, 0 or 1 Vita 3D Classical (A0, A1 Vita Classical), the white core works fine. For lower

value and higher chroma shades, the white-shaded core can be problematic. Both the Lava and Vita YZ systems allow for colored cores. The Lava cores come in seven different colors and the Vita YZ in five colors. The core shade that corresponds to the desired tooth shade is chosen. In the authors' experience, it is much easier to match the translucency and chroma of natural teeth if the correct shaded core is chosen versus using the white zirconia core material.

Core Bonding/Shading Agents

One strategy used to color or shade the core for the white zirconia was to develop "core-shaded porcelains." Company testing also found that the bond of the normal body porcelains fired and normal temperatures created a weak bond of the veneering porcelain to the zirconia framework. The materials developed to solve both of these problems were essentially high-chroma opaque materials used to shade the core and create a "bonding" layer to which the porcelain fused on subsequent porcelain firings. The materials are fired at a high enough temperature to melt the material to effectively wet the surface of the zirconia, creating both a micromechanical and chemical bond. After firing, the core basically looks like opaqued metal, which would obviously negatively affect the esthetic result (Fig 15).

The authors found a much more esthetic alternative to obtain the desired results of a bonding layer and developing core color. Translucent fluorescent liners or shoulder powders can be used as the bonding layer and to develop core color. With the VM9 system, the material called the Effect Liner is placed over the whole core in a thin layer (about 0.1 mm); this is fired 70°C higher than the normal recommended firing temperature for this material (Fig 15). This will melt the material, creating a thin layer that wets the zirconia surface. The surface should look like a "low glazed" porcelain surface. For 0 and 1 value shades, the authors use a mixture of 50% Effect Liner 1 and 50% Effect Liner 2; for value 2, Effect Liner 2; and for value 3, Effect Liner

3. It is important to note that this is used instead of the effect bonder. The coping is now ready for porcelain margin techniques and porcelain layering.

A recent study by Dr Giordano, as yet unpublished, of shear bond strength of veneering porcelains to zirconia found that using a dentin wash layer fired at approximately 950°C improves the bond strength of VM9 to Lava. This procedure is also a good substitute for the VM9 bonding material when using Vita YZ as the substructure. However, it must be noted that veneering porcelains appear to have different bond strengths depending on the zirconia and initial fired veneer layer.

THE SKELETON LAYERING TECHNIQUE AND VM9

The VM9 material is different enough from previous materials that the authors have found from experience that a slightly altered building technique is necessary to maximize the esthetic results. A number of years ago, a simplified porcelain building technique was described for building Alpha (Vita, Bad Säckingen, Germany)—the "skeleton buildup technique."¹⁴ This technique was adapted for use with the VM9 material. The skeleton buildup technique is a combination 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; layers are individually completed (fired) prior to veneering the skin (enamel surface), thus allowing maximum control of both shape and shade.

Porcelain Margin

Zirconia cores are slightly more opaque than dentin; thus, it is ideal to design the framework to allow for a more translucent porcelain margin material to be placed. There is a misconception that the margin material should have the same translucency as dentin. If the marginal area were at all visible, it would be noticeable unless the margin

material also had the exact same chroma and hue as the surrounding tooth structure. It is actually ideal for the marginal material to be slightly more translucent than the surrounding tooth structure so that it blends in by picking up some color from the tooth, the so-called contact lens or chameleon effect. As with metal or more opaque ceramic cores, a porcelain margin is mandatory for ideal esthetics.

The benefit over metal ceramics is that the framework only needs to be shortened slightly to allow enough light through to illuminate the gingival area to create a natural effect (Fig 16). The zirconia cores can be designed on the computer with a shortened framework. It is only necessary to shorten the framework 0.5 to 0.7 mm on the facial aspect. With the VM9, the authors use the Effect Liner porcelains with a direct lift technique for the porcelain margin; 30% Effect Liner 1 with 70% Effect Liner 2 works for the brighter shades (Figs 17 and 18).

The material has a fluorescence similar to that of natural dentin, which is most valuable at the margin or gingival area and of less importance 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 fiber optic. Light is carried from the marginal area, helping to illuminate the marginal gingiva and giving a more natural appearance to the restoration and the gingiva in this area.

Base Dentins

Base dentins are new materials to replace the traditional opaque dentins from other systems. The chroma and opacity are between those of conventional opaque dentins and dentins. The material could be used without dentin in thin areas where chroma is needed but little space is available for the dentin layer or for a basic shade buildup technique. If additional chroma is needed, Effect Chroma modifiers are added to

the base dentin. They are chosen based on the shade analysis and whether the shade is yellower or redder than the chosen shade. Generally, about 10% to 20% of the modifier is all that is necessary. The base dentins of the desired shade are built to mimic dentin that needs to be replaced, generally about 0.4 mm thick, allowing about 0.2 to 0.3 mm for the conventional dentins. If less than 0.6 mm is available for the base dentin–dentin combination, use base dentin only, with the added Effect Chroma if necessary.

To create the illusion of reality even for a bleached tooth effect, it is necessary to build in subtle intratooth color contrasts (ie, color zones) when building the base dentin and dentin. There are at least three distinct contrast zones within a tooth. As a general guide, the chosen base shade is placed in the middle third, slightly higher in chroma and lower in value in the gingival third, and slightly lower chroma and value in the incisal third (Fig 19). This layer should be slightly overbuilt at this point, and it is then fired (Fig 20). Slight overcontouring after firing is easily contoured with a bur.

Dentins

The dentins with the VM9 are more translucent than traditional dentins and are designed for the multilayer buildup techniques currently being taught. The dentin material should not be used without the base dentin, as it is too translucent by itself and the core will show through. For a basic shade guide, building technique dentins are not necessary and only the base dentins need to be used. For a polychromatic and more natural result, dentin materials are overlaid over the fired base dentin layer using the same color or contrast scheme as the base dentins; generally, 0.2 to 0.3 mm is the correct thickness with about 0.4-mm thickness of the base dentin. Again, it is best to slightly overbuild the dentins, which can be adjusted after firing (Figs 21a and 21b).

Incisal Framing

The enamel structures (layer) are started by building up what has been termed the incisal frame; essentially, it is the lingual half of the incisal edge. 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 Effect Enamel Light and the light-blue translucent Effect Enamel 9 for light shades, and for shade 3 value (A3 with the old shade system) and darker, a 50/50 mixture of Enamel Dark and Window (clear). This is then fired. Because of 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 22a and 22b).

Internal Effects

Internal incisal edge effects called mamelons need to be created to mimic a natural tooth. Special high-chroma porcelains called mamelon powders were developed for this purpose. Three mamelon powders come with the kit. The authors have found that mixing MM1 and MM3 50/50 for the mamelon effects did not end up overdone and worked quite well with most shades. The mamelons are layered on top of the fired dentin using a stain-type liquid to create mamelon effects (Fig 23). They are placed on thin and "drawn out" to a thin, feathery appearance with a brush. Other effects are created in the same manner. These are then vacuum fired to only 875°C to set them on the surface. Firing to 875°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 24). Wetting the surface with a glycerin-type liquid will alter the

refractive index to allow viewing the fired effects. This step can be repeated as many times as necessary until the desired effects are obtained. If the effects are excessive, it is a simple matter to remove them 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 is placed next; this is termed the "skin layer." VM9 has 11 different translucent materials, termed Effect Enamels. There are also three translucent pearlescent enamels that are useful to recreate a bleached tooth effect. The authors found the pearlescent enamels (Effect Pearls) to be too bright to be used straight. If they need to be used to create a bright reflective zone, they should be cut with 50% Effect Neutral. There are also three translucent highly opal porcelains for cases that require a bluish or whitish opal effect. For bright cases, the Effect Opal 1 is cut with 50% Effect Neutral 1 and used over most of the facial surface; this gives a believable bright result (Fig 25). Also, Effect Opal 3 (bluish opal) looks good when used at the mesial and distal incisal corners. Generally, in the gingival third, the light yellow/orange Effect Enamel 4 used in about 0.2-mm thickness gives a slight warmth to this region (Fig 25).

Because of the exact control of the internal layers (skeleton), the precise control of the enamel/translucent layer (skin) is fairly easy. Overbuilding is preferred at this point 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; also, 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 26). If, after the



Fig 14 Using the Noritake wheel to thin the zirconia core.



Fig 15 Core with bonder (maxillary right central incisor), which is too opaque, and adjacent core (left central incisor), with fluorescent liner used as the bonder, which demonstrates better apparent translucency.



Fig 16 Necessary core cutback for marginal esthetics.



Fig 17 Placing the porcelain margin.



Fig 18 Porcelain margin after it is fired.

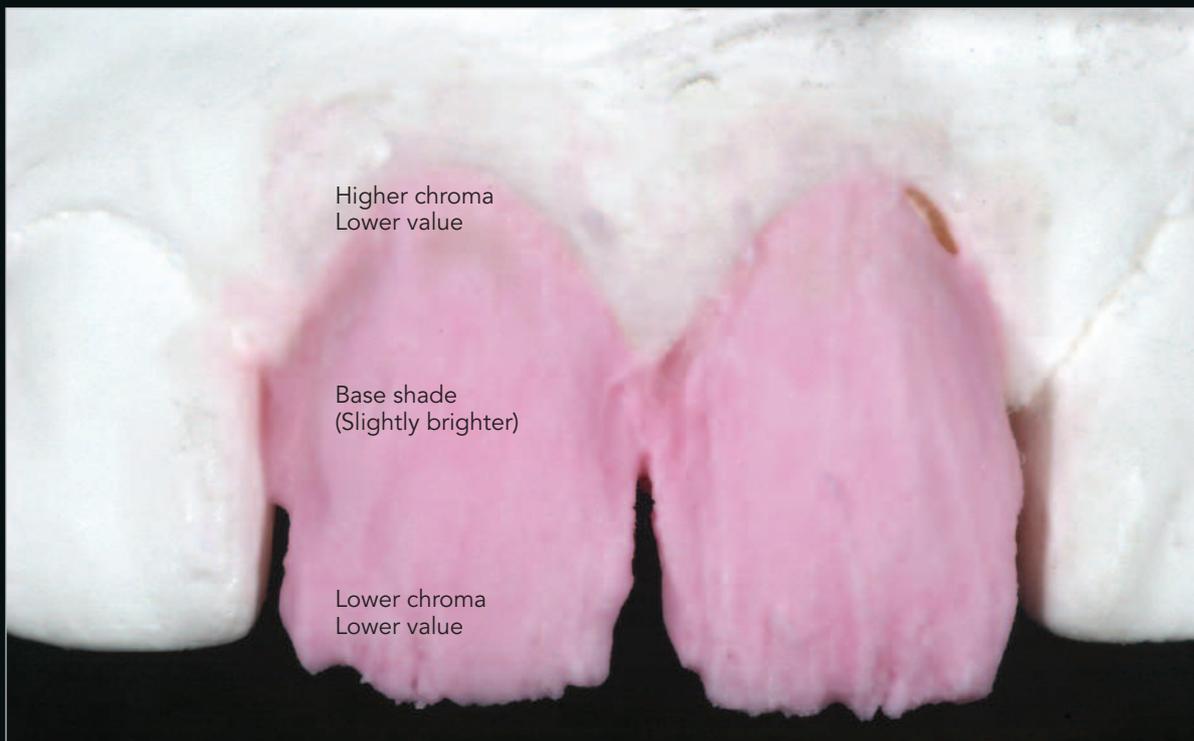
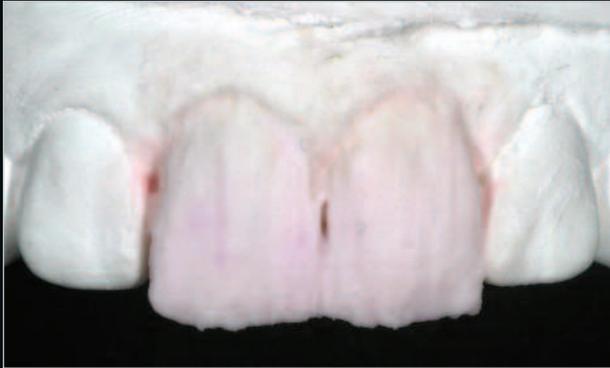


Fig 19 Built-up base dentins and zone contrast scheme.



Fig 20 Base dentins are fired.



Figs 21a and 21b Dentins are built up and fired.



Figs 22a and 22b Incisal framing is built up and fired.



Fig 23 Internal (mamelon) effects are built up with medium-viscosity glaze liquid.



Fig 24 Internal effects are fired at 875°C under vacuum.

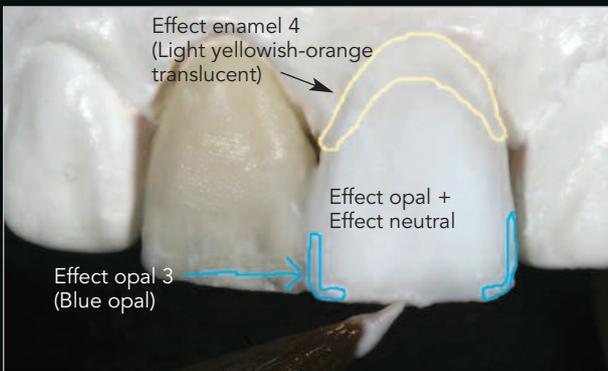


Fig 25 Enamel skin layer is built up with mostly Effect Enamel 1 and Effect Enamel 4 in the gingival third.



Fig 26 Enamel skin layer is fired.



27a

Fig 27a Preoperative condition of two all-ceramic crowns; the patient is unhappy with the discolored or dark area on the maxillary right central incisor.

Fig 27b Final crowns are a zirconia core with VM9. Note the effective masking of the discoloration of the right central incisor without an opaque appearance.



27b

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 in contouring and glazing in the scope of this article. It is important to note that natural teeth, even old teeth, have some surface texture. Proper contour and texture are prerequisites for natural-looking restorations. Figures 27a and 27b show before and after views of the case discussed in this article and treated using the new VM9 material as described.

DISCUSSION

CAD/CAM-generated zirconia crowns and FPDs offer an alternative to conventional PFM restorations, as the physical properties are exponentially improved over previous materials. It is important to note that long-term clinical data on whether zirconia can serve as a replacement for metal ceramics, especially for FPDs, are as yet unavailable. Even with improved physical properties, many processing and clinical issues will affect a material's performance.

Material testing of a new veneering porcelain has demonstrated improved flexural strength and decreased abrasiveness compared to previous-generation veneering porcelains. This is believed to directly relate to the fine microstructure in the newer materials; thus, microscopically, they are smoother. These finer-grained materials have abrasiveness similar to that of enamel, which is ultimately what is desired from a restorative material.

The skeleton buildup technique was reviewed and adapted for use with the VM9 material for zirconia frameworks. This technique might seem rather time intensive, but actually the time spent building porcelain is the same as for other techniques. The only difference is the oven time; as long as the ce-

ramist has 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. The technique is also a great teaching tool.

REFERENCES

1. Giordano RA. Dental ceramic restorative systems. *Compend Contin Educ Dent* 1996;17:779-794.
2. Blatz MB. Long-term clinical success of all-ceramic posterior restorations. *Quintessence Dent Technol* 2001;24:41-55.
3. McLaren EA. All-ceramic alternatives to conventional metal-ceramic restorations. *Compend Contin Educ Dent* 1998;19:307-325.
4. Christel P, Meunier A, Heller M, Torre JP, Peille CN. Mechanical properties and short-term in vivo evaluation of yttrium-oxide-partially-stabilized zirconia. *J Biomed Mater Res* 1989;23:45-61.
5. Sailer I, Lüthy H, Feher A, et al. 3-year clinical results of zirconia fixed partial dentures made by direct ceramic machining (DCM) [abstract 74]. *J Dent Res* 2003;82:B-21.
6. McLaren EA, Giordano RA, Poher R, Abozenada B. Material testing and layering techniques of a new two-phase all glass veneering porcelain. *Quintessence Dent Technol* 2003;26:69-81.
7. Lin CP, Douglas WH, Erlandsen SL. Scanning electron microscopy of type 1 collagen at the dentin-enamel junction of human teeth. *J Histochem Cytochem* 1993;41:381-388.
8. Warashina H, Sakano S, Kitamura S, et al. Biological reaction to alumina, zirconia, titanium and polyethylene particles implanted onto murine calvaria. *Biomaterials* 2003; 24:3655-3661.
9. Cales B, Stefani Y. Ytria-stabilized zirconia for improved orthopedic prostheses. In: Wise DL (ed). *Encyclopedic Handbook of Biomaterials and Bioengineering*. New York: Marcel Dekker, 1995:415-452.
10. Swain MV. Toughening mechanisms for ceramics. *Mater Sci Forum* 1989;13:237-253.
11. al-Hiyasat AS, Saunders WP, Sharkey SW, Smith GM, Gilmour WH. The abrasive effect of glazed, unglazed, and polished porcelain on the wear of human enamel, and the influence of carbonated soft drinks on the rate of wear. *Int J Prosthodont* 1997;10:269-282.
12. Oh WS, DeLong R, Anusavice KJ. Factors affecting enamel and ceramic wear: A literature review. *J Prosthet Dent* 2002;87:451-459.
13. Sorensen JA, Pham MK. Effect of under-sintering veneering porcelain on in vitro enamel wear [abstract 179]. *J Dent Res* 2001;80:58.
14. McLaren EA. The skeleton buildup technique: A systematic approach to the three-dimensional control of shade and shape. *Pract Periodontics Aesthet Dent* 1998;10: 587-597.