Over the last decade, laboratory procedures have changed dramatically due to the introduction of computer-aided design/computer-assisted manufacture (CAD/CAM) technology. This evolution began with the use of zirconia as a base material for dental restorations. Recently, the use of CAD/CAM-fabricated full-contour zirconia (FCZ) crowns for posterior teeth has become a popular restoration option among large commercial laboratories. In contrast, porcelain-fused-to-metal (PFM), pressed lithium disilicate (LD), and porcelain-fused-to-zirconia (PFZ) crowns remain popular among smaller laboratories. This article compares these four restoration types based on their material science and laboratory procedures.

**PFM CROWNS**

**Material Science**

Properly constructed and seated PFM crowns provide optimal strength and longevity. An anatomical framework design is crucial to provide proper support and...
maintain the appropriate thickness for the veneering porcelain.1–3

The following criteria are critical to proper fabrication1–3:

- The coefficients of thermal expansion of the porcelain and alloy must be closely matched to achieve a strong bond; otherwise, adhesive failure (eg, delamination or fracture) may occur.
- Proper casting temperature and timing are needed to prevent overheating or miscasting. Excess gas in the alloy can cause small surface pits and bubbles in the veneering porcelain.
- A smooth metal surface must be achieved via finishing procedures to strengthen the bond with the veneering porcelain.
- It is important to avoid sharp angles or pits on the veneering surface, which can lead to cracking due to internal stress.
- Heat treatment is necessary for degassing and to create an oxide layer, which promotes a chemical bond between the alloy and porcelain.
- The use of an opaque layer as the first porcelain coat is crucial for three reasons: (1) to ensure a strong bond at the interface of the opaque porcelain and alloy, (2) to mask the metal color, and (3) to provide a base color for the targeted shade.2,3 When a satisfactory opaque layer has been baked, the dentin (body), enamel, and incisal (translucent) porcelain layers can be applied to achieve the desired appearance.

The fabrication of PFM crowns involves many steps; therefore, errors may occur. Nevertheless, more than 50 years of research, development, and clinical experiences show that PFM crowns in the posterior region maintain a high survival rate (95%)4,5 with well-established strength and reliability.

**Laboratory Procedures**

Laboratory procedures have changed dramatically since the inception of CAD/CAM technology. Many large laboratories now rely on high-end CAD/CAM systems. In the beginning, CAD/CAM milling materials included only all-ceramic options such as zirconia or glass blocks. As the technology progressed, however, the milling capabilities expanded to include wax, composite resin, and cobalt-chromium alloy; further, some CAD/CAM systems are now equipped with the printing capability to create an acrylic resin pattern for PFM copings and full cast restorations. Cobalt-chromium alloy is particularly appealing because it is inexpensive and highly biocompatible.

The laboratory is responsible for scanning the dies, designing the virtual frameworks, and electronically transferring the digital information to a printing facility. The acrylic resin pattern provides a consistent thickness and sufficient support for the porcelain. However, these CAD/CAM systems do have limitations; it is often necessary to manually perform touch-ups and finish the margins with a wax-up to achieve an optimal marginal seal before investing and casting. Despite these imperfections, CAD/CAM technology is rapidly progressing.

There are three basic layering porcelain powders: dentin (body), enamel, and incisal (translucent). Dentin and enamel layers control the color, while the incisal layer provides translucency. When restoring anterior teeth, all three powders must be used to achieve acceptable esthetics. However, newly developed enamel porcelains (eg, EX-3 Speed Enamel, Kuraray Noritake, Tokyo, Japan) offer higher translucency than conventional enamel porcelain while remaining less translucent than incisial porcelain. For posterior crowns, these new enamel porcelains can be used in conjunction with dentin porcelain to provide acceptable color and translucency in only two layers. This two-layer technique offers esthetic outcomes similar to those of the more time-consuming three-layer technique (Fig 1). The two-layer technique is also more suitable for entry-level ceramists due to its simplicity.

The opaque layer must be baked twice; the first thin layer of wash bake ensures the bond strength between the porcelain and metal, while the second layer covers the entire metal surface to mask the dark color.2,3

One of the most challenging aspects of fabricating PFM crowns is the high light reflection at the marginal areas, which is caused by the lack of light transmission through the metal. Therefore, controlling light reflection during layering is important for a successful esthetic outcome.2,3 An internal stain (EX-3 Internal Stain, Kuraray Noritake) can be applied over the opaque layer to control the light reflection. Internal staining does not increase the thickness of the crown and is
ideal for use at the margins (Fig 2). When using the two-layer approach, the amount of body porcelain should be decreased with a cutback method, while the amount of enamel porcelain should be increased to enhance translucency (Fig 3).

**PFZ CROWNS**

**Material Science**

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) ceramic is commonly used in dentistry. This material offers high flexural strength and toughness as well as chemical and dimensional stability due to its transformation-toughening characteristics. The different brands of Y-TZP available on the market show similar coefficients of thermal expansion and other physical properties. Therefore, veneering porcelain from one system can be applied to copings from other manufacturers listed in Table 1. However, two or more different porcelain powders should not be mixed during application.

One of the unique features of Y-TZP is that its surface structure transforms from a tetragonal to monoclinic phase at low temperatures with moisture. Flinn et al found that this surface transformation triggered a
statistically significant decrease in the flexural strength of thin bars of Y-TZP. Flexural strength differs among various brands. Regardless, Y-TZP core materials have not been problematic in clinical use.8 The bond between the zirconia core material and veneering porcelain differs from that of PFM crowns because zirconia does not require an oxide layer for bonding. Thus, PFZ restorations show better bond strength between the core and veneering material than PFM restorations.6 This indicates that the bond strength may not be the primary determinant of veneer failure for all-ceramic zirconia restorations.

Chipping of the porcelain layer has been frequently reported as a cause of failure (13% to 25% of failures).5,9 Blatz et al10 reported the outcomes of 2,635 posterior crowns fabricated by the present authors’ laboratory for a variety of private practitioners (14 prosthodontists and 8 general dentists). This survey concluded that the survival times and probabilities of PFZ crowns (veneering layer: Cerabien ZR, Noritake) were statistically similar to those of PFM crowns.10 Another study evaluated the remake ratios of 24,392 zirconia-based porcelain crowns (23,787 Cerabien ZR crowns; 605 Lava Ceram crowns, 3M ESPE, St Paul, Minnesota, USA) fabricated in a private laboratory. The overall remake ratio was less than 1%.11 The results showed that the quality of the veneering porcelain greatly contributed to the success of the restoration.

Laboratory Procedures

Just as in PFM crowns, PFZ crowns consist of two different materials: the core porcelain and the veneering porcelain. Also as in PFM crowns, the veneering material is composed of feldspathic porcelain; however, the coefficient of thermal expansion (CTE) is approximately 9 ppm for PFZ crowns as opposed to 14 to 15 ppm for PFM crowns.1

The PFZ framework procedure is simpler than that of PFM because it does not require additional procedures to increase the bond strength. A chamfer preparation should be used at the margin, without a bevel or knife-edge finish line, to support the ceramic structure (Fig 4).12 Fine details of the framework design cannot be confirmed until milling and sintering; therefore, certain adjustments using a dental handpiece will be required. Additional buildup is not possible. The milling unit has limited burs, which means the inside of the coping usually needs further grinding to achieve optimal fit to the die. When grinding zirconia with a diamond bur and high-speed turbine, cooling water supply is necessary because excess heat can lead to microcracks at the coping surface and eventually to fracture. The thermal conductivity of zirconia is lower than that of metal alloy, which means PFZ crowns must be heated up and cooled down slowly. It is important to follow the manufacturer’s baking instructions (Table 2); otherwise, cracks or fractures may occur.6

The translucency of the zirconia core decreases light reflection at the cervical area; thus, PFZ crowns offer a more natural appearance compared to PFM crowns. Unlike glass-ceramic, zirconia also offers a certain level of masking ability. Depending on the targeted shade, the color of an abutment tooth and the light reflection at the cervical area can be controlled using appropriate internal stains. PFZ crowns can be fabricated using the same two-layer technique used for the PFM crowns.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Coefficient of Thermal Expansion (CTE) of Different Ceramic Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brand</td>
<td>CTE*</td>
</tr>
<tr>
<td>Cercon (Dentsply, York, Pennsylvania, USA)</td>
<td>10.5</td>
</tr>
<tr>
<td>CEREC YZ (Sirona, Long Island City, New York, USA)</td>
<td>10.5</td>
</tr>
<tr>
<td>KATANA (Kuraray Noritake, Tokyo, Japan)</td>
<td>10.5</td>
</tr>
<tr>
<td>Lava (3M ESPE, St Paul, Minnesota, USA)</td>
<td>10.0</td>
</tr>
<tr>
<td>Prettau (Zirkonzahn, Gais, Switzerland)</td>
<td>10.6</td>
</tr>
<tr>
<td>Procera ZR (Nobel Biocare, Zurich, Switzerland)</td>
<td>10.4</td>
</tr>
</tbody>
</table>

*As specified by the manufacturers.
pressed LD crowns

Material Science

Pressed LD has the highest flexural strength (400 MPa) among the glass-ceramics used in prosthetic dentistry. Clinical studies have shown excellent short-term results. Monolithic LD seems to be particularly well suited for posterior crowns.

The baking temperature of the feldspathic veneering porcelain is lower than that of many other types. The high baking temperature of the dentin and incisal porcelain is 750°C. In terms of the core material, the press temperature of an LD ingot ranges from 910°C to 930°C depending on the size and opacity. The veneering porcelain must be baked at a temperature well below the core ingot melting range. In contrast, the veneering porcelain for PFM crowns has a much higher baking temperature (910°C to 950°C). In general, high-fusing porcelains are stronger than low-fusing porcelains.

When veneering porcelain is applied over LD, a thin layer should be used to avoid possible chipping; further, the thickness of the core material must also be reduced. Thus, the fracture strength of the bilayer LD is affected by both the total specimen thickness and core thickness. Pressed LD crowns require resin bonding cementation to ensure sufficient strength and longevity.

Laboratory Procedures

In the authors’ commercial laboratory, trial tests were performed before the actual procedures of the clinical cases of pressed LD crowns. The results showed that LD crowns (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein) were twice as strong as Leucite-reinforced glass-ceramic crowns (IPS Empress, Ivoclar Vivadent) and three times stronger than standard glass-ceramic crowns (VITABLOCKS Mark II, VITA Zahnfabrik, Bad Säckingen, Germany) (Table 3). As a result of these findings, LD material replaced the earlier generations of glass-ceramic materials.

The laboratory procedures for pressed crowns are the same as for lithium disilicate or Leucite-reinforced
glass-ceramic as long as the crown is fabricated properly using the lost-wax technique. The fit and final anatomy are easy to manage. The acrylic resin pattern created by the CAD/CAM system should be finished manually by a technician to promote optimal fit and marginal sealing. Due to the high flexural strength of LD crowns, many clinicians who use chairside CAD/CAM systems also use lithium disilicate blocks despite the extra time required for sintering (Table 3).

Pressed LD crowns can be ideal for a simple-tone tooth color as a shade guide, especially in the cervical area. However, the high translucency of the final shade will be affected by the underlying tooth (Fig 5). For anterior restorations, it is important to create an extra die using tooth-colored resin or wax to mimic the stump shade. The final color of the LD crown can then be properly assessed (Fig 6). For posterior restorations, these extra steps are rarely necessary, and PFM or PFZ restorations should be used instead.

When fabricating LD crowns, selecting an ingot with the appropriate value and chroma is important. When the final shade is incorporated into the final appearance of a pressed LD crown, a low-translucency (LT) ingot should be used. The color of an LT ingot is similar to that of the dentin porcelain. The incisal area needs to be lighter in shade than the cervical area; therefore, an ingot with a lighter shade than the target shade should be used for monolithic crowns. If the target shade is A2, a lighter-shade A1 ingot is usually appropriate.

### Table 3: Mean Flexural Strength of Ceramic Restorations

<table>
<thead>
<tr>
<th>Material</th>
<th>Flexural strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressed LD (IPS e.max Press)</td>
<td>400</td>
</tr>
<tr>
<td>LD CAD block (IPS e.max CAD)</td>
<td>360</td>
</tr>
<tr>
<td>Leucite-reinforced glass-ceramic (IPS Empress)</td>
<td>150</td>
</tr>
<tr>
<td>Glass-ceramic (VITABLOCKS Mark II)</td>
<td>120</td>
</tr>
</tbody>
</table>

Figs 5a and 5b  The translucency and color of an LD crown can be influenced by the underlying tooth color, especially the margin area.

Fig 6  Custom die fabricated using tooth-colored resin or wax.
Porcelain-Fused-to-Metal and All-Ceramic Crowns for Posterior Teeth

**FCZ CROWNS**

**Material Science**

FCZ crowns, which are typically composed of 3-mol% Y-TZP, are the fastest-growing restoration in terms of popularity due to their slightly increased translucency than the core material, efficiency, and affordability. A previous clinical study showed that FCZ crowns on molar teeth performed well after 1 year in service, with no evidence of cracks, chips, or fractures.\(^{15}\) Another clinical study of the wear of dentition opposing FCZ crowns reported reduced wear rates compared to those of regular feldspatic porcelain.\(^{16}\) However, studies regarding the long-term durability of FCZ crowns are still needed.

Low-temperature degradation may be an issue over time. In clinical practice, the occlusal contact areas and marginal areas tend to be thinner than the manufacturers’ recommended range of 0.5 to 1.0 mm. As discussed earlier, Y-TZP surface transformation can lead to lower flexural strength; however, this effect varies among different brands of materials (Fig 7). In one study, hydrothermal aging of Y-TZP caused a statistically significant decrease in flexural strength following the transformation from a tetragonal to a monoclinic crystal structure.\(^{10}\) Table 4 shows the effect of accelerated aging on several brands of Y-TZP materials. Additional clinical studies are needed to more fully understand this effect over the long term.\(^{7,17}\)

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**Table 4** The Effect of Accelerated Aging on Flexural Strength of Y-TZP\(^{7,17}\)

<table>
<thead>
<tr>
<th>Brand</th>
<th>Flexural strength, MPa (SD)</th>
<th>Tetragonal</th>
<th>Monoclinic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lava (3M ESPE)</td>
<td>1,158.0 (88)</td>
<td>829.5 (71)</td>
<td></td>
</tr>
<tr>
<td>Prettau (Zirconzahn)</td>
<td>1,406.0 (243)</td>
<td>882.7 (91)</td>
<td></td>
</tr>
<tr>
<td>Zirprime (Kuraray Noritake)</td>
<td>1,126.0 (92)</td>
<td>976.0 (37)</td>
<td></td>
</tr>
</tbody>
</table>

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**Fig 7** Transformation of zirconia from a tetragonal to a monoclinic crystal structure.
Laboratory Procedures

In recent years, the majority of FCZ procedures have been performed using a CAD/CAM system. However, manual adjustment of the intaglio surfaces is often necessary.

Crown shading is usually performed before sintering. Two shading methods are available for FCZ crowns: monochromatic shading or multicolor shading using the Lava Ceram system.

For monochromatic shading, a milled crown is soaked in liquid dye to achieve a target shade of monochromatic color. After sintering, the crown is treated with an external stain (Fig 8). For multicolor shading, two or three different liquid dyes are applied with a brush at specific areas of the milled crown before sintering. The crowns are again completed with an external stain. The color of an as-milled crown is solid, chalky white. The dye is absorbed from the crown, and the color only appears after sintering. Thus, establishing both the mixing ratio of the liquid dye and the number of applications is crucial to achieve an optimal final color. The external stain will have only a small effect on the color.

Adequate occlusal reduction is necessary because occlusal and marginal areas may experience excessive stress and loading during service. Tight occlusal contact involves a preparation with at least 0.5 mm of occlusal space. For PFM this is crucial, as with less than 0.5 mm an undesirable spot of metal will show due to lack of space for layering porcelain. Considering the long-term function of a crown and the limitations of CAD/CAM systems, it may be prudent to maintain at least 0.5 mm of space at all aspects of the restoration to avoid fractures.17

CASE REPORT

This case report involves the fabrication a single crown for a mandibular right first molar adjacent to two healthy teeth. The case was received from a private practitioner.

A chamfer margin preparation and appropriate occlusal reduction had been carried out. Four crowns were fabricated with four different materials for comparison in the patient’s mouth:
Porcelain-Fused-to-Metal and All-Ceramic Crowns for Posterior Teeth

CASE REPORT

1. PFM: Ceradelta 2 (silver-palladium alloy; Cendres+Métaux, Bern, Switzerland) and EX-3 (Kuraray Noritake)
2. PFZ: Noritake KATANA coping and Noritake Cerabien ZR
3. LD: IPS e.max Press (LT A1 ingot)
4. FCZ: Lava Plus

A shade of A2 was instructed by the dentist based on the VITA Lumin shade guide (VITA Zahnfabrik). Shade photographs, which are often sent to technicians for anterior crowns, are not provided in posterior cases. The crowns were fabricated following the manufacturers’ instructions (Figs 9 and 10). Before the crowns were tried in, each shade was confirmed as A2 using a dental spectrophotometer (Crystaleye, Olympus, Tokyo, Japan).

Figures 10 and 11 show the differences between the crowns on the casts and in the patient’s mouth. On the casts, the cervical area of the pressed LD crown appears to provide the best color match. The PFM crown shows high brightness due to light reflection. The PFZ and FCZ crowns look similar and show superior esthetics compared to the PFM crown. The incisal...
areas of the feldspathic porcelain in the PFM and PFZ crowns show better color than those of the LD and FCZ crowns, which have monolithic material characteristics. The value of a monolithic crown is the same over the entire crown surface; therefore, the incisal areas of the LD and FCZ crowns have a higher value than would be ideal (Fig 11).

In the patient’s mouth, the PFM and PFZ crowns show better shade matching than the two monolithic crowns. Even though the A2 shade appeared acceptable on the casts, the occlusal aspects of the LD and FCZ crowns in the patient’s mouth appear to have a higher value than the adjacent teeth. For mandibular molar crowns, the occlusal surfaces are more visible than the buccal surfaces, which makes occlusal shade matching especially important (Fig 12). The use of shade A1 for pressed LD crowns would result in excessive value at the occlusal surface since the material is solid in tone. Shade A2 should be used for optimal color matching. The occlusal area of FCZ crowns can be improved esthetically by increasing the chroma before sintering.

CONCLUSIONS

Understanding the material science and laboratory procedures of porcelain-fused-to-metal, porcelain-fused-to-zirconia, lithium disilicate, and full-contour zirconia crowns is a primary factor for successful restorative treatment. Considering the range of options...
available on the market, dental technicians are challenged to master the techniques and technology necessary to achieve long-term clinical success.

ACKNOWLEDGMENTS

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