Aesthetic ceramic crowns have dominated dentistry since Glidewell Dental introduced BruxZir in 2009. Since then, the TRAC Research lab has studied numerous brands of crowns from three material categories: zirconia ceramic, glass ceramic, and polymer “ceramic” (Fig. 1). In the current study, there are 23 products, 20 labs, more than 100 dentists and 1,000 molar crowns (Fig. 2). The crowns differ in many ways, but all are tooth-colored, monolithic and CAD-CAM fabricated.

For more than 40 years, we’ve searched for materials with the characteristics illustrated in Fig. 3. Some formulations under study now may meet these criteria. Key findings are reported here to provide direction for clinicians who are trying to choose between a multitude of diverse formulations. We report on zirconia first, then briefly on glass ceramic and polymer “ceramic.”

Fig. 1: This laboratory in TRAC Research’s Clinical Science area contains thousands of gold-sputtered polyurethane replicas of test crowns and their opposing dentition under clinical study. The replicas provide evidence of the exact condition of every test crown at each yearly recare appointment. Scanning electron microscope images are made of the crowns using these high-resolution replicas.
**Zirconia**

Our most important key finding is the 100 percent survival of all the zirconia restorations, regardless of origin, formulation, disk manufacturing method, quality, and clinical differences among dentists, laboratories and patients. It’s noteworthy that of more than 200 tooth-colored materials tested in 43 years, only zirconia has 100 percent survival after nine years.

This includes nine service years for BruxZir, with the minimal tooth preparation advertised in 2009–2010 (0.5mm occlusal reduction and almost feather edge margins).

An important zirconia question today is: How do today’s zirconias, with translucence and internal coloring, compare with earlier formulations lacking these features, when both claim 1,000+ MPa flexural strength?

After nine years, we know the following about zirconia, some of which relates to this question:

**Point 1:** Low-translucent, noncolored zirconia (e.g., original BruxZir) is the most clinically durable tooth-colored monolithic restorative material ever used in dentistry. It has toughness (ability to resist fracture) that provides a “margin of safety.”

**Point 2:** Additives for translucence and internal coloring reduce zirconia’s toughness, which necessitates more gentle handling and deeper tooth preparations to increase material thickness.

**Point 3:** Adding veneer porcelain over zirconia compromises restoration longevity.

**Point 4:** Glazes are not long lasting, and glaze loss results in aesthetic characterization loss.

**Point 5:** Most zirconia restorations do not blend with surrounding dentition.

**Point 6:** No one cementation protocol is superior.

---

**Zirconia ceramic**

- Argen Z HT, Argen Dental, < 1 year
- BruxZir, Glidewell Dental, 9 years
- BruxZir Shaded, Glidewell Dental, < 1 year
- BruxZir Anterior, Glidewell Dental, 2 years
- BruxZir Esthetic, Glidewell Dental, < 1 year
- BruxZir Now (2016), Glidewell Dental, 2 years
- BruxZir Now (2019), Glidewell Dental, < 1 year
- DD CubeX², Dental Direkt, 2 years
- IPS E.max ZirCAD LT, Ivoclar Vivadent, 3 years
- IPS E.max ZirCAD MT, Ivoclar Vivadent, < 1 year
- Katana Zirconia Block, Kuraray Noritake, 1 year
- Katana Zirconia STML, Kuraray Noritake, 3 years
- Lava Esthetic Zirconia, 3M, 2 years
- Pavati Z40.1, CCRI, 2 years
- Zirlux 16+, Zahn, 2 years
- 2 unknown origin brands, < 1 year

**Glass ceramic**

- IPS E.max, Ivoclar Vivadent, 9 years
- Camouflage Now, Glidewell Dental, 1 year
- CeraSmart, GC America, 3 years
- Celtra Duo non-fired, Dentsply Sirona, 1 year
- Lava Ultimate, 3M, 5 years
- Vita Enamic, Vident, 4 years

**Polymer ‘ceramic’**

- IPS E.max, Ivoclar Vivadent, 9 years
- IPS E.max ZirCAD LT, Ivoclar Vivadent, 3 years
- IPS E.max ZirCAD MT, Ivoclar Vivadent, < 1 year
- Katana Zirconia Block, Kuraray Noritake, 1 year
- Katana Zirconia STML, Kuraray Noritake, 3 years
- Lava Esthetic Zirconia, 3M, 2 years
- Pavati Z40.1, CCRI, 2 years
- Zirlux 16+, Zahn, 2 years
- 2 unknown origin brands, < 1 year

---

**Searching for this material:**

Tooth colored
Reasonable cost
Serves trouble-free 10+ years
Requires minimal tooth removal
Cementation is durable and easy
Tolerates all kinds of abuse
Does not wear opposing dentition excessively

---

**Fig. 2:** Brand names, company names and years observed for 23 products in three categories in the TRAC Research study.

**Fig. 3:** Forty-three years ago, the lab listed the above seven criteria as a wish list for a tooth-colored material appropriate for use anywhere in the oral cavity. No material has yet met all seven criteria, but some now in clinical testing may qualify if they continue their present performance.
Point 7: Critical information relevant to patient hypersensitivity and restoration longevity does not accompany zirconia crowns. (This includes residual radioactivity, added oxides and ions, fracture toughness, and the milling disk’s flexural strength.)

Over the next several pages, I’ll discuss these points in sequential order.

### Points 1 and 2: Low-translucent, noncolored zirconia vs. high-translucent, colored zirconia

Fig. 4 contains critical information that dentists and laboratory technicians must know, including:
- The five ceramic classes recognized

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Flexural strength (Reported in Megapascals)</th>
<th>Fracture toughness (Reported in Megapascals/m0.5)</th>
<th>Example brand</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 5: Tetragonal Zirconia</td>
<td>&gt; 800MPa / $K_t$ &gt; 5</td>
<td></td>
<td>Original BruxZir</td>
<td>Four or more units, anterior or posterior</td>
</tr>
<tr>
<td>Class 4: Cubic-Containing Zirconia</td>
<td>&gt; 500MPa / $K_t$ &gt; 3.5</td>
<td></td>
<td>Lava Esthetic</td>
<td>Three units, anterior or posterior</td>
</tr>
<tr>
<td>Class 3: Lithium Disilicate–High-Strength Glass Ceramics</td>
<td>&gt; 300MPa / $K_t$ &gt; 2.0</td>
<td></td>
<td>IPS e.Max</td>
<td>Single unit or three unit anterior</td>
</tr>
<tr>
<td>Class 2: Leucite Glass-Ceramics</td>
<td>&gt; 100MPa / $K_t$ &gt; 1.0</td>
<td></td>
<td>Ceramco</td>
<td>Single unit, anterior or posterior, adhesively cemented</td>
</tr>
<tr>
<td>Class 1: Porcelains</td>
<td>≤ 100MPa / $K_t$ &lt; 1.0</td>
<td></td>
<td></td>
<td>Veneer ceramic, inlay ceramic</td>
</tr>
</tbody>
</table>

Fig. 4. This chart summarizes the key clinical points in current international standards for ceramics (ISO 6872/ADA 69). Five ceramic classes are designated, and each class is defined with a unique name and minimal values for flexural strength and fracture toughness. The chart also gives clinical indications and a popular example brand name for each class. Each class can be used for its defined indications and indications in classes that are lower.

Fig. 5a: Lack of zirconia crack propagation defined by the term “transformation toughening” is shown in a BruxZir 2009 Class 5 zirconia that had been under extreme clinical stress for seven years. The yellow arrows in the scanning electron microscope image show three very small areas on the crown occlusal within a prominent wear facet.

Fig. 5b: An enlargement of Fig. 5a shows more clearly the left chip that occurred by Year 1, the middle chip by Year 3, and the right chip by Year 5. The yellow rectangle defines the area enlarged in Fig. 5c.

Fig. 5c: This enlargement of the right chip indicates a much more ominous event than is evident at lower magnification. Clinically, these chips are not evident.
worldwide,1,2 rather than use of the often incorrect terminology of “3Y,” “4Y,” etc. (referring to the mole percent yttria added).

- Honest flexural strength and fracture toughness values for each class.
- Clinical applications for each class.

The first monolithic full-contour zirconia crowns (BruxZir) used Class 5 Tetragonal Zirconia. Later, Class 4 Cubic-Containing Zirconia introduced the translucence aesthetic upgrade, but did not inform clinicians that the gain in translucence came with loss of strength. Today’s modifications have a partially true claim of “high strength and high translucence, with 1,000+ MPa flexural strength.” Full disclosure would add the words “but lower fracture toughness than Class 5 Tetragonal Zirconia.” The words omitted are critical because fracture toughness (K_{IC}) measures a ceramic’s resistance to crack propagation—the failure nemesis of ceramics!

Zirconia ceramic has unique strength due to a property called “transformation toughening,” which is the ability of engineered zirconia to transform molecular structure and expand as stress cracks begin to form. This expansion significantly delays crack propagation, which is measured as fracture toughness. Figs. 5a–c (p. xx) show transformation toughening in action clinically with a BruxZir crown in a patient with severe continuous occlusal habits. The 24/7 stress caused his crown to develop chipping and cracks that have not propagated in seven years. Under the same conditions, Class 2–4 ceramics would fracture.

**Bottom line:** Additives to zirconia for translucence and internal color interfere with zirconia’s toughness. Clinicians in our study unwittingly demonstrated this when they handheld Class 4 zirconia crowns while grinding them to alter shape and caused 2% of them to fracture before or during cementation (Fig. 6). BruxZir 2009 crowns survived the same procedure, demonstrating its higher fracture toughness “margin of safety.” (Class 4 zirconia can withstand chairside grinding if cemented or bonded first.)

Clinical indications and patient demands are the criteria that determine the choice between low-translucent and high-translucent zirconia. When patients push for Class 4 “translucent” zirconia on molars or multiunit posterior prostheses, or have severe occlusal
habits, they should be informed that longevity could be compromised and take responsibility for their choice.

Points 3–5: Veneer porcelain and glaze over zirconia aren’t long-lasting

Is it possible we’ve forgotten the frequent chipping of zirconia veneer ceramic documented after 2010 (Fig. 7)? Veneering porcelain has extremely low strength, classifying it under Class 1 porcelains (Fig. 4). Yet these porcelains are placed on surfaces in direct paths of occlusion for aesthetic appeal!

Glazes have even less longevity—measured in months—on working occlusal surfaces (Figs. 8a–b). Laboratory technicians realize polished zirconia is superior, but resist changing because glazing is faster and easier. Unfortunately, loss of glaze results in loss of aesthetic characterization (Figs. 9a–b). Characterization loss further contributes to zirconia’s lack of blend with surrounding dentition because of its natural brightness and opacity (Figs. 10a–b, p. XX).

Fig. 7: Two magnifications of a scanning electron microscope image show the typical appearance of chipping in zirconia veneering porcelains reported frequently since 2010. These chips often occur at the edge of the occlusal table and shear down smooth surfaces of the restoration. Although originally denied as a problem, the high frequency of occurrence across many brands worldwide eventually highlighted this weakness in the porcelains designed specifically for veneering zirconia.

Fig. 8a: Scanning electron microscope appearance of the glazed surface of a zirconia crown immediately after cementation.

Fig. 8b: The same crown after clinical service. Note the distressed appearance of the surface as the glaze roughens before it recedes. The yellow dots show areas where the glaze has worn away completely and exposed underlying zirconia.
Blending zirconia with surrounding dentition is a continuing challenge, in spite of today’s diverse strategies to overcome it.

**Point 6: No single cementation protocol is superior**

BruxZir 2009 used sandblasting followed by resin-modified glass ionomer (RMGI) cementation. Nine years later, this has resulted in 5% retention loss in the TRAC Research study. In spite of this excellent record, today zirconia cementation has become increasingly complex.

Fig. 11, p. XX, shows cementation regimens designated by companies selling 15 of the 17 zirconia products in the study. The numbers indicate that since 2009, chemical cleaning has gained preference over sandblasting; use of no primer has slight preference; and resin cement bonding is now preferred over RMGI cementation. (However, a company’s directions for resin cementation could be caused by reluctance to recommend a competitor’s cement.)

The important point is that no regimen of the 15 specified has shown retention problems with more than 100 dentists seating more than 1,000 molar crowns in our study. This leads to the following conclusions:

- You can cement any way you prefer.

---

**Fig. 9a:** Clinical appearance of a zirconia crown immediately after seating when all of the glaze is intact.

**Fig. 9b:** Clinical appearance of the same crown after the glaze is no longer present. Note the dull, bright white surface in the absence of the glaze.
• The secret to retention is careful following of cement instructions. For example, most dentists have not noticed the final step in cementation directions: Retain isolation and wait 3–8 minutes after initial set before saliva contamination. (The time required depends on brand.)

**Point 7: Critical information relevant to patient hypersensitivity and restoration longevity is needed**

Zirconia restorations are not pure zirconia; different oxides, ions and chemicals are present. In addition, certain radioactive minerals occurring in association with zirconium ore must be reduced to acceptable levels during ore purification. This may or may not happen, depending on the manufacturer’s ethics and the alertness of FDA inspectors.

To date, the TRAC Research lab has received one inquiry concerning alleged patient hypersensitivity to a zirconia crown. Neither laboratory technicians nor dentists have information necessary to address this inquiry. Currently, laboratory technicians have sole knowledge of the disk milled for crown fabrication, while dentists are rarely made aware of the zirconia brand or flexural strength and fracture toughness value. This information should be available on all lab.

---

**Recommendation for BruxZir, 2009**
Sandblasting to clean, RMGI cement to adhere

**Recommendations for studied zirconias, 2019**

<table>
<thead>
<tr>
<th>To clean after try-in:</th>
<th>Primer use:</th>
<th>Cement selected:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ivoclean (9)</td>
<td>No primer (8)</td>
<td>Resin cements (9)</td>
</tr>
<tr>
<td>Sandblasting (5)</td>
<td>Primer (7)</td>
<td>RMGI cements (6)</td>
</tr>
<tr>
<td>Sodium hypochlorite (1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 10a:** An A3 Vita Classic shade tab shows the difference in the color ordered for the zirconia crown on the lower second molar and color of the crown received from the lab.

**Fig. 10b:** Comparing the difference between the opacity and color of the zirconia crown received from the lab and the A1 shade tab choice that had been ordered.

**Fig. 11:** In 2009, BruxZir was introduced as the first commercially available monolithic full-contour zirconia crown in the U.S., and Glidewell recommended sandblasting and RMGI for cementation. The blue color shows the 2019 TRAC Research compilation of the cementation steps specified by the companies now selling 15 of the 17 studied brands of zirconia.
prescription forms, so dentists and their patients can see what the lab offers and choose the option that best fulfills each need or desire. All zirconia disks are not the same!

**Glass ceramics and polymer “ceramics”**

E.max glass ceramic is a major competitor for zirconia today. CAD-CAM fabricated E.max molar crowns have an excellent 98% survival at nine years in our study, using the preparation design recommended by the manufacturer in 2009 (1.5–2.0mm occlusal reduction; 1.5 axial reduction; deep chamfer margin).

Future glass ceramic popularity may be affected by:
- The fact that commercial laboratories can complete multiple zirconia crowns in the same time needed for one pressed E.max crown.
- Four zirconia materials are now available for Cerec in-office milling/fast firing, and the popularity of E.max versus zirconia in this market is yet to be determined.
- A glass ceramic competitor, Celtra Duo, developed long cracks at one year in this study when it was not fired. When we surveyed 8,000 U.S. dentists, 51% of users had experienced this problem, regardless of whether Celtra Duo was or was not fired.

Although polymer “ceramics” are not considered a ceramic in Fig. 4, the study includes four brands listed in Fig. 2, all of which have shown 90% and higher survival up to five years. However, all have had debond problems. If this problem were overcome, polymer “ceramics” have potential because they mill rapidly and smoothly, cause minimal wear of the milling bur, do not require postmill firing, blend well clinically, and don’t wear opposing dentition.

**Final note**

The data indicate Zirconia Ceramics have superior durability, regardless of the formulation, manufacturing and origin differences. Glass Ceramics and Polymer “Ceramics” tested experienced more fractures or retention loss, and both required much deeper tooth preparation to enhance strength for molar crowns. Glazes were short-lived on all three material categories. ■

**References**

1. [https://ebusiness.ada.org/productcatalog?446/Dentistry-Materials/ANSIADA-Stan-
dard-No-69-Dental-Ceramic/ADA69-2010](https://ebusiness.ada.org/productcatalog?446/Dentistry-Materials/ANSIADA-Stan-
dard-No-69-Dental-Ceramic/ADA69-2010)