Zirconia Simplified
Find out why it should be your new favorite restorative material
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Abstract
The immense popularity of zirconia as an indirect restorative material in dentistry has led to seemingly countless numbers of companies selling zirconia discs and blocks. The reliability of zirconia, however, is subject to specific manufacturing and processing protocols. Thus, it is of paramount importance for any dental professional utilizing zirconia to be aware of the source of the material and the various factors that can affect the success or failure of a final restoration.

When zirconia was introduced as a structural framework for dental restorations, only a few companies provide the computer-aided design and computer-aided manufacturing (CAD/CAM) systems needed for fabrication. A typical system included a scanner, a milling machine, a sintering oven, and the compatible zirconia milling blocks. They were referred to as “closed” systems, meaning that a particular scanner worked only with that manufacturer’s milling machine, which would only accept the same manufacturer’s own zirconia milling block. Eventually, “open” CAD/CAM systems were introduced, which enabled the use of design files from one scanner to be read by different milling units. These open units could use milling blocks from outside sources, making it possible for suppliers around the world to provide zirconia milling blocks.

The rate at which zirconia milling materials are entering the dental marketplace has soared. The quality of these materials can vary in numerous aspects that include the zirconia powder, the further refining by the manufacturer, and the methodology used for processing the millable blocks and discs. So many steps are needed between extracting raw zircon from the earth and turning it into the zirconium end product used in dental restorations. The origin of the restorative materials you use and how they were processed can be the difference in a successful restoration or a failure.
From the classroom…
A primer on the science and terminology of zirconia restorations

Zirconium Dioxide
Also known simply as Zirconia, this is a polycrystalline material, meaning it is made up of many small crystals. Dental zirconia contains two main types of crystal phases: tetragonal and cubic. Tetragonal is used for toughening or strengthening zirconia. Cubic is used to increase translucency in zirconia.

Crystal material composition
The images below show cross-section comparisons of 3M™ Lava™ Plus Zirconia and 3M™ Lava™ Esthetic Zirconia crystals. Lava Plus zirconia is almost exclusively tetragonal crystals; this is why the material is tough and strong, but its translucency is only 30%.

In Lava Esthetic zirconia, we have increased the percentage of cubic phase crystals to more than 50%. The end result is a reduced percentage of the toughening tetragonal phase, in order to increase translucency to 40%.

>80% tetragonal
30% light transmission

>50% cubic
40% light transmission

Want more science?
Read these IADR Abstracts to see how Lava Esthetic Zirconia performs!
Sintering
The process of heating up the zirconia restoration to extremely high temperatures to enact a state change. As this material is heated, it becomes stronger and more translucent.

Monolithic or full-contour
Two names for the same restoration: a one-piece zirconia crown with no interfaces.

Built-in shade gradient
This means the zirconia blank, or puck, has shade gradients built into it to help attain correct shading with less technician time. Not all zirconias include this feature.

Fluorescence
A tooth’s interaction with UV light; natural teeth fluoresce, so restored teeth also should fluoresce to show vitality.

Why fluorescence matters
Lava Esthetic zirconia is the world’s first zirconia with inherent fluorescence, giving it a more natural, toothlike appearance in any light. No fluorescent glaze required.

Above, top row: 3M™ Lava™ Esthetic Zirconia
Bottom row: Vita® Classic
How to compare materials using ISO standards

ISO 6872:2015 / ADA 69 “Dentistry—Ceramic Materials” are the standards 3M uses for guidance as to the strength and fracture toughness required for different indications.

Flexural strength measurements are made on finely polished samples and is an indication of a material’s strength in a “pristine” state—when the material has not been scratched or damaged.

Fracture toughness on the other hand is a measure of the damage tolerance of a material. It is a measurement of how difficult it is to break a material after it has been damaged. As an example, materials such as glass, which break easily when scratched, have a relatively low fracture toughness which can be undesirable when used in many dental applications.

Here we plot the various classifications of dental ceramics as defined by ISO 6872:2015. These classifications were developed by the ISO TC106 SC2 committee, led by Dr. Robert Kelly, and are based on the clinical experience of a large number of dental ceramics used in various indications.

<table>
<thead>
<tr>
<th>Flexural Strength (MPa)</th>
<th>Fracture Toughness $K_{IC}$ (MPa * m$^{1/2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 2 ($&gt; 100$ MPa, $K_{IC} &gt; 1.0$)</td>
<td>Composite and Hybrid Ceramics</td>
</tr>
<tr>
<td>Class 3 ($&gt; 300$ MPa, $K_{IC} &gt; 2.0$)</td>
<td>ZLS and L2Si Glass Ceramics</td>
</tr>
<tr>
<td>Class 4 ($&gt; 500$ MPa, $K_{IC} &gt; 3.5$)</td>
<td>Lava™ Esthetic Zirconia</td>
</tr>
<tr>
<td>Class 5 ($&gt; 800$ MPa, $K_{IC} &gt; 5$)</td>
<td>Lava™ Plus Zirconia</td>
</tr>
</tbody>
</table>

Unlike strength, fracture toughness has been observed to generally correlate with clinical indications, leading the Technical Committee 106 (Dentistry) of the Internal Standards Organization to recommend fracture toughness values...

New ceramics just entering the market can be grouped accordingly with some assurance that their clinical indications will be similar to those used to develop the classification...

—Dr. Robert Kelly
Ceramics in Dentistry Principles and Practice, pp 19 and 31.
Clinical Cases
Keeping up with new materials
John Weston, DDS, FAACD – San Diego, CA

Just as with digital equipment, technology is also playing a major role in the rapid progression of dental materials. Demand for new, advanced full-contour all-ceramic crowns and bridges is growing. Patients are beginning to require restorative materials that are metal-free, esthetic, durable and affordable.

Case study and clinical considerations for success
A 40-year-old female patient presented with a molar with a porcelain-fused-to-metal crown (PFM) that was chipped on the lower left side, tooth no. 19. The porcelain was chipped at the porcelain/metal interface. This created an open contact between that tooth and the tooth behind it, and the patient complained of food getting lodged in the space between her teeth. Additionally, she felt her teeth looked bad, and she could feel with her tongue the sharp edge where the porcelain sheared off.

Upon examining adjacent teeth, it was obvious the large amalgam restorations on either side, adjacent to that crowned tooth, required attention—teeth 18 and 20. As it is always better to do quadrant dentistry to save the patient extra visits, we required a treatment plan for those two adjacent teeth, as well.

We elected to treat the premolars (tooth no. 20 and 21) with direct restorations, but tooth no. 18 had significant cracks. We could have opted for a direct restoration, but the size—more than half the width of the tooth—and multiple fractures present indicated the tooth should have cuspal coverage. Final treatment plan was crowns on both no. 18 and 19 (3M™ Lava™ Esthetic Fluorescent Full-Contour Zirconia) and direct bonded restorations on no. 20 and 21.

Conclusion
Explore new full-contour zirconia materials. Digital technology is only getting better and the future will see more options becoming available to clinicians. This case certainly demonstrates the excellent predictability of digital impressions and esthetic/strength combination that is now possible with modern materials.

The newest generation of full-contour zirconia restorations, 3M™ Lava™ Esthetic Fluorescent Full-Contour Zirconia, delivers the following:

- Inherent fluorescence, for a more natural-looking restoration
- Natural shades and translucency
- Strength: 800 MPa* full-contour crowns are stronger than glass ceramics
- Efficient CAD/CAM production
- Ease of use for clinicians: simplified clinical workflow—easy to adjust and cement; a real time saver

*3-point bending strength according to ISO 6872:2015; qualified for Type II, class 4; indications: crowns, bridges with one pontic between two crowns, inlays, onlays and veneers.

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Zirconia reinvented
David S. Hornbrook, DDS – La Mesa, CA

Every dental material ever created by a manufacturer has gone on a journey. Some are longer journeys than others and some have much shorter endings than others, too. Zirconium dioxide, or simply, zirconia, has had a longer journey than most and has steadily advanced since its inception.

In the case of a recently introduced material—3M™ Lava™ Esthetic Fluorescent Full-Contour Zirconia, 3M Oral Care—a new technology was developed where color ions found in dyeing liquids are incorporated as tiny colorant clusters dispersed within the disc in a manner that, after sintering, results in a natural gradient shading. By using color ions, the zirconia is shaded while minimizing light scattering, which helps maintain translucency for esthetics, flexural strength and fracture toughness.

If the potential of a restoration to mimic the natural tooth is based on translucency and color, this process gets us much of the way there via built-in features. This equates to not needing to incorporate add-ons, like stains, which take more time and are subject to inconsistencies. So, if our esthetics are most of the way there, what’s missing? Well, beyond the basics of understanding lighting conditions, we also know that sunlight has a UV component and that natural dentition interacts with the UV light and fluoresces. This fluorescence is what gives natural teeth their vitality, or life! This new material has inherent fluorescence like natural teeth.

Case Study
In the following case, we used the recently introduced Lava Esthetic zirconia. We found that it fits better than other materials we have used, due to it being digitally designed and milled, and is as translucent and esthetic as materials that are significantly weaker. It incorporates the elements of an ideal zirconia—full-contour, monolithic, built-in shade gradient, inherent fluorescence—and has all the advantages of traditional zirconia, but it looks better!

Our patient was a 42-year-old female who came in with a fractured onlay (leucite glass ceramic) on tooth #4 (top, right) that was placed seven years prior. She fractured the buccal aspect of the onlay while eating. Due to lack of retention of the preparation, we treatment planned for a full contour crown. The final restoration speaks for itself!
Production of screw-retained zirconia hybrid dentures

Sonia Catazzo, CDT

In the past 15 years, zirconium oxide (zirconia) has proven its worth as a dental framework material for the production of metal-free crowns and bridges. Due to its favourable mechanical properties including a high flexural strength (900 to 1,200 MPa) and fracture toughness (9 to 10 MPa√m), the classical yttria-stabilized tetragonal zirconia has not only become an aesthetic alternative to metal-ceramic crowns and short-span bridges, It also is used successfully for the production of complex implant-based reconstructions.

Case Study
In this case a 60-year-old female edentulous patient complained about discomfort wearing her conventional dentures. When the patient was smiling, the teeth of her maxillary denture were barely visible due to a decrease in the vertical dimension of occlusion caused by processes of wear. In addition, bone resorption, especially in the vestibular areas, had led to a poor fit of both dentures.

For these reasons, it was decided to place implants, which—after the radiographic examination—turned out to be still possible despite the limited bone height and width. For the prosthetic work, zirconia hybrid overdentures with pre-fabricated titanium bases (Toronto Bridges) were planned: zirconia offers a high strength needed to avoid the problems of wear present in the initial situation. Moreover, the combination with titanium bases cemented to the dentures enables the technician to compensate for minor dimensional inaccuracies within the complex reconstruction, so that a passive fit is obtained more easily. For aesthetic reasons, veneering of the anterior parts with feldspathic porcelain was planned. This ceramic has a coefficient of thermal expansion that matches the one of zirconia. The posterior teeth were to be made of monolithic zirconia.

Material selection and shading
The material of choice for the computer-aided production of the zirconia frameworks was Lava™ Plus High Translucency Zirconia (3M). This material is clinically proven²,³ and offers uncompromised strength and stability. In addition, it exhibits favourable optical properties due to its high homogeneity and lack of impurities ensured by high-quality processing. The alumina content and distribution within the material blanks was optimized in a specific way. As a consequence, a high translucency is obtained, while—different from some other zirconia materials—the aging stability is not affected⁴,⁵.
When the dentures showed the desired optical properties and functionally ideal shapes, the titanium bases were cemented into the zirconia parts using 3M™ RelyX™ Unicem 2 Self-Adhesive Resin Cement. In order to ensure a perfect fit, the bridges were immediately placed on the implant analogues of the models and carefully fixed with screws before the cement was light-cured. After intraoral fixation with screws in the mandible and posterior region of the maxilla and temporary cement in the upper anterior region, the screw access holes were sealed with filling material (above, far right). A good aesthetic integration of the Toronto Bridges was obtained. The increase in the vertical dimension appeared to be adequate and was well tolerated by the patient regarding functional and aesthetic aspects. The patient was highly satisfied with the result and stated that the new restoration lead to an improvement of her quality of life.

**Conclusion**

The described treatment is a more aesthetic alternative to screw-retained PFM restorations and superior to resin-based overdentures especially in terms of strength and stability. The main advantage of the Toronto Bridge lies in the fact that it is much easier to obtain a passive fit, since minor corrections are possible via the titanium abutments. Thanks to the fixation with screws, the reconstruction is easily removable at any time for cleaning and repair.
That was then...

“Dental zirconia has revolutionized our industry by providing optimal strength in an "all ceramic" restoration. It has, however, in it’s traditional tetragonal form, sacrificed esthetics due to it’s limited light transmission, translucency and monochromatic nature. Zirconia also requires investing in upgraded milling technologies and strategies to satisfy demand capacities and accuracy.

Zirconia has opened many new worlds to dental laboratories, restorative dentists and their patients. Largely due to it’s strength and bio-compatibility, most restorations, including full mouth rehabilitations, can be manufactured without metal alloys or complex multiple manufacturing steps. Most recently, a few select manufacturers of dental zirconia have introduced multi-chromatic shading within the puck itself. This aspect changes the zirconia game again.”

—Craig Yoder, CDT, Thayer Dental Lab

“Compared to other prosthetic materials at the time, zirconia, at its introduction, suffered from being too opaque. That made it difficult to match the shade of adjacent teeth when using it. Also, with zirconia it was difficult to make very small restorations such as inlays and onlays because of sprues. Of course, the great benefit zirconia brought (along with the CAD/CAM workflow) was the ability for labs to produce large quantities of restorations easily. And, because it is all ceramic, it is able to better replicate natural human teeth shading.” —Yong Min Park, President, YM Dental Lab

...This is now!

3M provided Thayer Dental Laboratory with an opportunity to participate in a milling and field evaluation trial in early 2016. We began beta testing 3M™ Lava™ Esthetic Zirconia intraorally in June of 2016.

“3M Lava Esthetic Zirconia is a unique cubic zirconia that fulfills all of the requirements of strength (800mpa, 3 unit bridges), accurate shades and esthetics. A substantial benefit is it’s intrinsic incisal translucency. Controlled by how it is positioned when it is nested in the milling puck, it has a 3 mm incisal translucency, and gingival to that, a 3mm transition to the body color. That beautiful, natural incisal blend provides high esthetics with monolithic strength, without the additional labor cost of layering a much weaker porcelain to achieve correct shading. This eliminates the chance of chipping and delamination which means fewer remakes. In our experience, Lava Esthetic zirconia’s natural fluorescence looks great in the mouth!”

—Craig Yoder, CDT

“Zirconium dioxide, or simply, zirconia, has had a longer journey than most and has steadily advanced since its inception. For many years, ceramists that worked with zirconia would tell you the same things: it has changed how we produce restorations, it has very impressive strength; however, the esthetics are only just okay.” —Dr. David S. Hornbrook

“It’s a home run. You have a material that is strong, looks good, and is easy to deliver. You can’t beat that.”

—Dr. John Weston
One of the greatest aspects of Lava Esthetic zirconia is that it reduces labor cost and working time for the lab. This is because it is preshaded: it’s milled, sintered, then clear glaze is applied—and it matches the shade guide 100%. No brush stain is required.

A unique feature of Lava Esthetic zirconia is that it shares the same characteristics of natural teeth under fluorescent light, allowing the prosthetic teeth to come to life like real teeth. It’s also very strong compared to other anterior zirconia in the market. We make single crowns and up to three unit bridges without any problems.

Another thing of note is that Lava Esthetic zirconia is not as translucent as other ultra-translucent zirconia in the market. We believe this is actually an advantage in this case: translucency is not everything in representing natural looking teeth—the other ultra-translucent zirconia feel like they do not have any dentine within them due to their very high translucency, but with Lava Esthetic zirconia, you can achieve an even more natural-looking result.

—Yong Min Park, President, YM Dental Lab

“We recently rigorously tested zirconias from eleven different manufacturers. Four of those products were of the transitional shading variety. 3M™ Lava™ Esthetic Zirconia stood out from the crowd in terms of correct shade, translucency, and fluorescence. 3M Lava Esthetic Zirconia is a great value to laboratories, restorative dentists and their patients.”
—Craig Yoder, CDT

“The benefit of fluorescence is what gives Lava Esthetic zirconia its vitality. Us adding fluorescence via a stain is not the same as having it built right into it.”
—Joe Apap, General Manager, Town & Country Studios

“Anecdotally, I have found in my own personal experience (not backed up via empirical data) that gingival and bony architecture responds much more kindly to Lava Esthetic zirconia than other materials, like PFM for example. If a zirconia restoration encroaches on the biologic width, there is less or no inflammatory response like there would be with PFM or lithium disilicate.”
—Dr. Alec Ganci

“That was always the dilemma... When do I need to optimize esthetics? When do I need to optimize strength? The nice thing about Lava Esthetic zirconia is that we have a material that is strong, fits unbelievably well, is milled by the lab so the accuracy is right on, and we really don’t compromise esthetics.”
—Dr. David S. Hornbrook