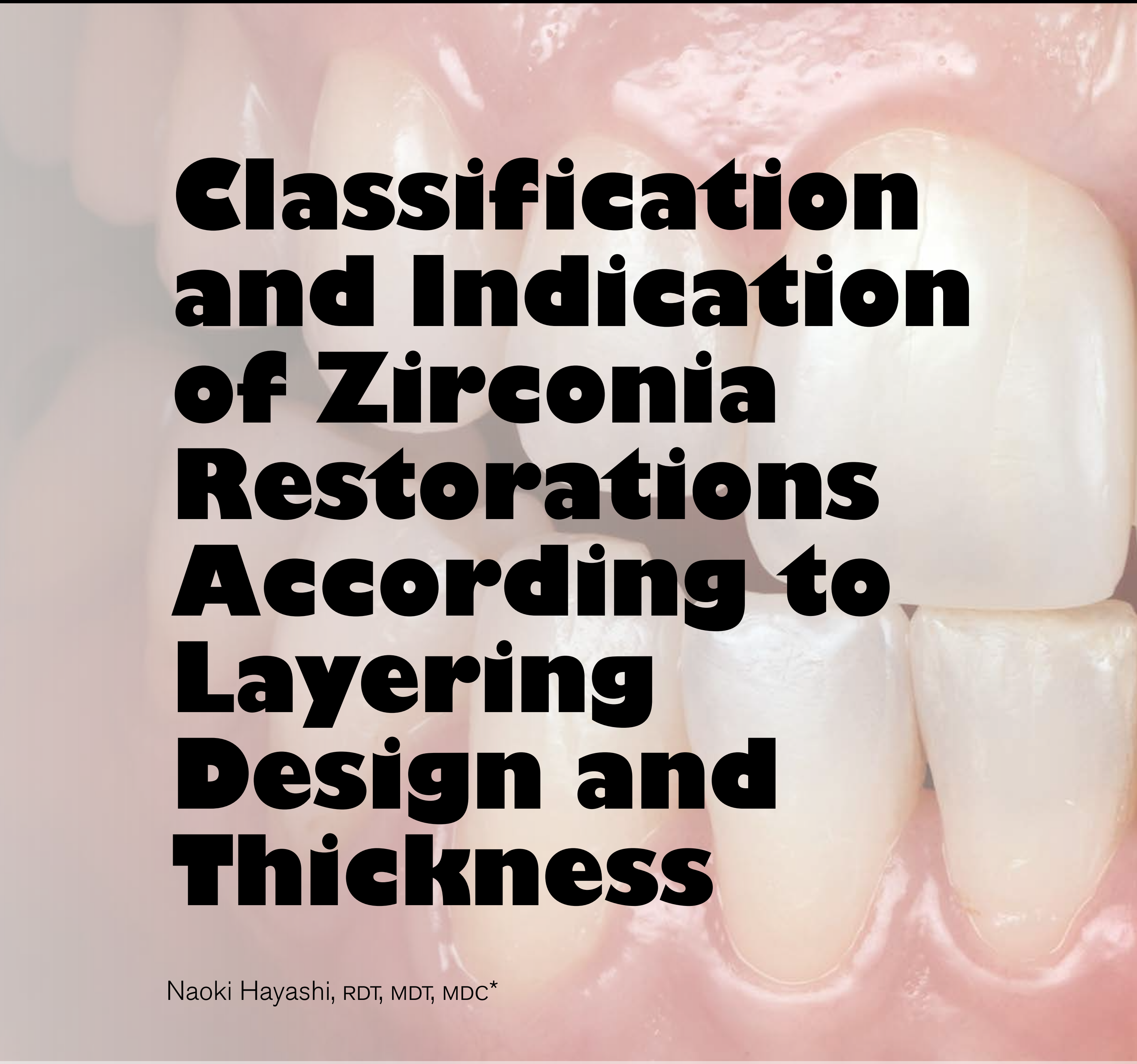

Classification and Indication of Zirconia Restorations According to Layering Design and Thickness

Naoki Hayashi, RDT, MDT, MDC*

Dental technicians, under the direction of the dentist, are responsible for fabricating restorative devices that contribute to the overall restoration of the patient's oral health. At times, technicians are also tasked with fabricating prosthetic devices that functionally and esthetically restore tooth morphology, color, and alignment in line with a patient's specific desires. In taking on such tasks, the dental technician faces the challenge of creating prostheses that mimic natural teeth as closely as possible.

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However, there are no standardized formulas for mimicking nature in such a way. And even if there were, any resulting dental prosthesis would only end up being limited by such standards, ultimately failing to resemble natural design.

As technicians, we are at a disadvantage when comparing our work to the design of the natural teeth. Therefore, we must exhaust all possibilities to overcome such challenges. The restorative devices that we fabricate must not be recognizable as such; rather, they must be indistinguishable from natural teeth and fulfill the needs and desires of the modern patient.

Over the years, numerous materials and techniques have been developed to aid in achieving the simple yet lofty goals of natural-looking beauty and lasting durability. We have consistently faced challenges in this field, ultimately resulting in new ideas and schools of thought. There have been many technologic advances and newly emerging concepts in prosthodontics and esthetic rehabilitation in recent years. The most significant developments have ultimately been the development and evolution of new, better materials, as well as the broadening of the range of applications of such materials.

When zirconia was first introduced into the field of restorative dentistry, it was often referred to as "white metal," and its reception was mixed due to its low translucency. Following this, the efforts of manufacturers, researchers, and clinicians led to the development of a highly translucent zirconia, which was achieved via increased yttria content and a mixture of cubic crystals. However, the increase in translucency came at the expense of the naturally high strength of the material.

I would like to take a moment here to go back to the transitional period of all-ceramic restorations. Due to its high translucency, aluminum oxide (alumina) was at one time the most widely used material for CAD/CAM all-ceramic restorations. But despite its favorable translucency, alumina restorations were consistently plagued by problems of chipped margins, cracking during fabrication, and overall instability in the oral environment. This was because the bending strength of the material was approximately 600 to 700 MPa, with a fracture toughness of 4.0 to 4.8 MPa $m^{1/2}$ (Procera Alumina, Nobel Biocare). These concerns regarding its strength are what eventually led zirconia to be introduced into the dental market a few years later. Although it was characterized by high strength, the dental zirconia introduced at the time was opaque, which in turn led to criticism regarding its esthetics. With that said, much progress has been made over the years, and the challenges surrounding translucency have been largely resolved in the area of zirconia-based restorations. Highly translucent zirconia is now widely available. What is interesting, however, is that the most translucent dental zirconia available today has a strength of about 550 MPa, which is lower than that of alumina.

It is somewhat of a paradox that clinicians, who at one time were concerned about the low strength of dental alumina, now prefer the use of high-translucency zirconia, which is characterized by even lower strength. Perhaps with the introduction of lithium disilicate glass-ceramic to the dental market, these comparisons of strength have simply ceased to be relevant. Whatever the case, the fact of the matter is that high-translucency zirconia has become one of the premier materials used in the field today.

In our efforts to achieve oral rehabilitation, two main goals that we wish to accomplish as dental technicians are long-term practical function and superior esthetics. Therefore, in each case, the careful consideration of the patient's dentition, occlusion, and esthetics are paramount in making appropriate decisions regarding material selection and structural design.

ZIRCONIA IS NOT WHITE METAL

As mentioned previously, zirconia is sometimes referred to as "white metal." It is an esthetic and safe material with high strength, toughness, and biocompatibility. Because of these characteristics, zirconia has become a mainstay in various industries, even outside of dentistry.

While zirconium (Zr) is classified as a metal in the periodic table of elements (see Fig 1), zirconia (ZrO_2) is a metal oxide and therefore classified as a ceramic material. Thus, in reality, zirconia is not a "white metal" at all. It is important to be aware of this distinction if we are to use it correctly and appropriately when fabricating our cases.

Like alumina, which is a metal oxide of aluminum, zirconia is a metal oxide of zirconium. When oxidized from zirconium, it loses its metallic properties and is transformed into a ceramic. One primary difference between metals and ceramics is that metals will deform when too much force is applied, while ceramics, instead of deforming, will fracture when they reach their limit.

In the industrial field, high-strength ceramic materials such as zirconia and alumina are known as fine ceramics, which are characterized not only by their high strength but also by their superior optical properties, acid/alkali resistance, and precision.

Although dental zirconia is far more esthetic when compared to metal due to its white color, zirconia in general is less translucent compared to other ceramics such as glass-based materials and alumina. The translucency of zirconia is correlated to its strength, thereby

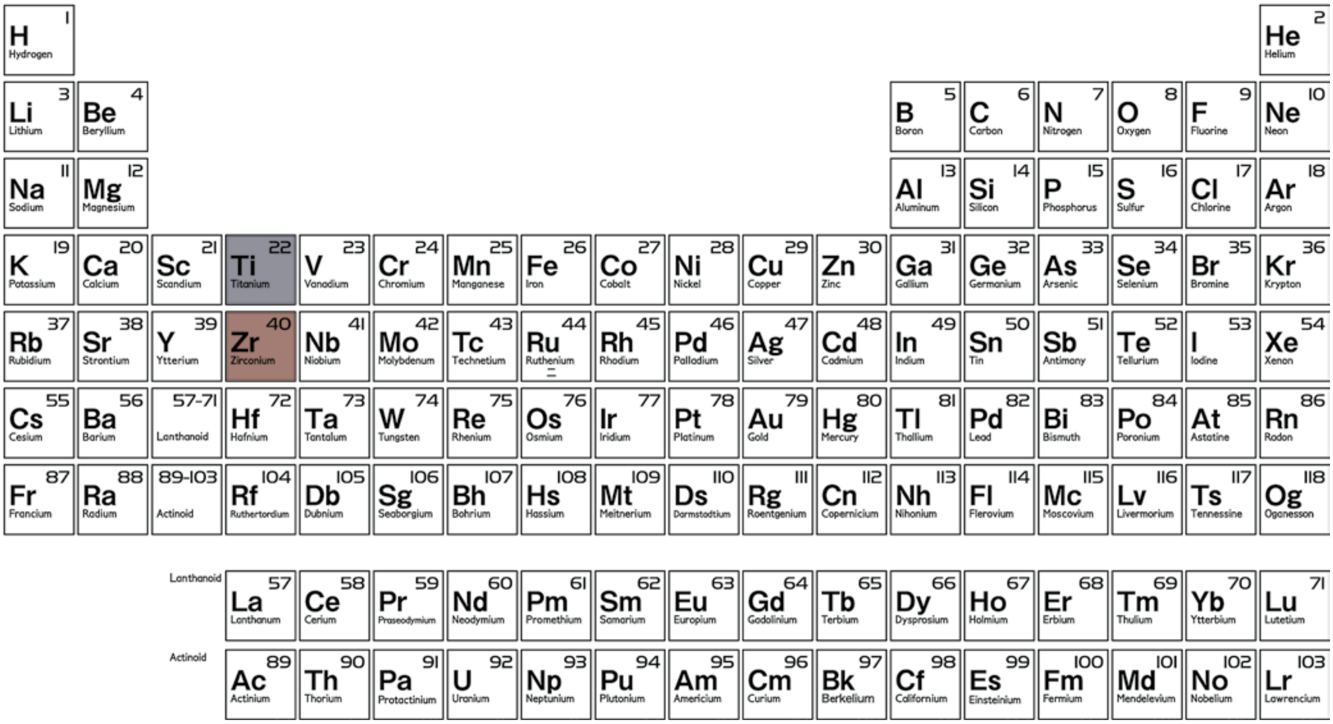

Fig 1 The periodic table. No. 40 zirconium and no. 22 titanium are in the same family of metals. However, when oxidized to become zirconium dioxide (ZrO_2), zirconia loses its metal characteristics and is transformed into a ceramic, much like alumina.

making it highly dependent on the formulation of materials and its crystalline structure during the manufacturing process.

Let us now take a look at zirconium, the basis of zirconia, on the periodic table of elements (Fig 1). The vertical columns of the periodic table are called “groups,” which are made up of elements with similar properties. Gold (Au) and silver (Ag), both frequently used in dentistry, are in the same group (vertical column), as are platinum (Pt), palladium (Pd), and nickel (Ni). These are all elements with high biocompatibility. In a similar vein, zirconium (Zr) is found in the same group as titanium (Ti), which is also often used in dentistry. It should also be understood that zirconium, which is a metal, and zirconia, which is a ceramic, are artificially made from a mineral called zircon ($ZrSiO_4$), which is buried naturally in the earth.

STRENGTH AND TRANSLUCENCY OF CUBIC ZIRCONIA AND ZIRCONIA

Zirconia changes its crystal structure and properties depending on the ambient temperature. In general, pure zirconia (without solid solution or additives) is in a monoclinic crystal state at room temperature, making it difficult to use in dentistry due to its low strength and translucency. The crystal structure undergoes a phase transition to a high-strength tetragonal crystal with about 4% shrinkage when fired at 1,170°C or higher, and subsequently transitions to a highly translucent cubic crystal at 2,370°C.

Due to its tendency to revert back to the monoclinic crystal state when returned to room temperature, yttria is added to stabilize the material, thereby allowing it to maintain its strength. After this process, it becomes what is known as *partially stabilized zirconia*, which is the material that is used in dental and industrial applications.

The relationship between the strength and translucency of the zirconia changes depending on the amount of yttria that is added. For example, when mixed with about 3 mol%

(5.4 wt%) yttria (3Y), the strength of the material is as high as 1,000 to 1,200 MPa, but the translucency is low (opaque), making it appropriate for use in bridge cases. Zirconia mixed with 4 mol% yttria (4Y) demonstrates a strength of 700 to 900 MPa, and its balance of strength and translucency allows for its use in anterior cases. Finally, zirconia mixed with more than 5 mol% yttria (Y5) is classified as high-translucent zirconia (with a strength of 550 MPa); demonstrating qualities similar to lithium disilicate, it is generally indicated for use in anterior single crowns.

While exact formulas are not publicly disclosed, if we take KATANA Zirconia (Kuraray Noritake) as an example, HTML and STML are recognized as equivalent to 4Y, while UTML is considered equivalent to 5Y. (Y indicates the yttria content. For example, 3Y indicates that the mixture is made up of 3 mol% [5.4 wt%] yttria with respect to the total of 100 mol%, which includes zirconia. Note also that mol% is a percentage of the total amount of substance, and wt% [weight percent] may also be used as a unit of measure.)

Originally, 3 mol% yttria was added to the partially stabilized zirconia to increase strength and stabilize the material. The amount of yttria was then further increased and heat-treated at higher temperatures to produce a cubic crystalline structure, thereby increasing translucency. The resulting material is what is used today to fabricate monolithic crowns. At 5Y, the strength of cubic zirconia is nearly equivalent to that of lithium disilicate glass.

The solid solution of yttria in zirconia occurs when yttria dissolves into zirconia crystals at 1,000°C. Zirconia crystals grow when treated with heat and interface binding begins between neighboring crystals. The yttria's function in these two processes is to "stabilize" the zirconia crystals, which shift back and forth between the monoclinic and tetragonal (strongly bound) crystal states as the temperature changes between room temperature and high temperature (1,200°C or higher). However, this stabilization does not reach 100% stability, and the resulting zirconia is referred to as *yttria partially stabilized zirconia* due to its characteristic of reverting back to its monoclinic state when affected by external stimuli (such as sandblasting, cracking, low temperature degradation, etc). The most stable and balanced range of high-strength (tetragonal) zirconia is called 3Y zirconia.

With the increase of added yttria solid solution, the crystals grow larger in size. This in turn reduces the number of times light is transmitted through the crystals, resulting in increased translucency. Rather than being completely transparent, the surface of each crystal can be likened to ground glass, meaning that light is scattered at the surface, reducing the penetration of light. When multiple layers of this type of glass are overlayed, the light is diffused at each layer, thereby reducing the amount of transmitted light.

For example, if 1.0 mm of zirconia coping were to consist of crystals with an edge length of 0.1 mm, light would transmit through the crystals nine times before passing through the entire material. If this crystal size were increased to an edge length of 0.5 mm, less light would scatter, and the light would transmit through the crystals only once. This means that more light would actually make it through the zirconia, thereby increasing its translucency. At the same time, however, the increase in crystal size would reduce the bonding area between crystals, thus resulting in a decrease in strength.

Zirconia without yttria solid solution requires a temperature of 2,370°C (2,700°C for complete dissolution) to generate cubic crystals. On the other hand, zirconia with yttria solid solution is able to generate cubic crystals at temperatures lower than 2,300°C, allowing the cubic crystals to remain even after returning to room temperature. In regard to the aforementioned 3Y zirconia, its crystal structure changes partially to cubic crystals at 1,500°C, while most of the cubic crystals return to a tetragonal crystal structure upon returning to room temperature.

CUTBACK OF THE LABIAL SURFACE AND ZIRCONIA LINGUAL BACKING DESIGN

Material characteristics

Building upon the previous discussion, we can now understand that zirconia has unique material characteristics and differences in strength. As the reader may already know, it is important to accurately identify which materials should be used for each case; available materials include lithium disilicate glass-ceramics and metal framework restorations. This section focuses solely on zirconia and provides some case examples on selection of strength, translucency, and frame design. We will take into consideration the possibility of layering, the tonal characteristics of the existing natural teeth, the positioning and quantity of the restoration, as well as the occlusion.

The following cases have been limited to anterior restorations and categorized into four types of layering thickness of zirconia, along with five types of lingual surface backing. By using a combination of these nine designs, it is possible to create restorations most appropriate for each case (Fig 2).

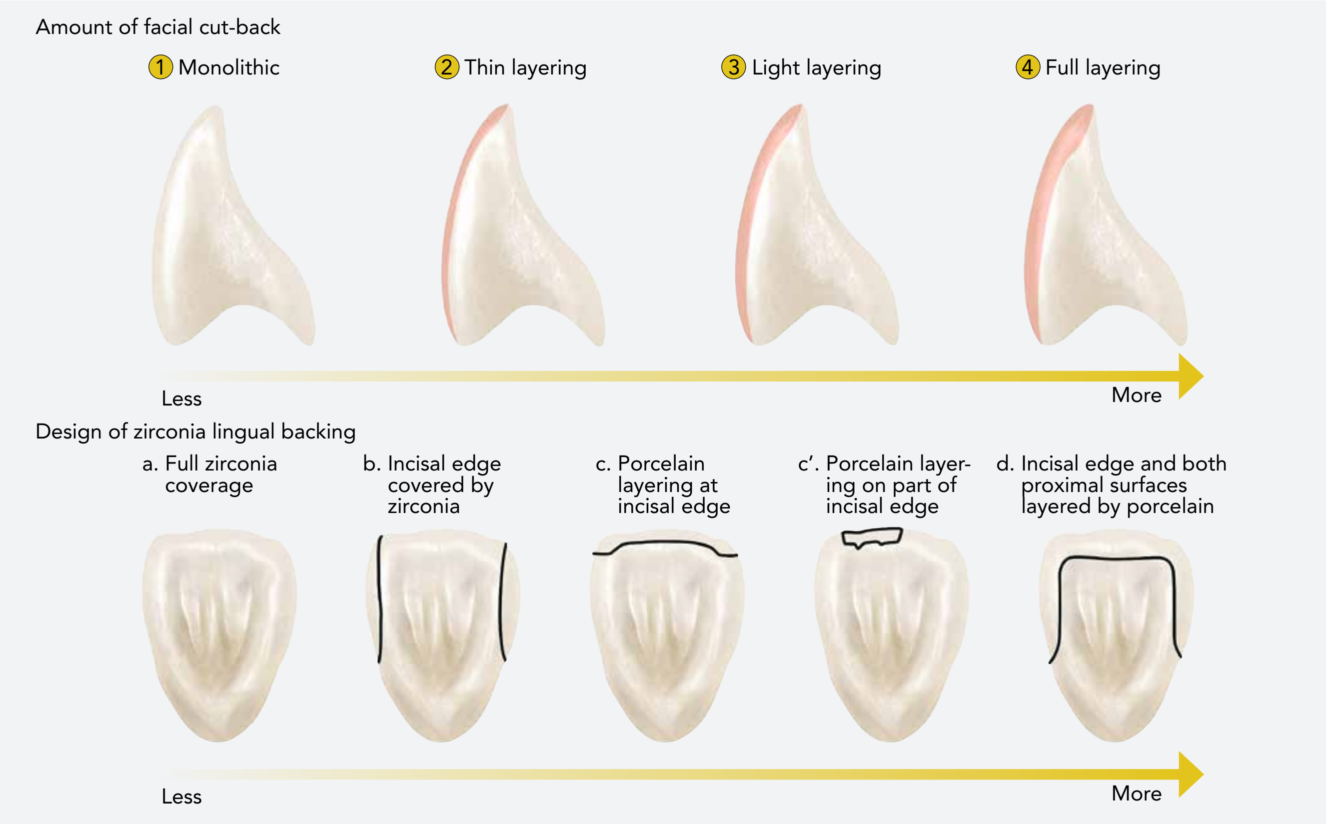

Fig 2 Amount of cutback on the facial surface *(top row)* and designs of zirconia lingual backing *(bottom row).*

Degree of labial cutback

① Monolithic

There is no cutback of the labial surface. Instead the color is controlled with staining on the zirconia surface without any porcelain layering.

② Thin layering

The labial surface of the zirconia is cut back approximately 0.3 to 0.4 mm, and a thin layer of porcelain is applied.

③ Light layering

The labial surface of the zirconia is cut back approximately 0.5 to 0.8 mm, and a thin layer of porcelain is applied.

④ Full layering

The labial surface of the zirconia is cut back approximately 0.9 to 1.3 mm, and porcelain is layered accordingly (sometimes extended to the lingual side if necessary).

Design of zirconia lingual backing

a. Full coverage with zirconia

The incisal margin to the contact point of the proximal surface is covered with zirconia. This is used for monolithic crowns.

b. Lingual incisal margin covered with zirconia

In order to replicate the opalescence and translucency of the marginal ridge to the proximal surface, both proximal surfaces (or only one side if applicable) are cut back to allow for porcelain.

c and c'. Part of the incisal margin covered with zirconia

In order to closely replicate the opalescence and translucency of the incisal margin, the incisal margin is partially (or entirely, if necessary) cut back to allow for porcelain.

d. Incisal margin and proximal surfaces covered with zirconia

To replicate the opalescence and translucency of the incisal margin to the marginal ridge, both the incisal margin and both proximal surfaces are cut back to allow for porcelain.

CROWN DESIGN

1. *Monolithic (combination ① a)*

In recent years, numerous anterior restorations have been completed using the monolithic process. However, in the course of my clinical experience, I have never completed a restoration by just applying staining to the surface of zirconia. This is because the process requires many applications of stain and repeated baking, along with a thick application of glaze materials to achieve surface texture, and shaping that must be done using a very thin layer. During the process, there is a high possibility that the coating of the staining foundation layer may get shaved off.

It is also a concern that even with this lengthy process, compared to a restoration constructed with layered porcelain, the degree of perfection and product quality is lackluster. Furthermore, in order to replicate the opalescence of the natural teeth using the staining process, a thin layer of blue stain is applied to the zirconia surface; however, I believe that it is almost impossible to achieve the desired effect with this step. When placed in the oral cavity, it can easily be observed that the blue stain is far different from that of the natural teeth.

At times, it may be possible to achieve a single central incisor restoration where the shade and characteristics are alike to that of the natural teeth using the monolithic zirconia design. However, it is my experience that this is the rare result of the natural teeth and shade characteristics being coincidentally similar to that of the zirconia chosen and therefore cannot be relied on to achieve a similar result with all restorations.

Nonetheless, in cases where detailed and complicated shade replication is not necessary, such as a restoration for six maxillary anterior units or more, and where the durability of the restorations is a priority, monolithic restorations have an advantage.

CLINICAL CASE OF THIN LAYERING WITH KATANA ZIRCONIA HTML

Fig 3 Three months after insertion of porcelain-fused-to-zirconia (PFZ) crowns on the maxillary central incisors. Note the location of multiple white bands observed near the enamel surface of the adjacent natural teeth. The opalescent layer is also observed from both marginal ridges to the proximal areas. Only a thin layer of porcelain is required on the surface layer to reproduce these features.

Fig 4 Abutment construction. The metal cores are exposed. A thick layer of zirconia structure, with an expected shielding rate of about 70%, is required to mask the metal color.

Fig 5 Design of the zirconia structure.

2. *Thin layering (combination ② b)*

In the case shown in Figs 3 to 5, notable opalescence (translucent layer) is not observed, so the zirconia structure on the lingual side was extended to the incisal margin to maximize durability and stability. An opalescent layer can, however, be seen from the marginal ridge to the proximal surface of the maxillary lateral incisors and mandibular anterior teeth, which was mimicked using porcelain in these areas. Hence, the zirconia structure was cut back accordingly so that the relevant areas could be restored with porcelain. Around the incisal edge, we can see a slight translucency as well as multiple thin white bands in the intracoronal area, and internal staining was used to achieve this effect. A substantial thickness of zirconia (0.3 to 0.4 mm thick) was required to closely replicate the white bands close to the enamel layer and to mask the metal core exposed from the abutment.

In cases like this, applying stain to the zirconia layer is extremely difficult, which is why I suggest the application of a thin layer of porcelain along the labial surface to achieve optimal results.

3. Light layering (combination ③b in maxilla and ③a in mandible)

For the case shown in Figs 6 to 9, the zirconia structure was extended to the incisal edge for both maxillary and mandibular reconstructions, prioritizing strength, because a distinctive opalescent layer (translucent layer) was not observed in the incisal edge area of the adjacent natural teeth. However, the incisal line angle to the proximal region of the maxillary left central incisor showed a strong opalescent layer, which was replicated with porcelain using a partial cutback in the lingual structure design. The porcelain that was layered onto the labial side was a deep warm color to mimic the color of the natural teeth, requiring 0.7 to 0.8 mm of zirconia in both reconstructions.

CLINICAL CASE OF LIGHT LAYERING WITH KATANA ZIRCONIA HTML

Fig 6 Delivery of a mandibular anterior PFZ fixed dental prosthesis (FDP). Securing the strength of the connectors is the priority. A full backing design was selected at the incisal and proximal areas without cutback of zirconia structure, because a definite opalescent layer (translucent layer) was not observed on the incisal margin.

Fig 7 After delivery of the mandibular anterior FDP. Delivery of the maxillary left central incisor crown followed.

Fig 8 After delivery of both maxillary and mandibular reconstructions. A distinctive opalesence effect was created at the proximal area by applying appropriate porcelain after cutback of the zirconia structure.

Fig 9 Design of the zirconia structures.

4. Light layering (combination ③c')

Th case shown in Figs 10 to 12 features a very notable opalescence effect and translucency in some areas of the incisal edge but not from the incisal ridge to the proximal area. Taking these characteristics into account, a full zirconia backing was selected, with a cutback at the incisal margin to closely mimic the translucency on the existing natural tooth using porcelain. The bandlike characteristics on the natural teeth were found under the enamel layer and were replicated in the crown using 0.6 mm of porcelain.

CLINICAL CASE OF LIGHT LAYERING WITH KATANA ZIRCONIA STML

Fig 10 Six months after insertion of an implant-supported crown at the maxillary left central incisor. A bright opalescent layer (translucent layer) was observed in the incisal margin, which was reproduced by porcelain application after cutback of the zirconia frame accordingly. Detailed surface texture and surface luster were reproduced by proper layering of the porcelain.

Fig 11 Insertion of implant-supported crown.

Fig 12 Design of the zirconia structure.

5. Full layering (combination ④d)

In the case shown in Figs 13 to 16, a notable opalescent layer (translucency) is observed on the incisal edge as well as the area from the marginal ridge to the proximal area. Taking these characteristics into account, the zirconia structure was cut back accordingly and restored with porcelain. The natural teeth had a thick enamel layer, so 1.1 to 1.2 mm of porcelain was required to replicate the mamelon structure intracoronally.

CLINICAL CASE OF FULL LAYERING WITH KATANA ZIRCONIA HTML

Fig 13 Pick-up impression using a custom impression coping for a cantilever FDP.

Fig 14 Nine months after insertion. Internal structures observed in the adjacent natural teeth are located deep in the enamel layer. A significant amount of porcelain depth is required to restore these features in the prosthesis. Zirconia backing is cut back accordingly to reproduce the opalescent layer, observed from the incisal margin to the proximal area, by porcelain.

Fig 15 The upper lip creates a shadow on the maxillary anterior teeth to some extent. The created opalescent layer (translucent layer) should look similar to that of the natural teeth even under the influence of the shadow. The ultimate goal is the total harmony of the prosthesis with the natural dentition and patient's face regardless of the condition of the lips in any direction.

Fig 16 Design of the zirconia structure.

CONCLUSION

Many clinicians are aware of the strength and translucency of zirconia due to publicly available data and likely already base their material selection and structure design for their cases on such figures. However, this article has taken things one step further and explained the cause of variations in strength and translucency of zirconia in relation to the inherent properties and characteristics of the material itself. Perhaps through this knowledge, some readers may gain a better understanding of their existing workflow, or perhaps they will be inspired to find a new approach to their clinical practice in the future.

In order to take maximum advantage of the dental materials available, both dentists and dental technicians must be willing to make the effort to acquire thorough knowledge and understanding of the materials and their possible applications. All-ceramic dental restorations enable us to produce highly biocompatible, functional, and esthetic prostheses, and the application of zirconia to anterior cases is now widely accepted. Whatever the material or system, our goal always remains unchanged—to achieve compelling results for the patient through a carefully planned process.

Modern advances and innovations in various systems related to all-ceramic prostheses have allowed us to more closely emulate the natural tooth than ever before. As technicians, it is our task to observe and analyze the patient's remaining natural teeth in order to reflect and realize those natural qualities in the materials and systems that we use during the fabrication of the prostheses. In this process, the morphology, surface texture, position, and tooth color become just as significant as occlusion and functionality. Also critical is the selection of the appropriate system and fabrication technique for each unique case.

The introduction and subsequent proliferation of CAD/CAM systems has brought tremendous benefits to the dental industry. In addition to widening the scope of applications and techniques, all-ceramic systems have expanded the potential for color reproduction and simplified methods of fabrication. Along with such advances, however, patient demands have also increased drastically. Such friction between progress and demand has become a driving force in the industry, and I welcome this synergy as it propels forward my efforts to achieve esthetic and functional excellence. As further technologic progress continues to bring forth improved materials and new demands, there will surely be no end to our acquisition of technique and knowledge. It is through experience that we cultivate technique—and with knowledge that we complement our artistry.

Acknowledgment

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