Revolutionary Development

Part 1

Dr. François Lelièvre

The new veneering ceramics are indicated for varied framework materials, including zirconium dioxide. Even multiple firing cycles have no impact on the ceramic material anymore. The author takes a scientific approach on the development of dental ceramics and describes various chemical and physical aspects.

Since their introduction in the 60s, dental ceramics have been continuously developed. At first, they were only used for cosmetic purposes on top of metal alloys; nowadays, the material composition has been developed further so that they can be used as framework materials instead of alloys. Due to constant investigation in material technology and technical development, all-ceramic systems have been significantly improved in the past years [1]. Three main aspects have marked this breakthrough:

- Continuous improvement of the physical-chemical and aesthetic characteristics of the new ceramics
- Step-by-step replacement of metal as reference material for frameworks by ceramics
- Increasing use of digital technology that revolutionized construction and manufacture of prostheses

Another important aspect is the significant development of implant supported prostheses, which now allow large span bridges. It is also possible to combine different techniques and material characteristics according to the indication.

Advantages of the all-ceramic concept

Today, all-ceramic prostheses unite high mechanical framework firmness and extraordinary aesthetic and biological characteristics. The customer demands have grown: Not only do they expect clinical functionality but also exceptional aesthetics of their long-lasting and biocompatible prosthesis. These chemically inert all-ceramic prostheses do not interact with any other prosthetic material in the mouth, which prevents bimetallism. Since there is no corrosion, no discoloration is caused. As opposed to metal prostheses, metal-free prostheses do not present dark borders at the cervical area or brightness loss that darken the tissue if the gingiva recedes. Without interactions, medical imaging exams with magnetic resonance imaging and scanner become easier. There are many advantages to all-ceramic prostheses for the doctor as well as the dental technician and of course for the patient. Dental practices can provide patients with a long-lasting prosthetic treatment concept that has aesthetic as well as biocompatibility advantages. Dental laboratories have the possibility to expand their range of services and products and develop new skills that give them an advantage over their competitors. Patients that have a high esteem for aesthetics and biocompatibility will get their smile back since the new prostheses are less and less noticeable.

Which material to use for the framework?

Since all-ceramic systems have appeared in the 80s, various materials for ceramic frameworks are available. From a clinical point of view, two materials have to be highlighted since they meet all demands in mechanical firmness, aesthetics and application: lithium disilicate and zircon [2 to 6]. While the first material is used mainly for prostheses on singular teeth or for smaller bridges on the frontal teeth, the second material is used for large-span all-ceramic bridges on implants. Even if their chemical composition (glass ceramics vs. crystalline ceramics) and their physical-chemical characteristics are different [7], they can both be veneered with the same material due to their similar expansion coefficients – provided that the veneering material

Type	Coefficient of thermal expansion 10 (25 -500°C)	Flexural strength (MPa)	K1c (MPa √m)	Young modulus (Gpa)	Chemical solubility (ug/cm²)	Temperature of firing (°c)
Lithium disilicate	10,3-10.5	290-400	1	90-110	10-50	930
ZrO2	10,4-10,6	1000-1400	7-10	200-210	<20	>1350

Fig. 1: Comparative table of the physical-chemical characteristics of lithium disilicate and zircon

was designed for both applications (Fig. 1).

Importance of veneering materials

Once the framework material was chosen – which veneering material should be used? There are three answers to this question:

- A high-quality aesthetic ceramic that satisfies even demanding patients
- A simple ceramic concept that ensures the labs profitability
- A reliable material that guarantees long-lasting success

CeraMotion Zr has been developed with a suitable expansion coefficient for both zircon and lithium disilicate. It can be used for the conventional build-up, the cut-back technique and the technique of surface masking with stains. This allows the combination of central singular teeth on lithium disilicate and mechanical long-lasting posterior bridges on zirconium dioxide in the same clinical restoration. Using the same veneering material for both framework materials guarantees a consistent aesthetic result. The press-over technique on zircon (ceraMotion PZr) is an interesting alternative because the finishing can be done with conventional build-up or by masking the surface.

Synthetic glass

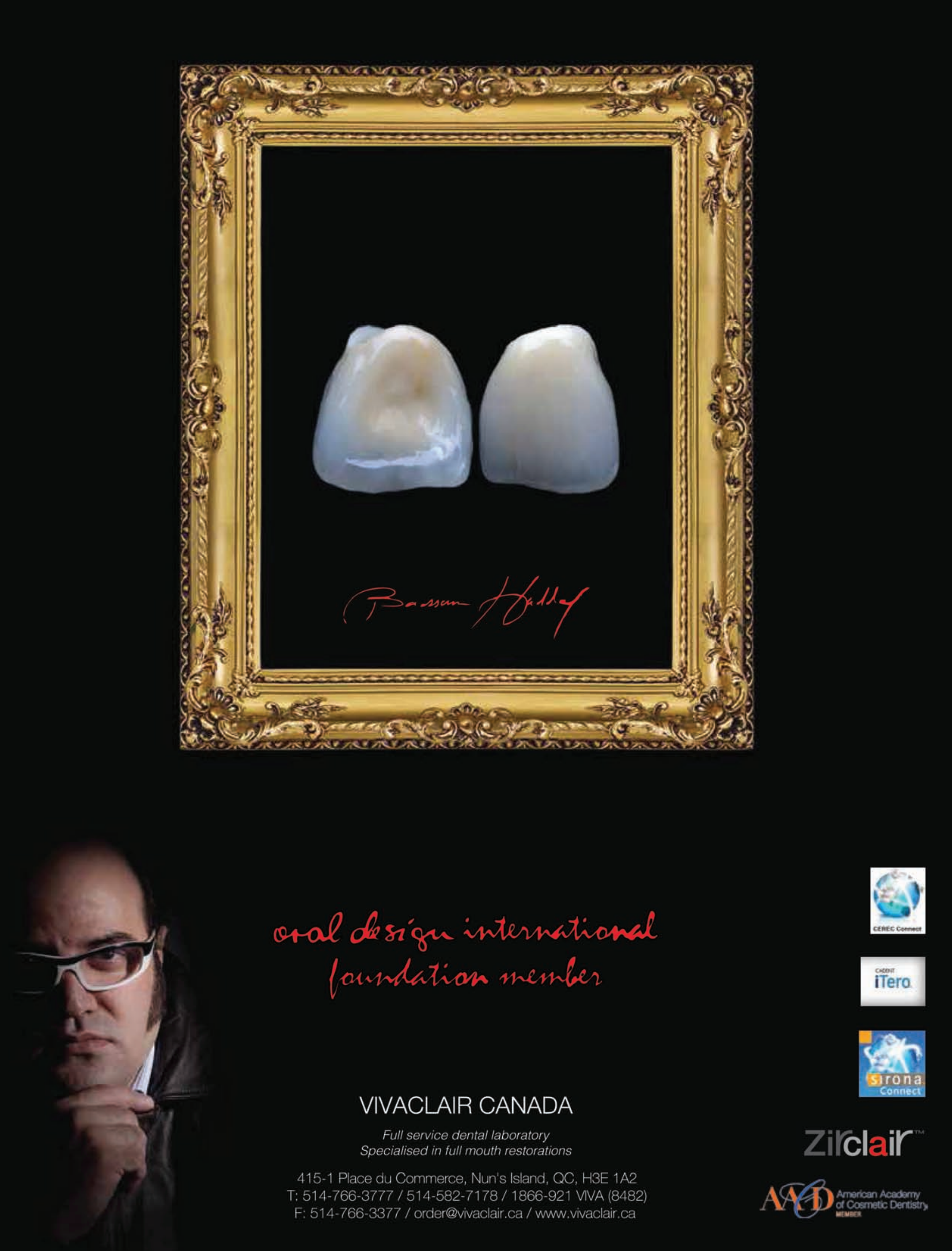
The development of a new dental ceramic is a complex iterative process that requires a competent multi-discipline team (engineers for material technology, dental technicians and dental surgeons). Extensive work is necessary to bring the ceramic material characteristics up to the standard in dental medicine. The goal is to reproduce the physical, chemical and aesthetic characteristics of natural teeth with a ceramic material. In the process of developing this new ceramic, the required demands lead to choosing a synthetic ceramic to avoid random factors as they tend to appear with materials based on feldspat.

The new synthetic glass is made of highly pure ceramic oxides. It was chosen based on extensive investigation aiming at optimizing different manufacture parameters: thermodynamic studies on the phase depositions of glass melts, the effects of the curing speed, the influence of additives on the flowability, behavior during dissolution of turbidity substances etc. Glass is a naturally non-crystalline material characterized by the phenomenon of glass transition [8]. De facto, it is a non-crystalline solid material. After melting a series of components (silicon, aluminum hydroxide, calcium carbonate, barium carbonate, calcium fluoride, etc.), the ceraMotion Zr base glass is cooled (water cooling) rapidly to avoid crystallization and to harden the liquid into a solid glass material. The opacity can be regulated by adding Zr02 or Ti02. The absence of feldspat eliminates the problems resulting from composition deviations.

This guarantees a constant lot quality. Even with multiple firing cycles, the characteristics of the ceramic do not alter.

Optimized expansion

As the pressure resistance of ceramics is generally higher than the tensile strength, the expansion coefficients of the material layers should be chosen carefully in order to put a light pressure on the veneering ceramic during cooling. Fig. 1 (Comparative table of the physical-chemical characteristics of lithium disilicate and zircon) shows the behavior of the ceramic materials during firing. The slope of the curve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corresponds to the expansion coefficient of the material. The expansion coefficient of CeraMotion Zr (9.2·10-6°C-1 between 25 and 500°C for the dentin) has been optimized so that it is slightly lower than the expansion coefficient of the zircon or lithium disilicate framework (10.5 ±0.r2·10-6 °C-1 between 25 and 500°C) (Fig. 2).

The glass transition temperature (Tg) is the temperature that marks the transition from the cooled liquid to glass on the expansion curve. This temperature depends on the composition and microstructure of the material (530°C for the dentin CeraMotion Zr). It oscillates slightly depending on the cooling conditions. Tg has the tendency to increase with rapid cooling and decrease with slow cooling.

To control the expansion coefficient and the flowability of the ceramic when increasing the temperature, it is necessary to carefully monitor the manufacturing parameters of the glass. This flowability is also known as pyroplasticity.

Pyroplasticity, wettability and surface quality

The pyroplasticity must be controlled to avoid deformation of the restoration contact points during the firing cycles. The ceramic should also not lose its natural ability for gloss formation. The chemical composition of the glass mass and specially the amount of additives (K2O, Na2O etc.) play an important role in this.

The ceramic has been adapted so that it allows a good framework wettability with the veneering ceramic and shows excellent pyroplasticity during the firing cycles (Fig. 3). Ceramic restorations should not modify the antagonist teeth. Abrasion of the natural tooth enamel due to ceramic restorations can cause a series of clinical problems, such as a modification of the vertical occlusion or a heightened temperature sensitivity.

It is also necessary to access the glass surface to limit surface defects, since these can increase abrasion. This parameter gains even more importance in patients with bruxism or uneven occlusion. The medium hardness (530HV), which used to be considered the main parameter, is now only one of many factors that need to taken into account when choosing the material.

Thanks to the extraordinary microstructure and the complete material density, the surface quality is one of the top features of ceraMotion Zr. As the surface is free from porosities, it prevents plaque accumulation or surface defects that are unaesthetic and can cause abrasion. The condition of the surface can be assessed with atomic force microscopy (AFM) [9].

Testing the surface topography in the micron range is a relatively new procedure. In the past, dental technicians would rely on the "gloss aspect" without seeking a better understanding of the direct and indirect consequences that the surface quality can have on the in vitro reaction of the veneering material. Surface roughness can be recorded with a mechanical sensor (Fig. 4) that is moved across the tooth with a stepping motor. The device is connected to electronics and a computer for data output. This renders a three-

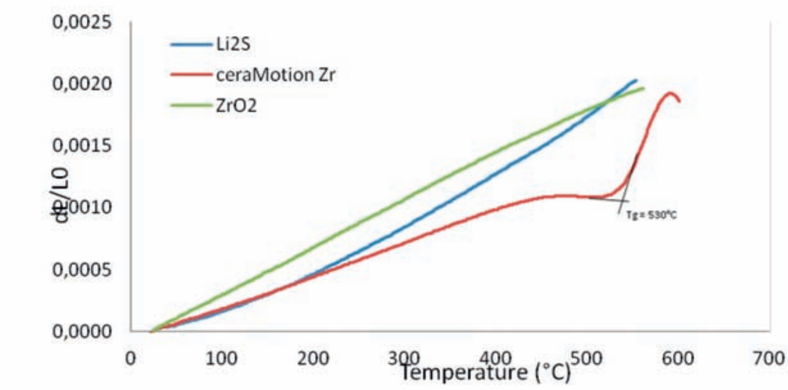

Fig. 2: Comparison of expansion curves of zircon, lithium disilicate and ceraMotion Zr

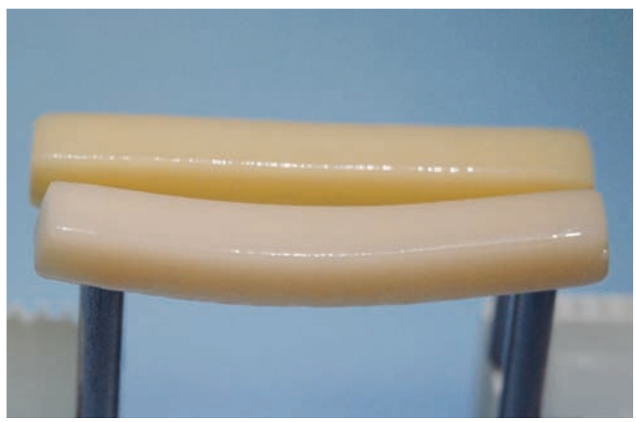

Fig. 3: Test piece of ceraMotion Zr (upper) after eight firing cycles compared to a conventional feldspar ceramic

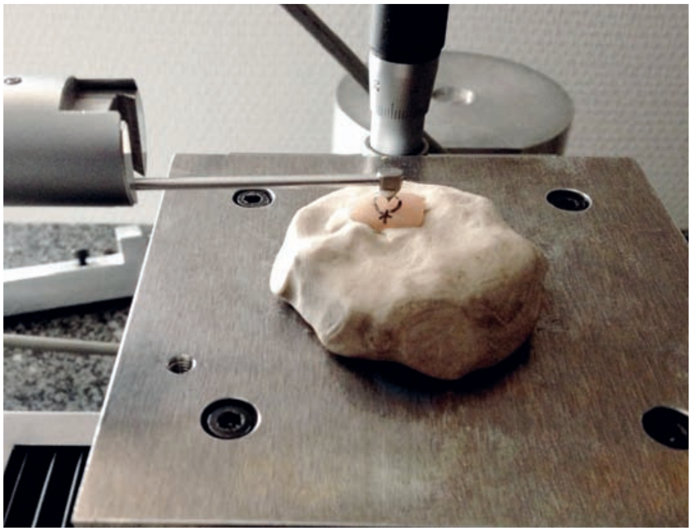

Fig. 4: Sensor for recording surface topography of a ceramic crown

dimensional image that shows surface defects and a slight visualization of the restoration result. The sensor moves in 1 m steps, which leads to a very high resolution. The right pyroplasticity adjustments can ensure a controlled surface roughness during biscuit firing (Fig. 5).

It also promotes natural gloss formation (Fig. 6). In addition to the natural gloss formation, the Touch Up Concept (correction firing and gloss firing in one step, at lower temperature) can contribute to a smooth surface. Limiting the surface defects prevents split offs or fractures of restoration elements common after constant use. Despite its high density, ceraMotion Zr is easy to mill and polish. When veneering zircon or lithium disilicate with veneering ceramics, the materials must bond perfectly to obtain a "sandwich". With this new material, the framework can be perfectly wetted. The low fusion glass composition diffuses the veneering material across the complete zircon surface. On zircon frameworks, the temperature must be increased by 30 °C when firing the first layer so that the temperatures can be adjusted at the transition zircon to veneering ceramic. Zircon has a very low thermal conductivity of 3 W·m-1·K-1 (gold = 300). Due to its lower heat absorption, the temperature of lithium disilicate only has to be increased by 10 °C. The following layers can be fired with normal firing temperatures according to the instructions of use for the veneering material.

Mechanical properties

All-ceramic prostheses are layered like "sandwiches". Their mechanical hardness is determined by the properties of the framework material and the veneering

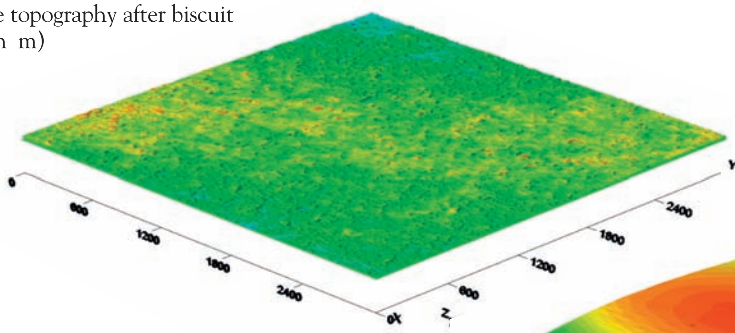

Fig. 5: Surface topography after biscuit firing (scale in m)

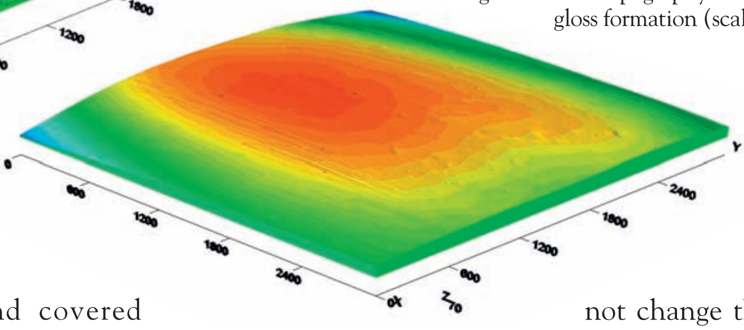

Fig. 6: Surface topography after natural gloss formation (scale in m)

material. The restorations were tested extensively to recreate the load a prosthesis has to bear in the mouth (repeated load during chewing, eccentric movement, rapid temperature changes in wet environments, different types of impacts, etc.). The mechanical firmness is measured with the internationally standardized 3-point bending test (ISO 6872) [10 to 12]. In this test, a force F is applied on a test object in a defined size until it completely breaks. Fig. 7 shows the measured values for the ceraMotion Zr product range. The values are twice as high as the international norm. In all-ceramic prostheses, the transition between the framework material and the veneering material is more cohesive than in metal-ceramic prostheses.

The internationally standardized Schwickerath test (Norm ISO 9693) [13] measures the adhesion of ceramic to zircon. In this test, the central third of a band covered with veneering ceramic undergoes a bending stress test (Fig. 8). The result is determined by the type of material, the wettability and the surface roughness. Since the substrate can be perfectly wetted with the ceramic, the values are twice as high as the international norm.

The values do not depend on how the prosthesis was sandblasted or how the framework was prepared (Fig. 9). Compared to the metals, ceramics are thermally nearly inert. This isolates the pulp-dentin-complex and the mounting materials from temperature changes. The thermal diffusion coefficient of ceramics is lower than the one of metals. Ceramics are therefore the ideal veneering material for healthy dentin. However, this does not change the fact that prostheses – and natural teeth – should not be exposed to big temperature changes, such as in case of having ice cream right after coffee. This is a significant change in temperature that can affect prostheses over time.

These shocks can be simulated in different tests. These tests are currently discussed in order to set an international standard. During development, two tests were performed to find out which ceramic properties react best to temperature changes and lead to less split offs. The thermo-cycle test consists of exposing three-unit bridges (Fig. 10) to successive thermal shocks by sinking them into ice water and then into boiling water. In the thermal resistance test, the bridges are

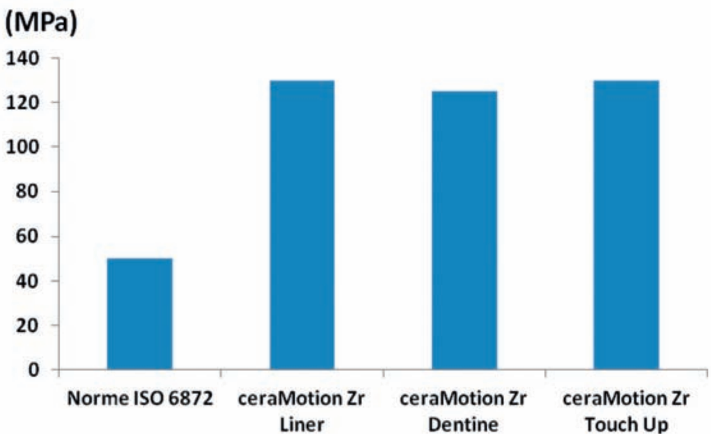

Fig. 7: Mechanical bending strength according to ISO 6872

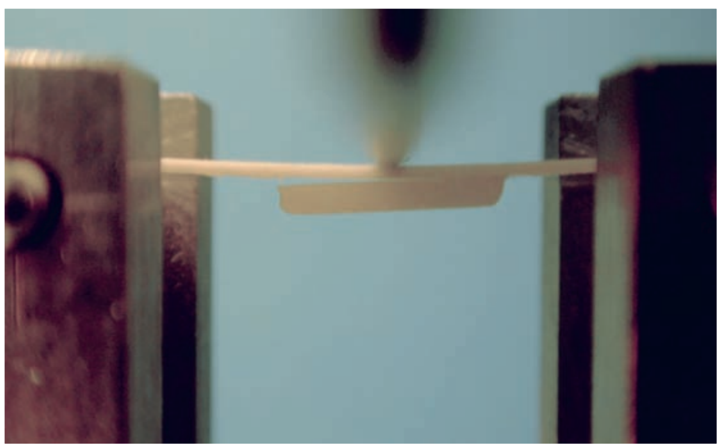

Fig. 8: Adhesion test according to ISO 9693

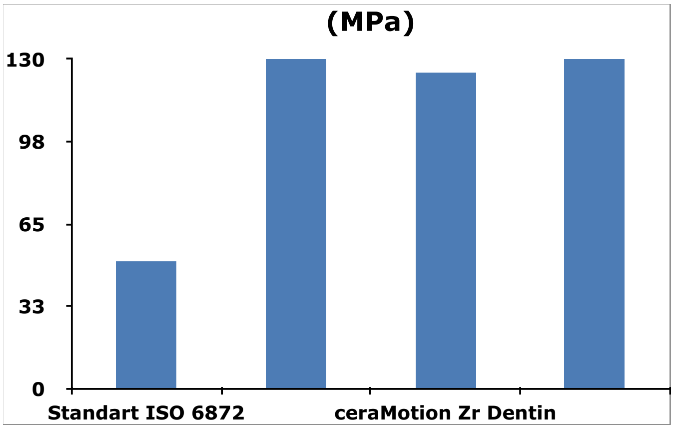

Fig. 9: Adhesion tests subject to different conditions in preparing the framework

Fig. 10: Ceramically veneered (left) and non-veneered (right) bridges used to optimize the reaction to thermal shocks

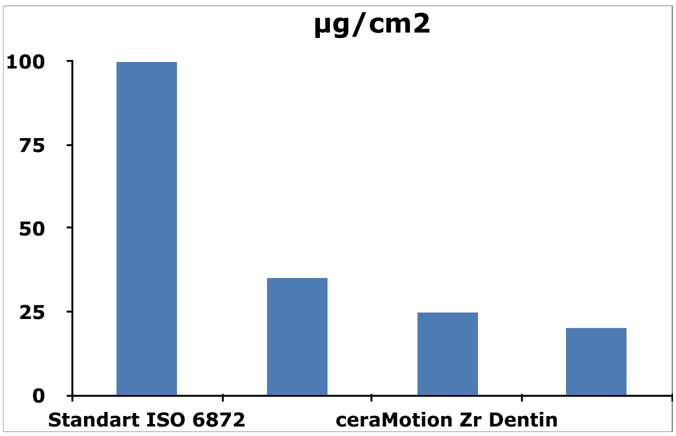

Fig. 11: Measuring chemical solubility of different ceramics according to ISO 6872

Fig. 12: Cell culture for cytotoxicity test

heated in the oven and then cooled abruptly in ice water (the pre-heating temperatures are increased in 15 °C steps from 80 to 165 °C). Since there is currently no standard test, the materials are optimized based on comparative tests with competitive products.

Chemical inertia and biocompatibility

The chemical dissolution of the ceramic has been minimized to avoid infiltration effects on the ceramic-to-ceramic transition. The material surface shows no damages that could debilitate the transition between the veneering ceramic and the framework material or lead to damaging the outer surface of the prosthesis. The chemical resistance is determined with the solubility test defined in the ISO 6872 norm. The damaging of the ceramic in the mouth is simulated with acetic acid solution in an accelerated manner. The mass loss caused by the chemical attack must remain under 100 g /cm2. The values listed below remain significantly under the limit value (Fig. 11) regardless of the type of ceramic veneering. The ceramics used in dental prosthetics are chemically more stable than metal and plastics. Ceramics are not affected by corrosion and do not cause any reactions in the organism.

It is a biocompatible material. All-ceramic bridges have regularly shown less gingival reactions than metal-ceramic bridges. Biocompatibility was verified with tests that were performed according to ISO 10993-5 [14].

These tests excluded the cytotoxicity of the materials (Fig. 12). The chemical inertia and the complete biocompatibility of ceramic materials prevent any rejection reactions due to allergies or tissue damages.

Handling

Easy handling is an important factor in choosing a veneering ceramic. Though the framework material often is manufactured mechanically, veneering itself remains a manual operation. Choosing the correct grain size of the powder and the correct mounting liquids can optimize handling. The dentin powder has an average grain diameter of 26 m and a specific surface of 0.7 m/g (inner surface area that directly contributes to the reactivity of the surface, contrary to the outer surface). To optimize the raw density, grain sizes (Fig. 13) must be mixed so that the optimal grain density is achieved. Viscosity of the material mash is determined by the type of liquid. Two liquids with the same viscosity can have different dispersion capacity due to different electrokinetic surface potential. The electrokinetic potential (electric charge of the surface) depends on the surface of the particles. The liquids used for modeling have polyelectrolytes that contribute to modifying the electrokinetic behavior of the powder surface. They can unite different components: dispersing agent, water, alcohol, etc.

In the second part of this article, the author analyzes the aesthetic quality of ceraMotion Zr by presenting a clinical case study. Sd

- The bibliographical references [1] through [14] can be found in the second part of the article.

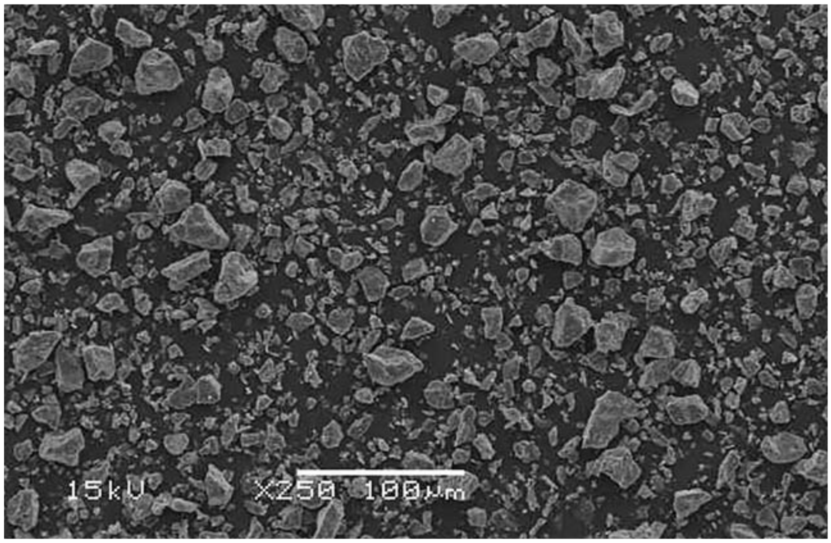

Fig. 13: Glass powder to manufacture CeraMotion Zr extracted by means of air flow crushing

About the Author

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Revolutionary Development

Part2

Dr. François Lelièvre

The new veneering ceramics can be used for many framework materials. In the first part of the article, the author explained some of the chemical and physical aspects of this new generation of ceramics. This part of the article focuses on aesthetic criteria.

Over time, the purpose of prostheses has changed. In the beginning, they were supposed to meet basic clinical necessities (tooth loss due to caries, accident. etc.). Today, the top priority is meeting aesthetic criteria, which created a new, growing market. This required extensive work fine tuning the shades by means of spectrophotometrical analysis and computerization. The color shades were developed using a special thermo-coloring manufacturing technique. This technique allows mixing the transparent base vitro mass with colored mineral pigments. The mass undergoes a ten-hour thermal treatment firing it at 1000 °C. This results in a firm mix of the glass masses and the grains of the colored mineral powder that can be turned into homogeneously colored material. With this technique, prostheses later present a higher vitality in the clinical environment. Since the process is performed at 1000 °C, the colors have a high stability in the following firing cycles at 750 °C.

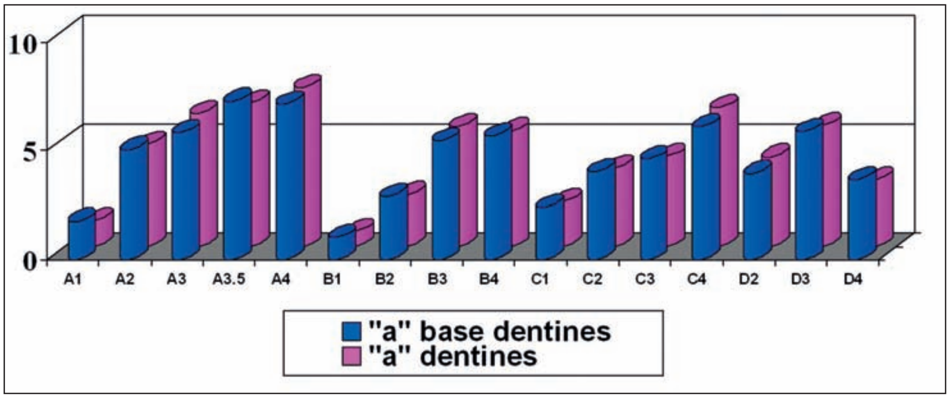

Fig. 14: Coherence of color shades (parameter a) of dentin base and dentin

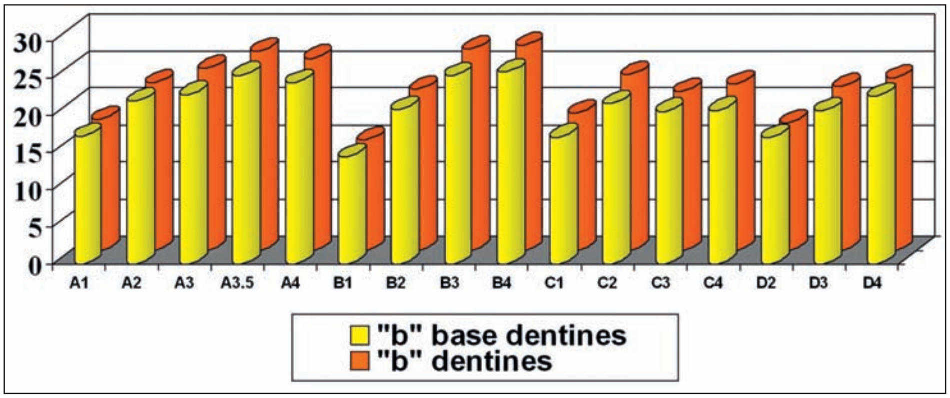

Fig. 15: Coherence of color shades (parameter b) of dentin base and dentin

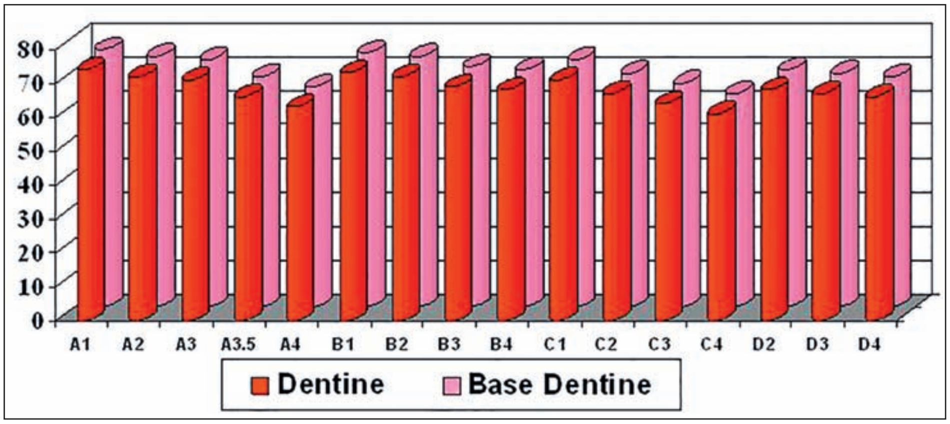

Fig. 16: Coherence of lightness of dentin base and dentin

Fig. 17: Example of transparency of a natural tooth

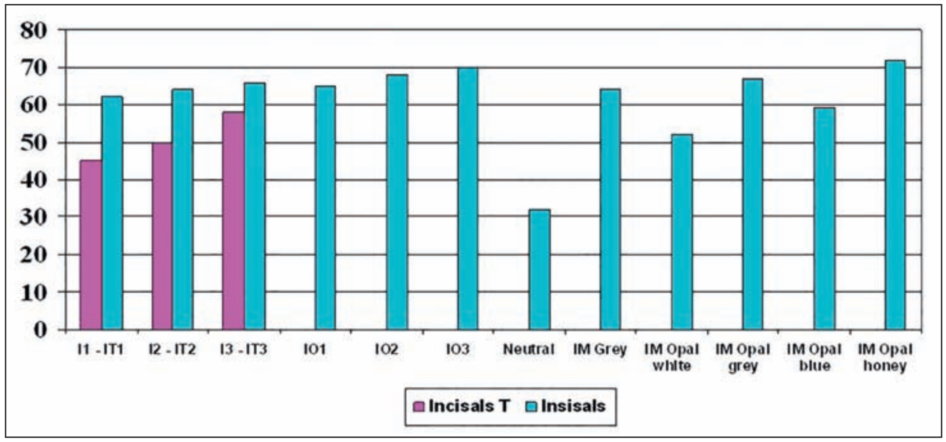

Fig. 18: Comparison of opacity of different incisal materials

Fig. 19: Opalescent glass melt developed by Dentaurum Ceramics

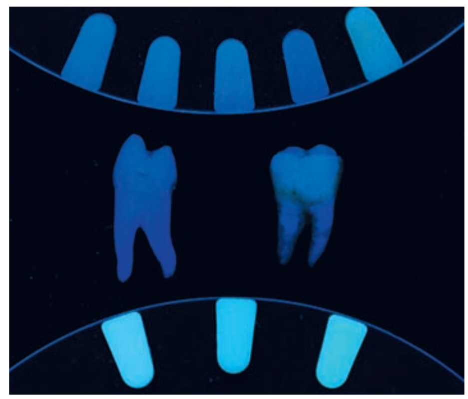

Fig. 20: Comparison of the fluorescence of fluoro-modified dentins (lower) and conventional materials (upper) with the fluorescence of a natural teeth

Transparency levels and color shades

The ceramics range offers a wide spectrum of transparency levels and color shades to cover pulp studs without dyschromia, root dyschromia and stubs that shine through. Chromatic coherence between the layers of opaque, dentin base, dentin and incisal allows creating a depth effect with very low thickness. Thanks to the minimally invasive prostheses, the tooth structure can be preserved. The color shades of dentin and dentin base achieve a perfect coherence between the trichromatic coordinates of both powders. The color shades are controlled by means of spectrophotometry in the classic system L*a*b*. Fig. 14 through 16 highlight the coherence of the trichromatic values L*a*b* and the lightness values of dentin and dentin base. The parameters and the development of the lightness that determine the shade (a and b) are similar for dentin and dentin base. A natural tooth has very different transparency levels from the incisal edge to the core (Fig. 17). This requires a material range that can represent a 32% transparency for the dentin base and a 90% transparency for the incisal area. This opacity can be measured with the spectrophotometer. Opacity is the ratio between the reflected light intensity and the transmitted light intensity. There is also a range of incisal materials with special transparency, color shade and opalescence characteristics (Fig. 18). Since absorption and light refraction of the glass compositions are under control, the transition between the prosthesis and the natural tooth is invisible.

New chromatic layer

The Chroma Concept is an additional kit that allows creating new color shades improving the technical options of the material. This line of ceramic masses was designed by a group of European dental technicians. It adds unconventional chromatic shades to the color variations of the ceramic. The new chromatic layer was designed for chromatic areas with more red or strong coloring and for areas with white shades. These dentin colors have the same opacity as dentin and can either be used in pure form or mixed with other dentin masses. The variety of nuances that can be recreated has no limits. All standard nuances of the ceramic masses can be reproduced and other shades such as the Vita 3D master or the Ivoclar Chromascop can be lightened. The opalescence of a natural tooth is probably the characteristic hardest to reproduce. It is created when light reacts with the particles that are smaller or equal to the wave length of the light. To recreate this effect, special glass melts were produced that include a dispersed phase (Fig. 19). Another characteristic

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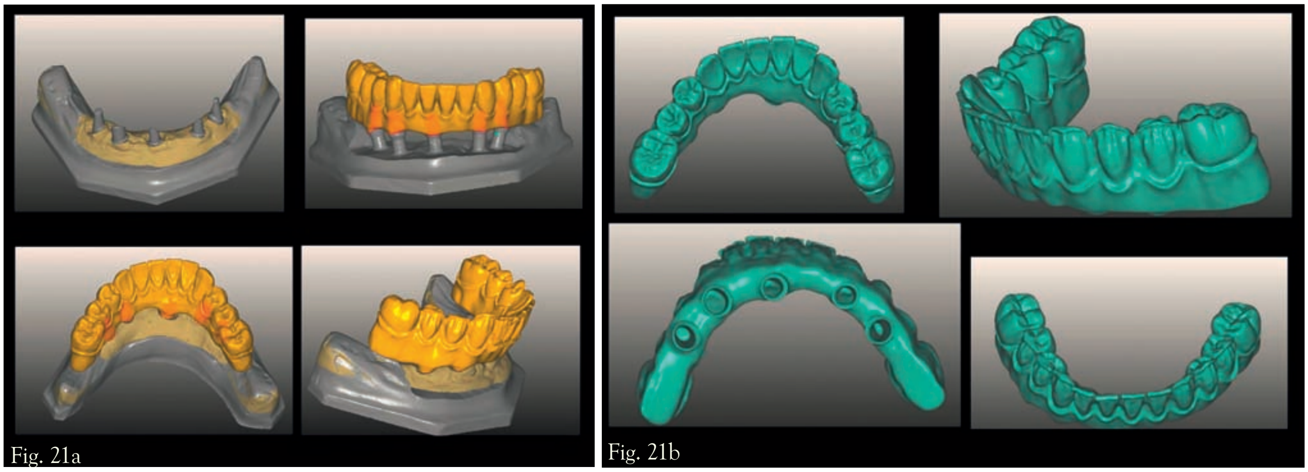

Figs. 21a and b: Manual fabrication of wax forms after being scanned

that has to be reproduced is the fluorescence of the natural tooth [15]. Fluorescence is the emission of visible light under UV irradiation. It is achieved by adding special pigments in small quantities (often less than one percent) to the glass powder. During development, the engineers of Dentaurum Ceramics tested different types of fluorescence to create fluoro-modified dentin and adjust the level of fluorescence of classic ceramic masses. After the lengthy investigation of various natural teeth of different age, the development department chose the level of fluorescence that best reproduces the fluorescence of natural teeth (Fig. 20).

Case study

The following case study shows the aesthetic quality of ceraMotion Zr and the growing demand for implant supported bridges manufactured with CAD/CAM. The

Fig. 22 Left: Monolithic pre-sintered zircon Right: Zircon after coloring Upper: Result after complete sintering

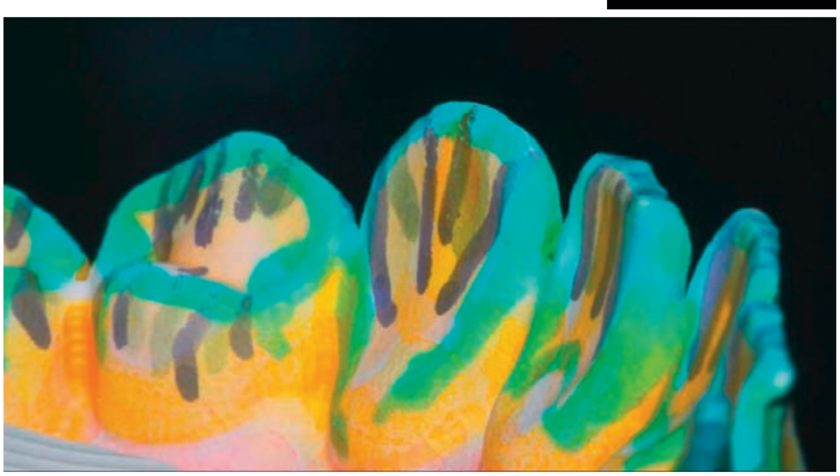

Fig. 23: Detail of coloring with liquid colors that can be used for teeth and gingiva.

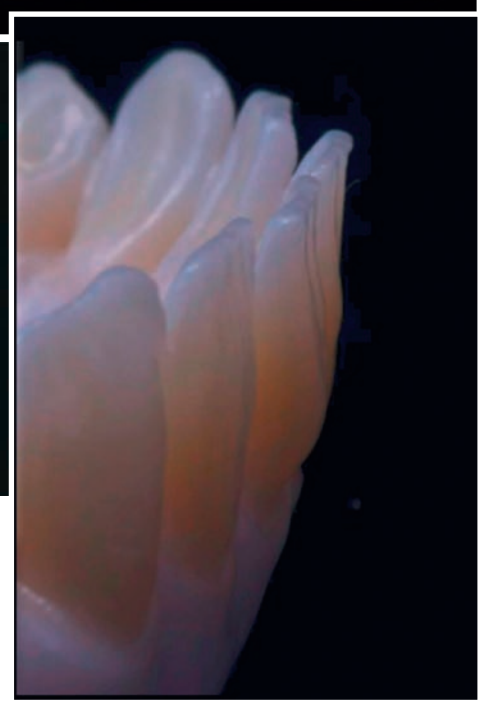

Fig. 24: Frontal area of the massive zircon bridge after sintering. The transparency of these new zircon types come close to the transparency of glass ceramics made of lithium disilicate.

Fig. 25a

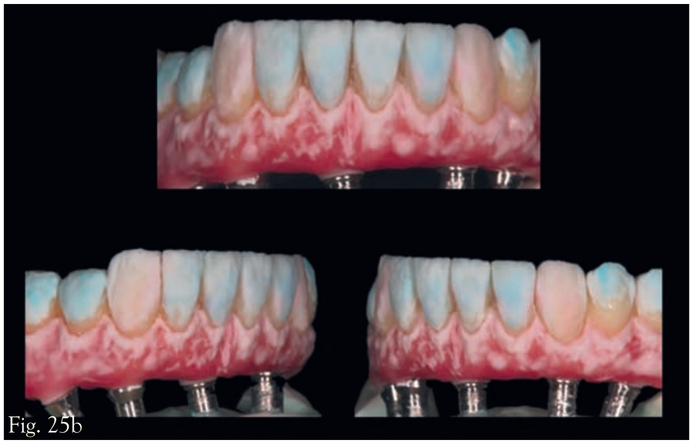

Fig. 25b

Figs. 25a and b : Mounting dentin and incisal materials and gingival materials as surface veneering

prosthesis was made by Germano Rossi in his laboratory in Italy, Alba Adiratica. It is a complete bridge on tioLogic implants (Dentaurum) used on a 50-year-old woman, patient of implant specialist, Dr. Enzo De Santis, in Roseto degli Abruzzi (Italy). The zircon (Sagemax) was colored with liquid colors in its pre-sintered state. This new technique allows coloring the zircon material in its pre-sintered state without adding to the ceramic material thickness (Fig. 22 through 24). Dentists and dental technicians design more and more prostheses that not only recreate the teeth but also the gingiva, especially in case of complete bridges on implants. This entails larger tissue loss. Due to the natural depth of ceramics, the natural shade of the gingiva can be imitated (Fig. 25). With this recreation, the patient is given a feeling of volume that used to be lost. Thanks to the wide range of colors, the natural look of the gingiva can

Fig. 26 Frontal area: Shade B2 and B3 with a thin layer of T-incisal and opalescent incisal

be easily reproduced by creating surfaces that are more or less smooth or protruding profiles (Fig. 26). It presents a reliable and simple-to-reproduce solution for aesthetic all-ceramic prostheses (Fig. 27).

Conclusion

With a simple concept and easy to use, CeraMotion Zr is suited for prostheses for singular teeth as well as complex large-span bridges. One veneering material can be used for different types of prostheses: fixed singular prostheses or multi-unit prostheses on stumps and implants in the frontal and lateral region. The intrinsic nature of ceramics allows ceramists to easily adapt color and transparency of the veneering to the optical and chromatic characteristics of the ceramic framework, whether it is made of zircon or lithium disilicate. While the result of a prosthetic treatment is essentially determined by the right manufacturing conditions (balanced occlusion, no bruxism, following the protocols, etc.), choosing a ceramic that has been scientifically optimized over years guarantees an aesthetic and reliable result. Thanks to this new generation of ceramics, the main complications that existed with all-ceramic prostheses, such as fractures and split offs, have been reduced to a minimum. It does not matter, whether the laboratory decides to work with CAD/CAM, press-over or conventional build-up: the veneering material can be used for all these techniques.

Special thanks to Germano Rossi, Dr. Enzo De Santis and to the investigation department of Dentaurum Ceramics for their contribution to this project. Sd

Fig. 27: Bridge in the mouth

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