Anatomical Multi-layered Zirconia

Part 1: General overview

Over the past few years, there has been an increase in the choice of zirconia materials available, and these materials are becoming better adapted for dental applications. Material performances have continued to progress. The flexural strength of standard zirconia materials has improved, increasing from 100 MPa to 1200 MPa, and in some cases 1400 MPa.

Translucency has also improved – just think back to the first zirconia materials, which were highly opaque, and compare them to today's materials, which are more translucent and / or stronger. However, it is unfortunate that no standard has been established to measure the level of translucency exhibited by materials. This is a fine example of a time when an established norm would have been really useful, but there isn't one in place!

An indicator of light transmission would be a welcome advancement (*box 1). It is difficult, perhaps impossible, to precisely imagine the level of translucency (or opacity) exhibited by a zirconia material without having tested it – remember the essential condition for validating all tests is precise sintering, which is not always so easy to gauge... But I will discuss that in a later article.

In this article, I would like to discuss high-translucency multi-layered zirconia. In the past few years, we have seen the arrival of several new zirconia materials which are partially constituted of cubic crystals. We have tested several, without being convinced by them, due to their lack of translucency.

I could limit my discussion on this material to simple guidelines for its application, but I do not believe that would be very useful, since the basic implementation is fairly straightforward. I also want to discuss some essential details for optimising results, and invite you to experiment further in your use of the product.

By Remy Desprez

Dental Technician

BOX 1

Indicator of light transmission

To know the precise value of the translucency or opacity of a material, you need to measure the quantity of light transmitted. For this, as Pentron Ceramics do, you can use a pastille of the material in question (such as zirconia or porcelain, for example) with a standard thickness (between one and three millimetres). This sample is placed in a beam of light. The amount of light travelling through the pastille is then measured (as it comes out the other side). Part of the light emitted from the source is lost, firstly by being reflected from the surface of the pastille, and secondly through diffraction (the absorption of light) in the material. The more opaque a material, the greater this phenomena is, and therefore the less light will be transmitted on the other side of the pastille: it is therefore possible to translate this to a percentage, either as a translucency indicator or an opacity indicator. For example, in the case where a material transmits 80% of the light, we could say that its translucency indicator is 80, or we could say that its opacity indicator is 20 as the opposite value.

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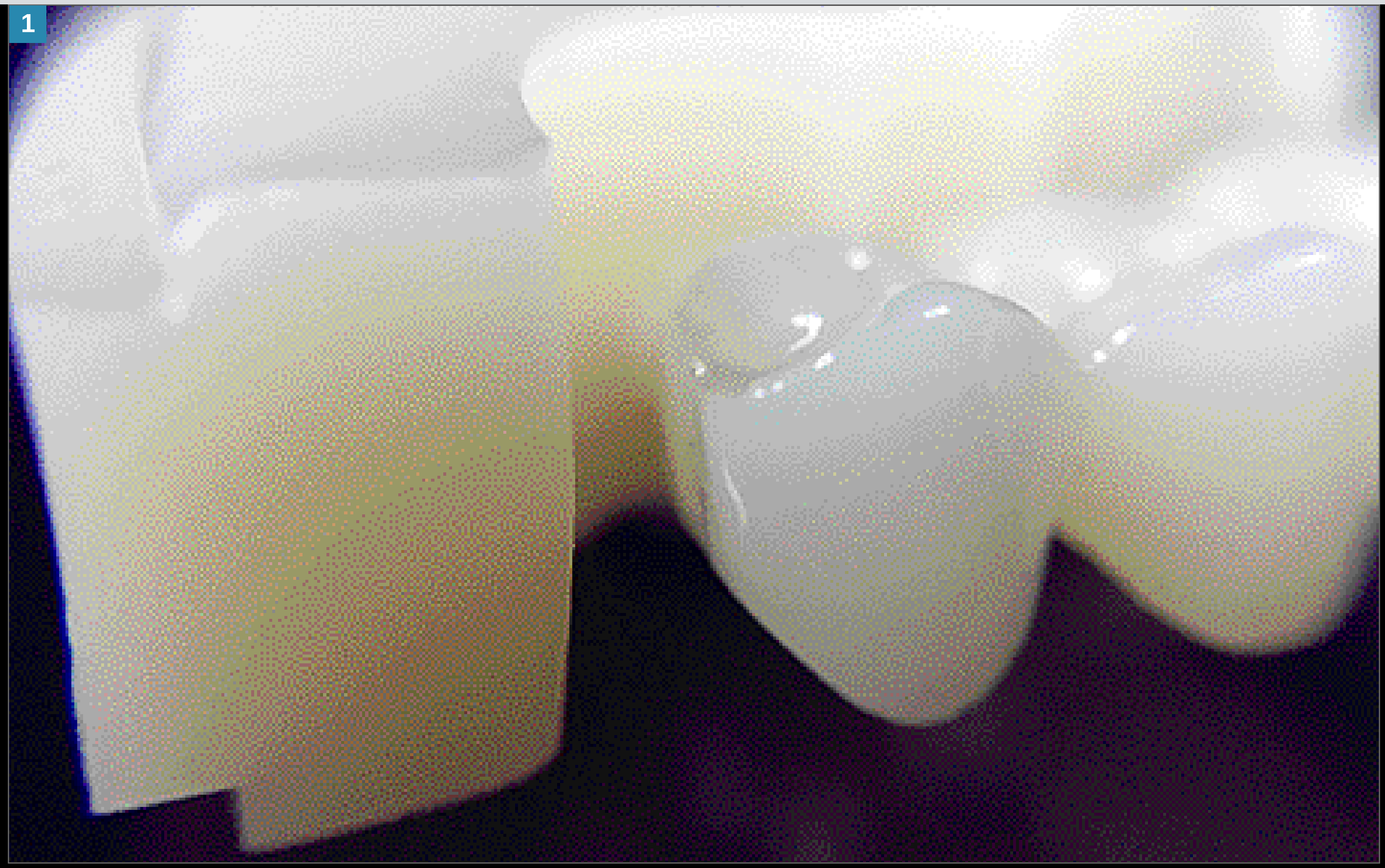

Cross section of a Zirlux Anterior Multi disk

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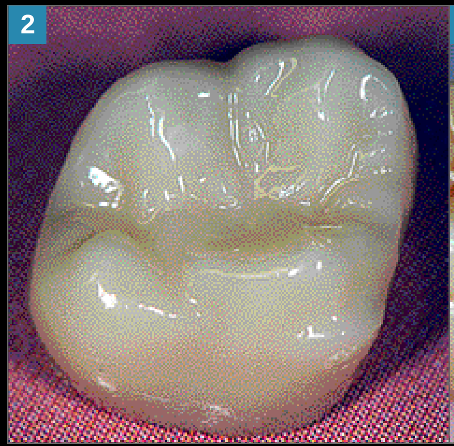

Classic translucent Zirlux T16 zirconia (1200 MPa, 3 point flexural testing), without internal colours or stains

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Same material with simple infiltration for another case

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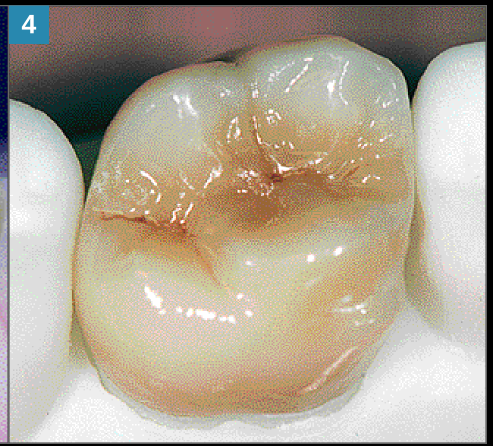


Same case as fig. 2, with infiltration and stains

WHAT IS MULTI-LAYERED ZIRCONIA IN RELATION TO TRADITIONAL ZIRCONIA?

Multi-layered zirconia

This zirconia integrates a gradation of colours (fig. 1). The base material has the same translucency indicator on the entirety of its thickness. During manufacturing, several layers of zirconia in various saturations of colour are superposed and pressed.

They are layered from the most saturated to the least saturated, and the effect is to create variations in tone that come close to those of a natural tooth. It becomes easy to make a crown with gradient shading from the dentin to the incisal. Before going into more detail on multi-layered zirconia, let's take a look at other zirconia materials and how we use them in my lab.

Traditional zirconia

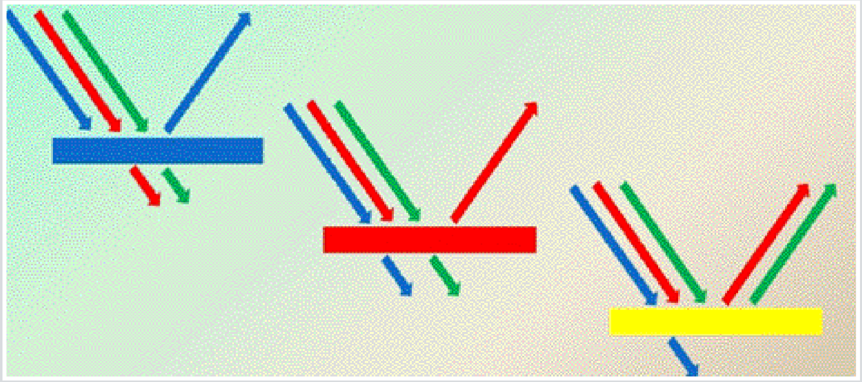
For the fabrication of frameworks to be layered with porcelain and for basic full contour restorations, we use Zirlux 16+ in our lab (figs. 2 to 4).

We were very pleased with the results obtained using this material, which has heightened translucency, close to that of a natural tooth. Its flexural strength is 1200 MPa, and it is available in all the classic Vita shades.

We find this is an excellent, versatile product, which we use both for the fabrication of basic full contour restorations and restorations where volume is limited, as well as for making copings.

BOX 2

Tip: managing light diffraction



This is a notion that is often used in the cosmetic industry, one example being hair dyes. Strangely, this notion is often forgotten or ill-known in our industry, where it could be used more often.
In short, Newton discovered in 1666 that light is colour (and vice versa). Light constitutes the visible spectrum, and each colour corresponds to a wavelength. If light is projected on a white surface, it will be reflected. This is in fact the entire spectrum of visible light which is reflected. On a black surface, the whole beam of light is absorbed. On gray (50% white and 50% black), an equal quantity of light will be reflected and absorbed.
But which wavelengths (colours) are reflected or absorbed in relation to the colour of a receptor / emitter surface? Without going into too much detail, it is useful to know that red absorbs green and blue, and yellow reflects green and red.
Bearing this in mind, we can use it to our advantage by applying pink (desaturated red) to the back face of crowns and under bridges, so that the greenish tone is absorbed.
The more saturated a shade, the more obvious the benefit, so the greenish distortion of an A4 shade will disappear, leaving a more browny-orange tone.
Be careful when working with thin restorations, not to over apply the pink, since it could become visible through the material, which would change the tonality of the whole restoration to pink (photos of application and comparison).

Addition of Erbium Oxide

More recently, zirconia translucency has been improved by several factors, the main one being a high percentage of cubic crystals. Zirlux material uses this technique, and the addition of Erbium Oxide (Er_2O_3) in addition to Yttrium Oxide and Hafnium Oxide produces an internalised pinkish tonality which favours aesthetic integration.

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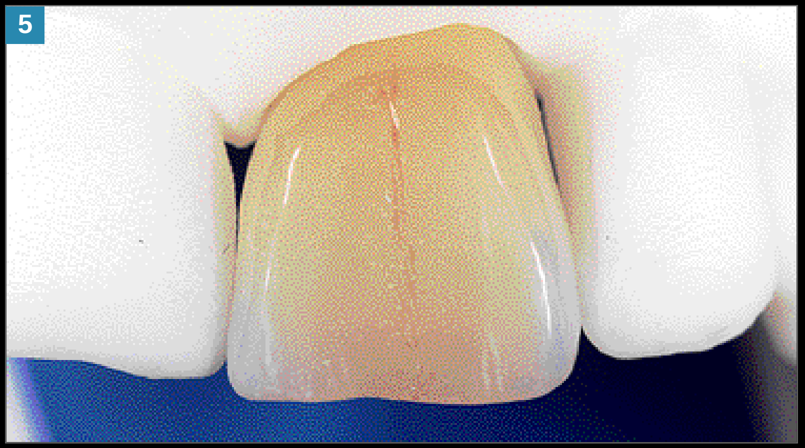

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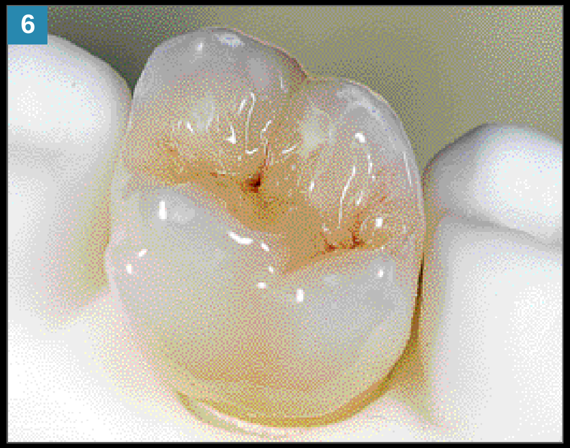

5 & 6: Crowns fabricated in a high translucency neutral zirconia, coloured by infiltration (Smile HT)

HIGH-TRANSLUCENCY ZIRCONIAS

As far as high-translucency zirconia is concerned, we use a shade-neutral material, which we shade through infiltration (figs. 5 and 6). Several manufacturers offer similar products which have pleasing levels of translucency.
However, the difficulty with these infiltration zirconias is mastering the internal shading.
It is not so easy to get a spot on, regular shading effect. The colour accuracy, as well as the degree of saturation, can be rather unpredictable after sintering. I also find fault with this material, because - whatever the colours used - it tends towards a green tonality, producing an unsightly result (this is the case for numerous zirconias and ceramics). However, this greenish effect can be attenuated using a little trick (box 2).
I also find the drying stages after infiltration and before sintering quite fussy.
These preparatory stages are extremely important in order to obtain the best results for translucency, as well as being essential for the optimisation of mechanical properties.
As for cosmetic porcelain, these factors go hand in hand.
For these reasons we were looking for a better solution that would combine both aesthetics and good mechanical properties.

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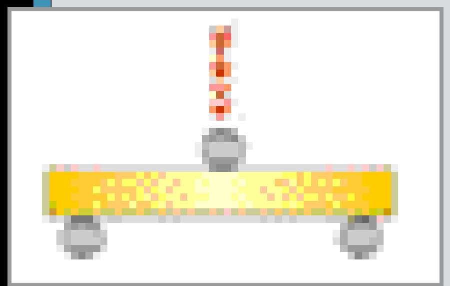
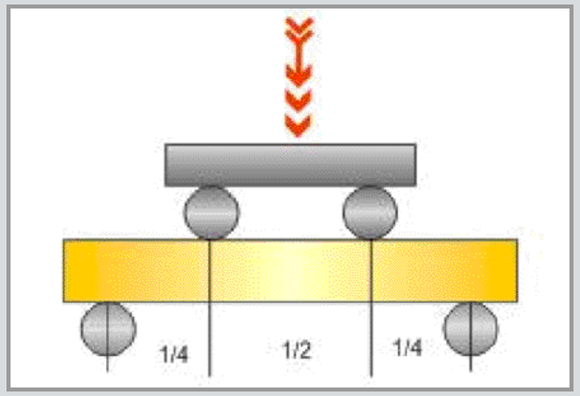
Zirlux Anterior Multi zirconia

BOX 3

Strength and flexural testing

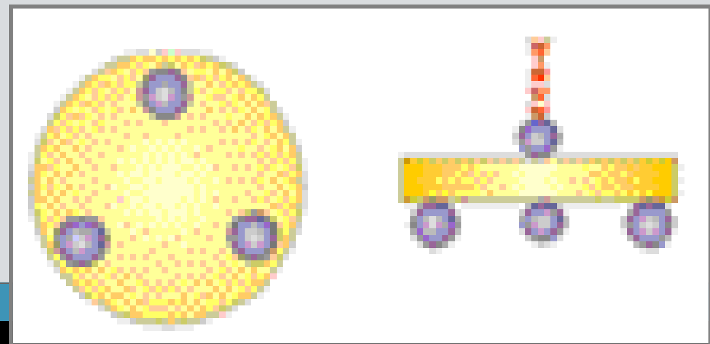
For a three point bending flexural test, the norm is to use a length of 12 to 40 mm between support pins, a test piece thickness of 2 to 3 mm and a width of 4mm.





For a four point bending flexural test, the norm is to use a length of 16 to 40 mm between support pins, a test piece thickness of 2 to 3 mm and a width of 4mm, which offers much higher resistance figures than three point testing.

Furthermore, the figures are even higher when using biaxial bending testing. This method generally uses a disk which is 1.2mm thick, with a diameter of 14mm. The three supporting balls are placed to form an equilateral triangle at 120°; the centres of the three balls are positioned at 5.5mm from the centre of the disk.



(Pictures, G Bourelly).

ZIRLUX ANTERIOR MULTI ZIRCONIA

We have not tested all of the multi-layered zirconias out there. Our experience described earlier meant that we were keen to try Zirlux Anterior Multi. This multi-layered zirconia has three different layers of internal saturation (fig. 7).

Its originality lies in the fact that the middle layer is a gradation of saturation melding the surface cervical and incisal layers progressively and not with layers. This leads us to expect good shade results and time gained during the drying phase prior to sintering, in the case of a standard application.

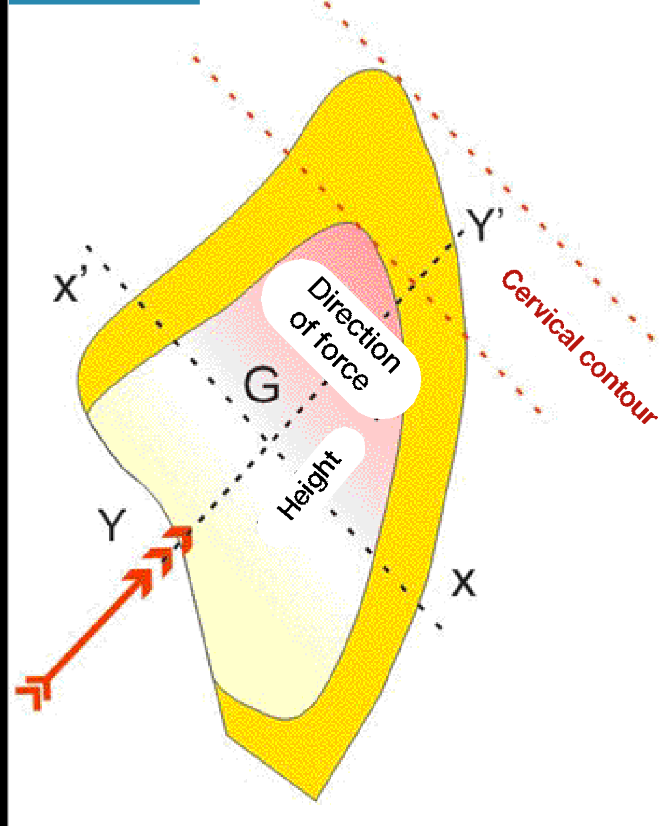
WHAT CAN WE DO WITH MULTI-LAYERED ZIRCONIA ?

The bend strength is 600 MPa in three points (manufacturer data), which represents a satisfactory value for a ceramic material offering this level of translucency. Lithium disilicates has a bend strength of between 330 to 440 MPa (three point flexural testing). It is worth noting on the subject of bend strength values, that certain zirconia and disilicate manufacturers use four point or even biaxial flexural testing. The results are therefore more favourable, but cannot be compared against three point flexural testing. When evaluating a material,check which type of test has been used (see Box 3).

TABLE A	Comparative table of mechanical properties		
Material	**Bend strength**	**Fracture toughness (K1c)**	**Modulus of Elasticity**
Ni Cr	600 to 700 MPa hv 3 points	70 to 100	300 000 MPa
Zirconia	550 to 1400 MPa* hv 3 points	10	205 000 MPa
Fibre posts	900 MPa		60 000 MPa
Alumina Oxide**	400 to 600 MPa***	4.6 to 6.5	280 000 MPa
Emax Disilicate****	330 to 360 MPa hv 3 points	3.6 to 4.8	75 000 - 115 000 MPa
GC Lisi Disilicate	508 MPa hv 4 points		

* High translucency zirconia between 550 and 600 MPa; semi translucent zirconia between 1000 and 1200 MPa; opaque zirconia 1400 MPa
** In ceram (Vita); Procera (Nobel) *** Before and after the cosmetic bake **** Ivoclar figures, first value milled block and second value pressed ingot, 440 MPa in 4 points flexion testing

Diagram A



The ideal shape for anterior connectors, the main load axis is shown in red, but protusive movements should also be taken into account (diagram, G Bourrelly).

Zoom on the palatal reinforcement of the connectors, reinforcement is advised where possible

The cross section of the connector for the same bridge, here in 3D print, allows us to evaluate its dimension of 7x4.5 mm, which is sufficient. Note also the flat shape at the base, which reinforces it

Similarly, and although this is a determining factor on the longevity of the restoration, it is surprising to note that the fracture toughness (K1c) values given by manufacturers are all almost the same (around 10) for all types of zirconia (opaque, translucent, multi...) whilst their bend strength and elasticity all vary greatly (Table A).

Anteriors

Given its bend strength, this multi-layered zirconia is best suited to anterior restorations: single units and single pontic bridges and even certain veneer cases. For anterior bridges, it is best to ensure that the connectors have a section of minimum $14mm^2$, even though determining the surface is not everything. The greatest dimension of the connector must always be in the axis of the principal stress. However, you should not forget palatal to labial efforts and should reinforce the connectors in relation to this (Diagram A and figs. 8 and 9).

Posteriors

Concerning single unit posteriors, it is best to be cautious. In the case where there is not enough occlusal space - less

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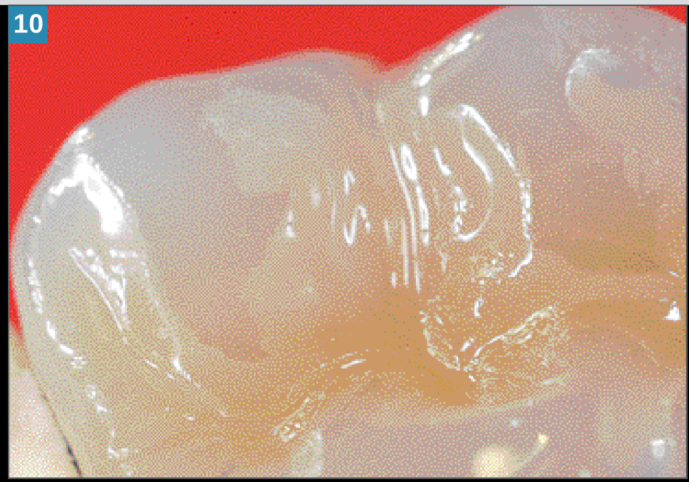
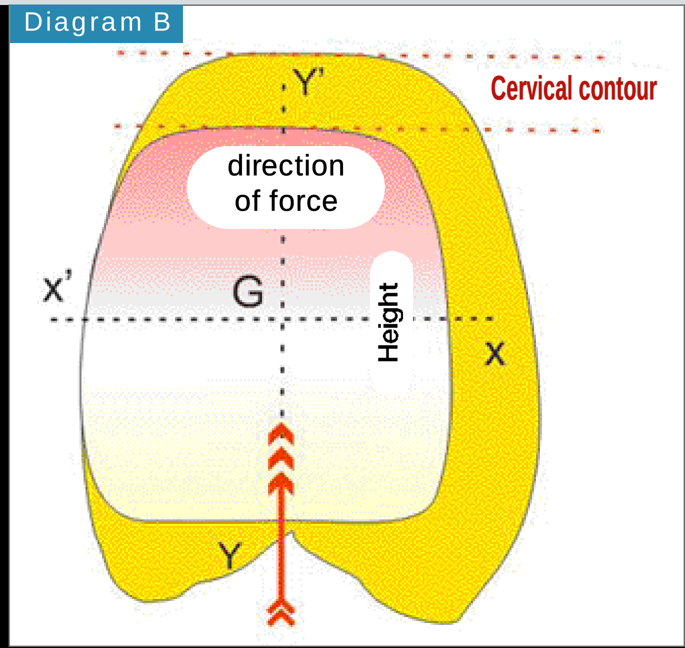


The surfaces of the occlusal contacts have been polished correctly: this is a guarantee of the low abrasiveness of the material

Diagram B



The ideal shape for posterior connectors. The main load axis is indicated in red, but protrusive movements should also be taken into account (diagram by G. Bourrelly)

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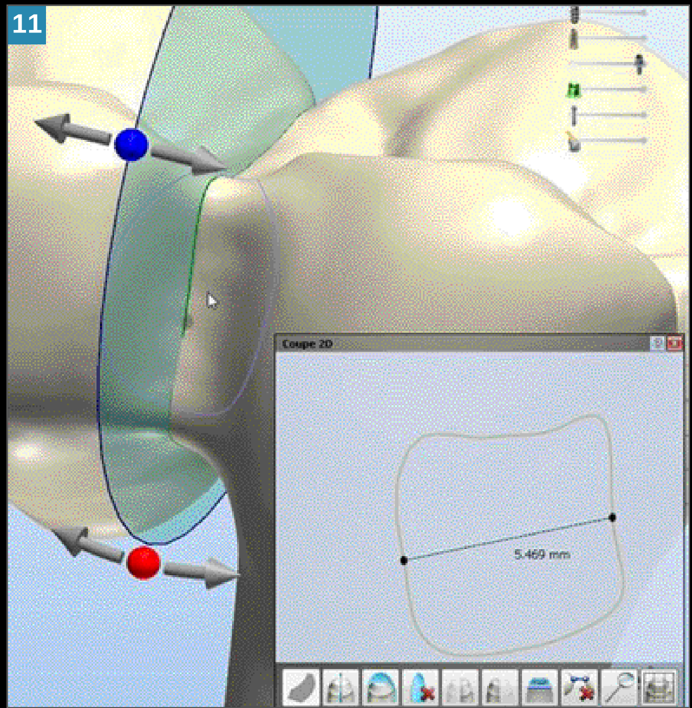

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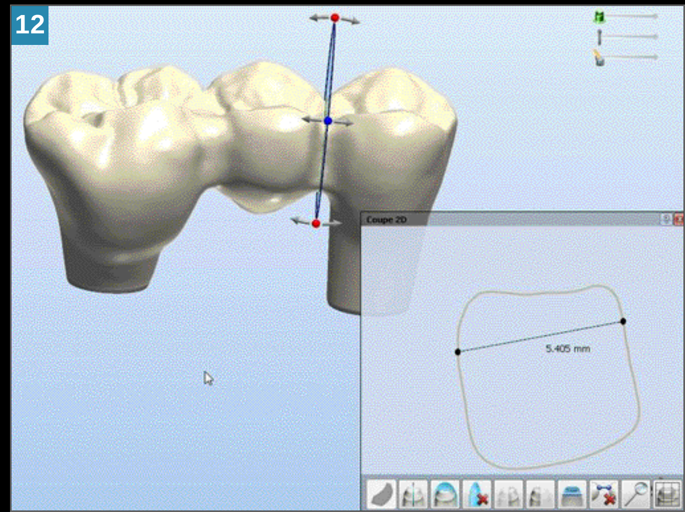
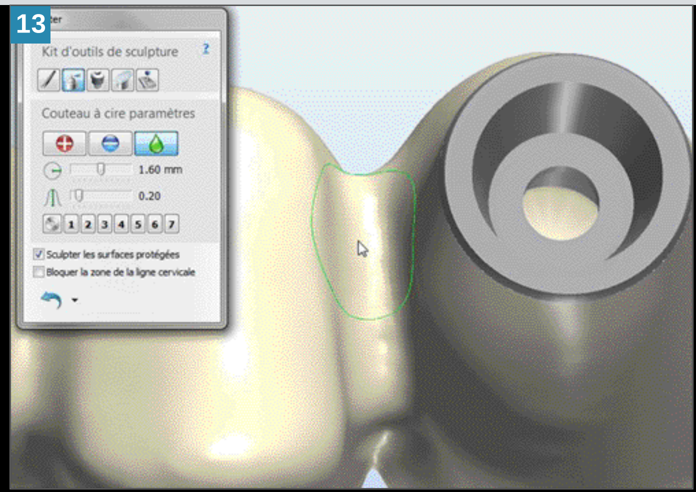


11 to 14: design and minimum dimensions of the connectors (Source, G. Bourrelly)

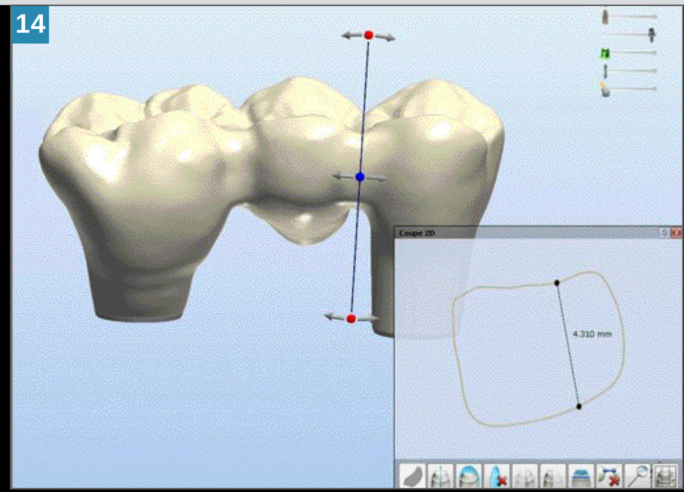
than 1.5mm - it would be better to use a zirconia with a higher bend strength, with a value of at least 1100 MPa in three point flexion, or Zirlux 16+, which has a bend strength of 1200 MPa (fig. 10). If the occlusal space of the future crown is more than 1.5mm - say at least 2 mm space between the preparation and the opposing tooth, there is much less risk of breakage.

Posterior bridges

I would be more cautious about using this material for the fabrication of posterior bridges. The manufacturer does not recommend this application. If you are extremely careful with the specifications, the risk of breakage can be mastered and limited - this is a completely personal opinion based on concrete experience.
A single premolar pontic would be my recommendation. Furthermore, it is absolutely necessary to ensure the vertical dimension of the connectors is as large as possible in the effort axis: greater than for anterior bridges, in order to bear the chewing loads that the restoration will be subjected to.
Once again, it is important to bear in mind the lateral forces that the bridge will be subjected to (Diagram B, and figs. 11 to 14). If the height of the connector is always greater than its width, the latter will not be too reduced. Their cross sections must be at least 18 mm^2: again this value is subjective, since it is determined by many other factors.
Do not consider using this material if the supporting tooth abutments are too short, or if the bridge has a pontic as an extension (possible with 1200 MPa zirconia): you would not be respecting the conditions for the application of this material.
Insufficient vertical dimension makes this material completely incompatible. If you think you can

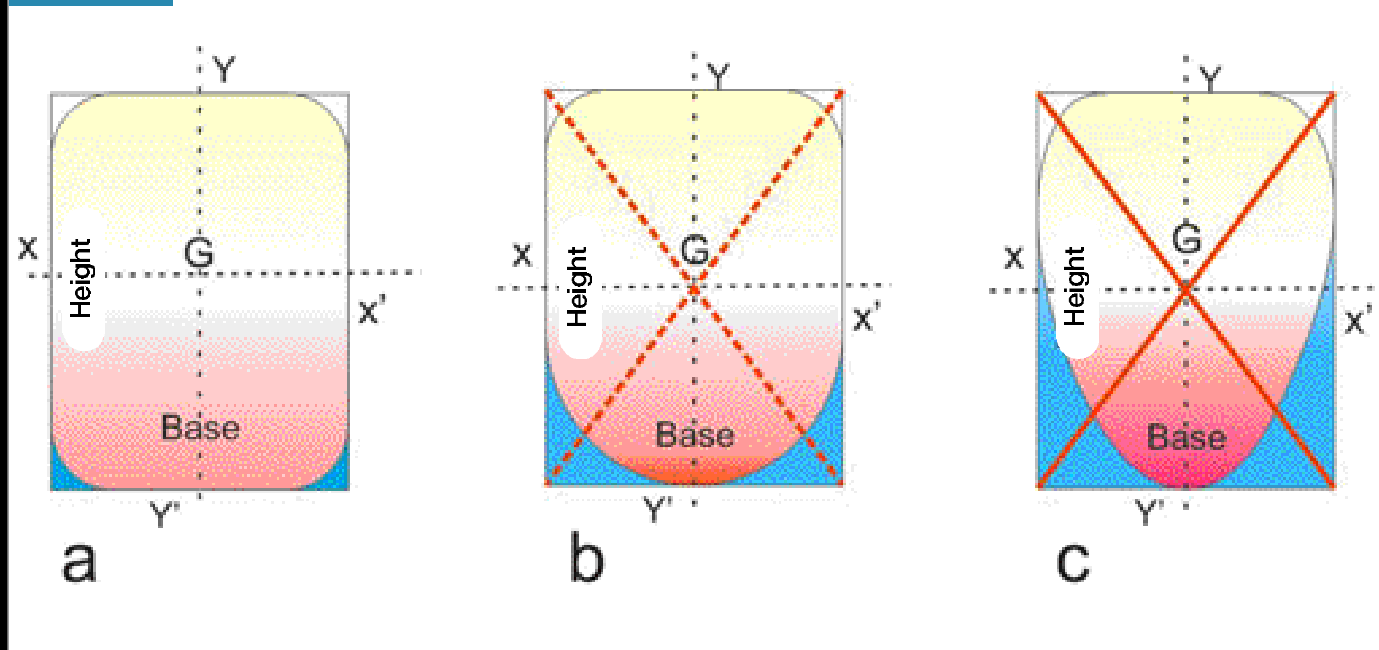


(Source, G. Bourrelly)



(Source, G. Bourrelly)

Diagram C



Ideal shape for the base of a connector (a), the more oblong this is (b and c)... the greater the concentration of effort in this area and the connector will be weakened (diagram, G. Bourelly)

compensate this weakness by designing horizontally oversized connectors - that is to say in a bucco-lingual direction - then bear in mind that this solution will only be relatively efficient: it is the increase of the cross-section in the effort direction - that is to say vertical - which will provide sufficient reinforcement.
In this case, doubling the cross section multiplies the load bearing capacity by four.
This is the case for all designs, regardless of the materials used and the chosen application, whether full contour or frameworks for porcelain layering (see Table A on the previous page).

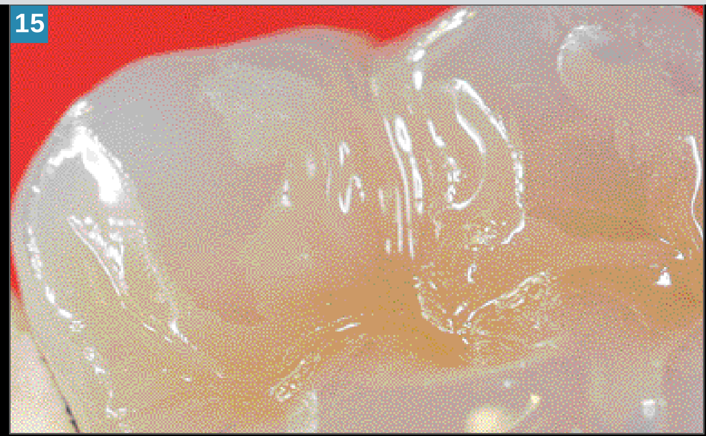
In all cases, where possible the connector base should be a flat surface and not elliptic (Diagram C). Bear in mind that a polished material offers better mechanical properties, so this area should be polished to make it as robust as possible.

Fixed-free bridges

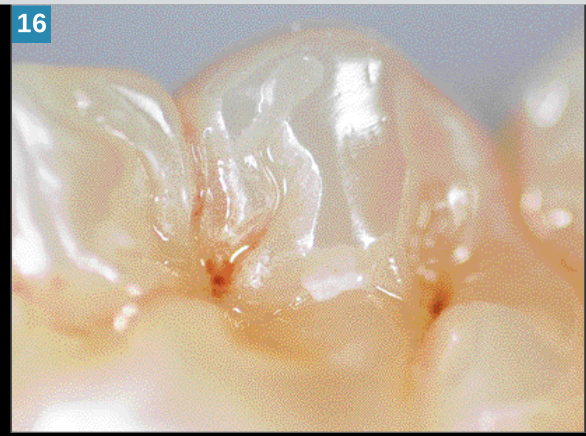
This can also be used for fixed-free bridges with a stress breaking rest. It would be best to take the precaution, where possible, of dividing longer span restorations, particularly for mandibular bridges.

Long span bridges

The high bend strength of this zirconia (see Table A on the previous page) and its low ductility (ability to undergo significant plastic deformation) should be taken into account. In the case of long span full contour restorations, the rigidity will prevent resilience in the abutments. Once prevented in this way, the ligaments of the supporting teeth will no longer serve their purpose. There would then be a risk of ankylosis.
Groups of three crowns represents a reasonable alternative in this case. This is equally valid for zirconia frameworks destined for a cosmetic porcelain layer.



The surfaces of the occlusal contacts have been polished correctly: this is a guarantee of the low abrasiveness of the material...



... Here this is not the case, and the abrasiveness will greater due to insufficient polishing

TABLE B

Abrasiveness of zirconia

- Zirconia polished with 200 000 cycles: 0.1 mm3
with 400 000 cycles: 0.2 mm3
- Natural enamel with 200 000 cycles: 0.25 mm3
with 400 000 cycles: 0.48 mm3
- Open porosity of zirconia: 0 %

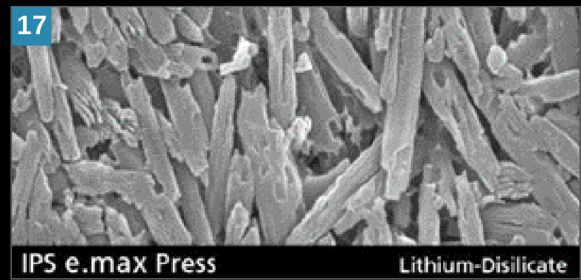
John Burgees study, Birmingham Alabama

Cementing, shear strength:

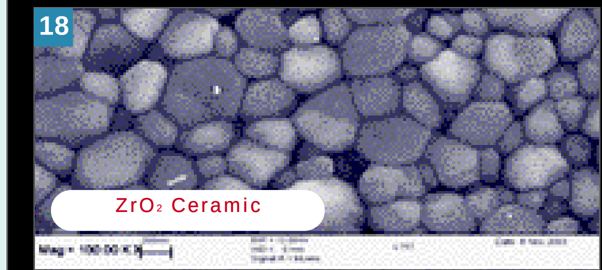
- Zirconia: 26.9 MPa
- Lithium disilicate: 32.8 MPa
- Composite: 46.8 MPa
- Glass ceramics: 21.5 Mpa

Breaking load: Instron machine testing

- Glass ceramic: 1.179 N
- Zirconia: 3.932 N



MEB photo of lithium disilicate structure: note the needle-like crystals



Zirconia structure, absence of glass phase and density, even though the photo is magnified ten times more than fig. 17

IS THE HARDNESS OF ZIRCONIA A DISADVANTAGE ?

To conclude this discussion on mechanical properties, I think it is worthwhile examining the assertion that zirconia is too hard, which you have probably heard numerous times. If this were the case, then the same assertion is valid for other ceramic and porcelain materials, and we should only use materials that have a hardness and abrasion close to that of natural teeth; meaning that our restorations should all be made from micro-filled composite.

All the ceramic and porcelain materials used for restorations - whether layered with low or high fusing porcelain, whether lithium disilicate or zirconia - are harder than natural teeth and do not have shock absorption capacity, even if these materials have numerous other qualities that make them indispensable to our work. To reason that zirconia is too hard is to forget that the harness of polished zirconia is balanced by it being less abrasive - two times less abrasive than natural teeth (figs. 15 and 16). I will discuss this important factor in more detail in my next article, which will cover practical applications. This low abrasiveness is the result of the material's high level of hardness - 1200 HV - and lack of open porosity; it does not lose its surface state through chewing movements. These factors make zirconia the least abrasive material (Table B). Opposing teeth are spared, and in this area, zirconia sets the best example!

Micro-filled composites initially have an abrasion speed which is comparable to that of natural teeth, but how does this evolve over time? Cosmetic porcelains for layering cannot match these performances in abrasion, particularly if the bakes are not managed accurately. Lithium disilicate crystals, which are needle shaped, can become extremely abrasive. The crystals have been compared to a plane tool, and some even advise against using this material on occlusal surfaces that are not covered with a cosmetic layer (figs. 17 and 18).

Moreover, the surface polish will not last as well over time, and this factor will progressively increase the abrasiveness of the restoration.

NB: the latest generation of products have made considerable progress in this area, such as Lisi Press from GC, for example. ◆

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Part two in issue 131: Practical applications