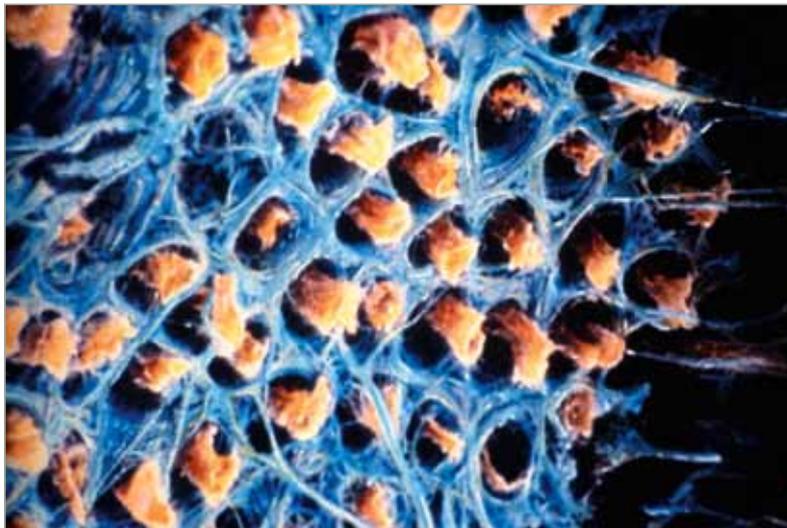


The Proceedings of the 2011 Autumn Meeting of the EAED (Active Members' Meeting) – Versailles, October 20–22nd, 2011

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SEM image of a section of occlusal dentin 1 mm far from the pulp. The dentinal tubules and the odontoblastic process are visible (courtesy of Vassilios Kaitsas/Luciano Fonzi).

Material interfaces in Esthetic Dentistry

Prologue of the Scientific Chairman

One of the major scopes of the EAED is “to provide leadership in the profession by defining the highest ethical standards and to foster interdisciplinary communication and research through publications and educational presentations.”

In the pursuit of esthetics within the human body, the issues of beauty, health and integrity ought to be found in a non-disrupted link. In Esthetic Dentistry, heterogeneous substances ought to come into a long lasting synergy and conduct the realization of the ultimate integral response of an esthetic outcome. Thus, in restoring the mutilated dentition, the material interfaces act as a most delicate link in composing a clinical intervention of harmony. A clear documentation, definition and demonstration of the limits in applying the materials and executing the procedures at a level of clinical excellence through an interdisciplinary official communication is still academically missing.

The Versailles workshop was structured under the general theme: “Material Interfaces in Esthetic Dentistry.” The presented essays addressing specific issues were prepared well in advance,

all containing cutting-edge experimental evidence information of the material science, and the relevant clinical interpretation and were communicated to all participants beforehand. The interactive and comprehensive discussion that followed the presentations was recorded, and after careful editing and accurate evaluation, conclusions were drawn. Thus, from the proceedings of the meeting the present document was developed, the publication of which intends to become of help for all readers – clinicians or researchers.

At this point, it is more than appropriate for the Scientific Chairman of this meeting to extend his genuine gratitude to the three Essayists, Prof Angelo Putignano, Prof Markus Blatz and Prof George Eliades and to the two Moderators, Prof Vassilios Kaitsas and Dr Stefano Gracis for their willingness to invest their hard work and precious time for the success of such a demanding workshop, which was structured as follows:

- Part I – Adhesion On Dental Substrates
- Part II – Cementing, Supporting and Veneering Prosthetic Dental Materials.

Part II: Cementing, Supporting and Veneering Prosthetic Dental Materials

Moderator:

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Essayists:

Clinical Parameters:

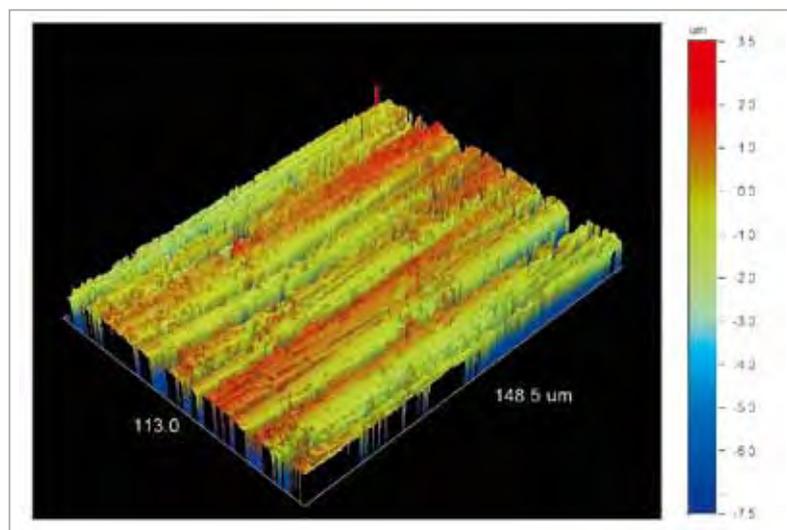
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Aris Petros Tripodakis and **Stefano Gracis**



Zirconia surface roughness: 3D image as recorded by optical interferometric profilometry (courtesy of George Eliades).

Introduction

*by the Moderator,
Dr Stefano Gracis*

Bonding capacity of luting agents to alloys and ceramics

For the successful integration of a restoration in the oral cavity, the act of cementation is a crucial step which influences profoundly the prostheses' longevity. The choice of luting agents has increased over the years, responding to the needs of a market requiring easier handling, less technique sensitivity, shorter setting times, higher retention, insolubility in the oral fluids, antibacterial properties, and improved esthetics. This and a more conservative approach to tooth preparation, which often does not follow the classical rules of retention and resistance form, has prompted the profession to shift to the predominant use of adhesive cements. Furthermore, the clinician's perception is that these cements can potentially improve the seal at the interface between tooth structure and restorative materials.

While the protocols for true adhesive bonding to enamel and dentin with auto-polymerizing and dual-cured resin composite cements are well known, there is not as much clarity regarding the surface treatment of different artificial substrates prior to cementation. What is the proper procedure for allowing or enhancing a chemical bond to metals, alumina or zirconia? Are metal primers and silane coupling agents effective, and how should they be handled? Are self-etching cements as reliable as the "traditional" resin cements? Is proper field isolation

mandatory and crucial? These are the main topics being addressed in the first Essays (1a and 1b).

Exploring the interface and the reliability of ceramic veneers on metal and ceramic substrates

The successful restoration of teeth and implants requires not only the esthetic integration of the prosthesis, but of course, its long-term clinical performance as well. The longevity of any restoration depends, to a large extent, on the reliability of the materials employed and on the lasting capacity of its luting agent to provide retention and marginal seal.

Up to now, porcelain-fused-to-metal crowns and fixed dental prostheses employing precious alloys has been considered the "gold standard" combination since it reconciles excellent mechanical and physical properties with the ability to deliver, at least in many situations, good esthetics. Its clinical performance and relatively low incidence of mechanical complications has been well documented in the literature.

In recent years, the advent of less expensive alloys and new metal-free ceramic materials and systems seems (or attempts) to challenge this standard. The question that any responsible clinician should pose to him/herself is whether there is evidence that these materials provide a similar degree of reliability. One crucial aspect that has an impact on clinical performance is the quality of the link between veneering ceramic and supporting structure, whether it is made of non precious alloys, titanium, disilicate-based glass ceramics, alumina or zirconia. If this bond

fails, adhesive failure of the veneer will occur. Depending on the extent of the chipping, a replacement of the restoration may be necessary. If this complication occurs frequently and within a relatively short period of time after having placed the prostheses in the mouth of the patient, the clinician may suffer an economic damage and, possibly, negative publicity for his/her reputation.

In the recent literature, which has documented zirconia-supported restorations, it is the chipping of the veneering ceramic that has indeed been highlighted as the complication with the largest incidence, varying from 10% to 60% after 5 years of clinical use.

Many hypothesis have been presented to explain such behavior, ranging from the mismatch of thermal expansion between veneering and framework ceramics to insufficient support of the veneering material by the framework design, and from unfavorable surface and heat treatment of the zirconia framework and associated phase transformation to accelerated strength degradation of ceramics. The second Essays (2a and 2b) will address this issue, providing data and recommendations that have an impact on clinical choices and technical protocols.

1. Bonding capacity of luting agents to alloys and ceramics

The Essays

Essay 1a: Clinical interpretation of the scientific evidence

Essayist, Prof Markus B. Blatz

Dental luting agents can be classified into two groups: conventional and adhesive cementation media.¹ Conventional cements, such as zinc phosphate and glass-ionomer cements, simply provide retention for indirect restorations and no or only limited adhesion to tooth structures and dental materials. Still, they reveal excellent long-term clinical success due to some of their other physical, chemical, and biologic properties.¹⁻³ In certain situations, such as lack of retention, high occlusal dislodging forces, and less-than-ideal marginal fit, clinical success of indirect restorations may be significantly increased through adhesive bonding. In addition, several indirect materials, especially silica-based ceramics, rely on the support and increased fracture strength achieved through strong resin bonds.⁴ Adhesive treatment options, such as laminate veneers and resin-bonded fixed partial dentures (RBFDPs), completely rely on strong adhesive bonds.

Adhesive luting agents, typically resin composites, require multiple pre-treatment steps to create strong bonding interfaces to the supporting tooth structures and the restorative materials, including metal alloys as well as silica-

based and high-strength ceramics. Due to their fundamentally different compositions, these materials require substantially different bonding protocols, pre-treatment methods, and materials.

Metal alloys

Adhesive resin bonds to cast-metal and porcelain-fused-to-metal (PFM) restorations (eg, cast post and cores, inlays/onlays, single crowns, and fixed partial dentures (FPDs)), can be increased by fabricating the metal segment with base (ie, nonprecious) alloys. In contrast, the noncorrosive nature of noble and high-noble alloys makes resin bonding more difficult. Various materials and procedures (eg, special alloy primers, tin-plating, and silica coating) increase resin bonds to metal alloys.⁵⁻⁸ Systems that embed silica particles into the intaglio surfaces of the restorations (eg, Rocatec, 3M ESPE, Berkshire, UK; Silicoater MD, Heraeus Kulzer, Hanau, Germany) have demonstrated excellent bond strengths.^{5,7,8} A silane coupling agent is applied to the silicated metal surface for micromechanical interlocking and chemical covalent bonds. Some resin cements contain adhesive monomers that have the ability to chemically bond to metal alloys (eg, Panavia; Kuraray, NY, USA).

Silica-based ceramics

Silica-based ceramics (glass ceramics, feldspathic porcelain, leucite-reinforced feldspathic porcelain, lithium disilicate) are widely used for porcelain laminate veneers, inlays/onlays, and even full-coverage crowns due to their un-

matched optical properties. These brittle restorations derive their strength and clinical long-term success from a proper adhesive bond of the definitive restoration to the supporting tooth structure.⁴

A sufficient resin bond to silicate ceramic materials relies on chemical bonding and micromechanical interlocking through surface roughening and silane application. Grinding and air-particle abrasion (eg, aluminum-oxide particles) may increase bond strength, but are not suitable for silica-based ceramics due to the structural damage. Depending on the product and the crystalline content, most studies recommend acid etching of the ceramic surface with 4% to 9.8% hydrofluoric acid (HF) for 2 minutes.⁹ Silane coupling agents provide a chemical covalent bond and micromechanical interlocking.^{4,9}

Various characteristics of the ceramic restoration, such as type (veneer, inlay, etc), shade, thickness, and opacity, influence the selection of the resin composite cement. The curing mode (chemical-, photo-, or dual-activated), composition, and viscosity of the resin cement influence clinical handling and physical properties of the bond to the ceramic substrate. Photo-activated resin composite cements are preferred for thin porcelain laminate veneers due to long working times and shade variety. Dual-activated resin cements should be used for silicate ceramic restorations thicker than about 2.5 mm. Strictly chemical-activated composites are used for very thick and/or opaque restorations (eg, metal alloys, alumina, zirconia).⁴

Aluminum-oxide ceramics

Glass-infiltrated and densely sintered aluminum-oxide ceramics (eg, In-Ceram Alumina, Vident, USA; Procera crown alumina, Nobel Biocare, USA) are unsusceptible to bonding protocols successfully applied to silica-based ceramics (ie, HF etching, silane application). Air-particle abrasion and modified resin-based composite cements containing special adhesive monomers (eg, Panavia 21, Kuraray) have demonstrated high bond strengths to glass-infiltrated alumina.¹⁰⁻¹²

Similar protocols can be successfully applied to densely sintered high-purity aluminum-oxide ceramics.¹³⁻¹⁷ Long-term bonding studies recommend air-particle abrasion (30–50 μm Al_2O_3) and use of a modified resin cement together with the corresponding ceramic priming agent (eg, Ceramic Primer, Kuraray) containing an adhesive phosphate monomer (MDP).^{15,17}

Zirconia ceramics

Numerous studies have investigated resin composite bond strengths to zirconia.¹⁸⁻²⁷ Whenever resin bonding is needed, airborne-particle abrasion with Al_2O_3 sufficiently pretreats zirconium-oxide ceramics even when applied at a very low pressure. Various studies have shown that the application of a ceramic primer (eg, Ceramic Primer, Kuraray) that contains special adhesive monomers is a crucial step to create long-term durable bonds to the intaglio surfaces of zirconia restorations.^{18,22,27} A silica/silane coating (eg, Rocatec and CoJet, 3M ESPE) can also be successfully implemented for zirconia ceramics and allows the use of conventional resin composite cements of choice.²²

Recently, self-adhesive cements have literally flooded the market with promising prospects. The idea is to obtain decent resin bonds to tooth structures and various dental materials without the additional pretreatment steps. Bonding studies on these cements, however, reveal very mixed results and great variability among the different materials and manufacturers.²⁸

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Essay 1b: Experimental evidence

Essayist, Prof George Eliades

Introduction

Modern luting agents may be classified in three major groups based on their composition: (a) water-based cements (zinc phosphate, zinc polycarboxylate, glass-ionomers); (b) methacrylate-based luting agents (MMA/PMMA, dimethacrylate composites) and (c) hybrids (resin-modified glass-ionomers, polyacid-modified resins, glass-phosphonates). The first group sets by an acid-base reaction (cement), the second by free-radical polymerization, whereas the third combines both setting mechanisms.

According to their adhesion capacity, glass-ionomers, glass-phosphonates and resins with acid-functionalized monomers are characterized as adhesive agents.¹ Adhesive resin luting agents are differentiated from their non-functionalized analogues which are essentially combined with a 3- or 2- step adhesive system to mediate adhesion. From all these materials, composite dimethacrylates, including their hybrids, are considered as the strongest, with the lowest solubility offering durable adhesion to dental hard tissues. Nevertheless, the necessity of additional bonding to a variety of substrates (alloys, polymers, ceramics) has established a number of adhesive strategies integrated into different clinical protocols.

Bonding to alloys

Clean alloy surfaces at atmospheric conditions are covered by an oxide layer composed of oxidizable elements. On base-metal alloys, most alloying elements may form surface oxides, mainly basic in character, which may react with acidic groups (phosphate, carboxyl, etc), establishing bonding condition at the interface.^{2,3}

Phosphate groups are considered more reactive than carboxyl, although the use of both creates a synergistic effect. On precious alloys, the surface oxides are strongly reduced and thus, the active sites for bonding are diminished.⁴ However, thiol groups may bond to precious metals, since it has been identified that Au (under specific conditions) is hydrophilic. These observations have led to the development of a variety of metal primers for bonding alloys with resin luting agents. Some manufacturers designed mixtures of vinyl-phosphate and vinyl-thiol monomers to be used as universal metal primers, while others, to avoid monomer phase separation, synthesized vinyl monomers with both phosphate and thiol groups. Moreover, adhesive resin luting agents have been introduced with phosphate or/and carboxyl-functionalized monomers, achieving high bond strength to base-metal alloy substrates.⁵

To obtain more stable interfaces, high energy treatments have been proposed, like pyrolytic and tribochemical silication treatments, followed by application of silanol coupling agents to form Si-O-Si bonds with the substrate.^{6,7} A tribochemical coating can be further used for intraoral repair of exposed alloy surfaces.

From the acid-base cements, glass-ionomers have been shown to induce a weak chemical bonding with base-metal alloys (complexation via carboxyl groups). The hybrids demonstrate improved performance over glass-ionomers, but inferior to resin composites. Recently, the self-adhesive resin composite cements have been introduced, combining the free-radical setting mechanism with the acid-base mechanism of phosphate cements or/and glass-ionomers. Although considered as universal cements, there are great variations in the composition and properties of the commercially available materials, which may affect their clinical performance.¹ Of major importance is the finding that many of these materials demonstrate low C=C conversion, especially after dark setting.⁸

Selection of the proper luting agent depends, as well, on the marginal and internal adaptation of the frames. Full crown alloy frames with tight fit require low viscosity luting agents. In such cases, resin composite luting agents, due to their structure and viscosity, may lead to occlusal interferences. It should be mentioned that the film thickness given according to international specifications is measured under 15 kp load, a value of limited clinical reliability. Furthermore, it has been documented that adhesive luting agents offer the highest strength at a thickness of approximately 100 μm .^{9,10} Other luting agents, like glass-ionomers or their resin modified analogues, may be used in cases of tight fitting frameworks.

Bonding to silica-glass containing ceramics

The etching capacity of these structures has established HF etching as the most effective method of creating a micro-retentive pattern, by taking advantage of the differential acid dissolution of the crystalline from the glass phases.¹ Care should be exerted to avoid over-etching and to neutralize any residual acid entrapped in the complex porous structure of etched ceramics. Treatment of these surfaces with silanol coupling agents is considered important to transform the hydrophilic etched ceramic substrate to a hydrophobic one compatible with resin composite luting agents, while concurrently mediating molecular bonding.

From the variety of silanol coupling agents, the ready to use prehydrolyzed materials are more reactive.¹ Since activation of silanols is mediated by low pH, instead of the commonly used acetic acid, modern materials incorporate acidic monomers (mainly phosphate methacrylate derivatives) to provide a synergistic effect. When using silanols on rough surfaces, careful drying should be performed, since these compounds are more reactive in monolayers; otherwise, instead of forming Si-O-Si bonds with the Si-OH bonds of the hydrated ceramic substrate, they produce secondary-bonded siloxane polymers.¹¹

From the resin composite luting agents available, light-cured materials with no adhesive monomers are considered to be the best for transparent laminates, providing better color stability and less water sorption, due to absence of polar and highly chromophore

chemical groups. Dual- or chemically-cured versions may be used for other applications, where activating light is attenuated by the thickness or the opacity of the restoration.

Bonding to glass-infiltrated and densely sintered ceramics

The very low content or lack of etchable silica phase in materials like glass-infiltrated alumina, alumina and zirconia (Y-TZP), render the previously described treatment inadequate for bonding.¹ Airborne particle abrasion with alumina is commonly used to roughen surfaces for micromechanical bonding. As silanols are not compatible with alumina and zirconia, adhesive composite luting agents with phosphate monomers have been proposed, to provide the highest strength on such substrates, although concerns have been expressed on their long term hydrolytic stability (the main reason being the reduced polarity of alumina and zirconia oxides).

Especially for Y-TZP, the oxygen vacancy left on crystal structure (Y³⁺ replaces Zr⁴⁺ sites) creates conditions that favor adsorption of polar groups, like phosphates, and may establish a bonding condition, although evidence for such a reaction is still missing. Based on this property, zirconia primers have been recently introduced, containing phosphate- and carboxyl-functionalized methacrylate monomers to be used as coupling agents.¹² The laboratory performance of these primers is still under evaluation. Alternatively, the use of universal phosphate primers dissolved in excess of silanols with thiol components has been recently advised.¹³ Although the bonding mechanism is not fully understood, it has been claimed to be quite effective.

Clinically proven methods, like tribochemical silicating, have been proposed for zirconia.¹⁴ However, sandblasting zirconia may destabilize the tetragonal phase and inducing monoclinic phase transformation, then activating the low temperature degradation mechanism.

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Discussion on bonding capacity of luting agents to alloys and ceramics

Edited by Aris Petros Tripodakis and Stefano Gracis

Stefano Gracis

It has been said that silica-based ceramics must be bonded, high-strength ceramics, and that there is no evidence that traditional metal-ceramic crowns and bridges made with precious, non-precious or titanium metal substructures need any bonding, with the exception of adhesive fixed dental prostheses. Let's start the discussion on the use of precious alloys, non-precious alloys and titanium, and clarify if there is any indication to bond these materials.

Tidu Mankoo

Are we talking about luting or actual bonding? Why should we waste time to bond these restorations when we can cement them traditionally?

Markus Blatz

Bonding is recommended for some partial coverage metal-supported restorations, and for full coverage preparations that lack proper retention and resistance form in order to counteract the dislodging forces. Furthermore, bonding can be beneficial for metal cast posts and cores.

George Eliades

It depends on the fit of the post. If the post is a gold post with a good fit, it is better not to bond because the resin film would be too thick. In this situation, a glass-ionomer or zinc phosphate cement would be preferred because their film thickness would be lower. If the preparation does not provide adequate retention, we should not rely on bonding since, in the long run, it will fail. Proper retention and resistance form in the preparation design is still a valid principle that cannot be disregarded, even in the light of the current developments in adhesive systems.

Nicola Pietrobon

So crowns with porcelain margins should be bonded?

George Eliades

If you have a good adaptation, around 20 or 30 microns as usually provided by the precious alloy castings, I don't think there is a need to bond the cervical porcelain. When you use anaerobic Panavia or similar types of cements, you have to be aware that these materials start polymerizing from inside where air is excluded and then, in the end, at the margins. That's why I insist that, for this application, the old traditional systems will work quite well.

Stefano Gracis

If you were to bond precious or non-precious alloys and titanium, how would you treat the inner surface? Is there a difference among the three?

Markus Blatz

Yes, there is a difference between the three, based on the ability to create an oxide layer. The best metal to bond to this is titanium because it has a thick oxide layer. It is so thick that it is difficult to control when veneering porcelain. However, for bonding it is ideal since none, or only little surface treatment is needed. With the other metals, a treatment with silica/silane is recommended, for example Rocatec (3M ESPE) or Sili-coater MD (Heraeus Kulzer).

Guido Bracchetti

Does it make sense to use metal primers?

Markus Blatz

What I deduce from the literature regarding bonding to metal and metal alloys, is that silica treatment is better than the application of metal primers.

George Eliades

I agree. Silica treatment is much better than the primers, which are not as reliable. Many of them upon application demonstrate phase separation, which is separation of hydrophilic from hydrophobic monomers; therefore, the primer layer is not homogeneous. When resin cements are chosen, the prerequisite is to use a silica treatment (ie, Rocatec) with a silane. Which silane? I would say that the type of the silane is not as critical as drying the field in order to bond to what is called "in-depth absorbed water," that is the strongly bound water monolayer formed on clean surfaces exposed to air. Just a comment on the new silanes that Markus showed: the Clearfil Ceramic Primer and Monobond Plus are mixtures of silanol and phosphate methacrylate functionalized monomers. These are strong, stronger than the simple silanols and are considered as universal primers for all metals and ceramics. Nevertheless, there is some evidence claiming that the phosphate monomers produce water instability in the siloxane layer formed after silanol condensation. So, we should be careful.

Stefano Gracis

In conclusion, if you want to bond precious or non-precious alloys, your recommendation is to use silica and silane, like Rocatec, plus a silane agent.

Markus Blatz

Yes, but I would always recommend to stay within the product line. For example, if you use the Silicoater MD, use their silane; if you use Rocatec, use their silane. Their silane actually comes in a clear bottle. It is prehydrolyzed and contains solvents that keep it from polymerizing. If the solution turns milky, it has to be thrown away because the polymerization process has started already.

Stefano Gracis

It has been said that bonding results in a thicker film. Is that so? Is such a statement based upon a clinical feeling, scientific evidence or both?

George Eliades

Film thickness measurement is quite tricky. According to ISO, after mixing the cement, the film thickness is measured under 15 kiloponds load, 10 seconds before expiration of the setting time. This has no clinical relevance at all and not all assessments are made under these conditions. In many cases, specimens are loaded immediately after mixing. Practically, more viscous materials, lacking thixotropy, result in increased film thickness.

For some resinous cements, preheating to 37°C gave the best results, probably due to reduction in viscosity and better conversion, like in the case of Panavia 21 as it has been documented by Matthias Kern. Nevertheless, this material is quite different from Panavia 2F which is dual curing, not taking into account the advantage of the anaerobic setting. The anaerobic setting that was so efficient in Panavia 21 has been strongly reduced in Panavia 2F in order

to control the “dark” setting time, assigned to the chemically curing component of the catalyst system.

Stefano Gracis

So, it is true that resin cements have a thicker film?

George Eliades

Yes, in clinical practice.

Stefano Gracis

Many clinicians stress the message that field isolation is necessary for bonding. Resin cements can be used as a cementing medium for the metal substructure of a FPD, but they can also bond. The difference between the two does not depend on the material, but on the procedure and how effective field isolation is.

Markus Blatz

My first statement is that a bad bond is worse than a good cementation. Without good isolation, the real bond strength is not attained and the result may actually be worse than what is obtained with traditional cementation.

George Eliades

Apart from avoiding contact with saliva or blood, the humidity of the mouth has also to be considered when bonding a restoration. Some materials, like the water-based cements, tolerate some degree of humidity, but the adhesive systems that do not usually contain water are very sensitive to humidity. So, it is good to isolate the field as much as possible for bonding. On the contrary, for cementation with glass-ionomer cement, a completely dry field is not necessary.

Thomas Meier

When a crown has received acid etching or a Rocatec treatment in the laboratory and is then contaminated with saliva during trying-in, can it be cleaned or will the surface be compromised?

Markus Blatz

Bonding should start with a clean surface. Surface treatments in the laboratory should be done after trying-in.

George Eliades

A contaminated surface should be cleaned with phosphoric acid and ethanol; remove everything and start the surface treatment from scratch.

Stefano Gracis

What is the surface treatment for bonding alumina?

George Eliades

No efficient sandblasting treatment can be provided for alumina. It is difficult to roughen alumina by air-abrasion because the strongest abrading particle is alumina! It may clean the surface, but is not enough to create a rough morphology, as with other substrates.

Kony Meyenberg

Adhesion requires some kind of roughening. If nothing is done, the surface remains very smooth and, if one of the chemical treatments fails, there will be a problem. In general, physical or chemical roughening is required for all surfaces. My question is if you can give any recommendation for the mechanical roughening of alumina.

Markus Blatz

Not much roughening can be expected by air abrasion on an alumina surface. Still, in order to get good bond strength, some air abrasion is needed because, without any air abrasion, no bond can be achieved. Even with low pressure and small particles, the possibility of adherence is enhanced. Just the presence of alumina splinters on the surface seems to increase the bond strength on alumina.

George Eliades

Actually what happens, from the physical point of view, is that when the alumina surface is attacked by the same material, this is not implanted, but small particle fragments stay on the surface, probably reinforcing a little bit the bond with the resin cement. The topography of the surface is not substantially changed.

Stefano Gracis

So, the consensus for alumina is that air abrasion is recommended, even though it is not very efficient. What about a zirconia surface?

George Eliades

For zirconia, only soft and low-pressure air-abrasion is recommended (chair-side, at 1–1.5 bar). Strong sandblasting (in the laboratory, at 3 or more bar) affects the surface by activating tetragonal phase transformation to monoclinic.

Stefano Gracis

So, low-pressure air abrasion combined with a phosphate adhesive is recommended for zirconia.

Danuta Borczyk

If bonding zirconia and alumina is recommended only in order to attain more retention, couldn't some additional mechanical retention be added in the software during milling?

Markus Blatz

Adding this kind of modification during cutting might have a negative effect in the overall physical strength of the material. Another idea is to add a layer of a glass phase by firing it not just on the outside, but on the inner surface as well. This can then be etched and a silica-coupling agent can be used on top of that.

George Eliades

Silanes not only improve bonding, but, first of all, they modify the wettability of the surface in order to avoid porosity at the interface. Silanes do not produce instant bonding, but bond strength increases over time as the setting reaction with the substrate is a condensation type, like the one in condensation silicone impression materials.

Tidu Mankoo

Bonding of a crown implies bonding to dentin. What is the long-term efficacy of this bond?

George Eliades

Considering the long-term efficacy of dentin bonding in operative dentistry, as it was presented by Angelo yesterday, a better performance can be expected under full coverage crowns, where the volume of the resin material is much less and the problem of bulk resin polymerization shrinkage is reduced. On the

other hand, water-based cements, like glass-ionomers, create a durable bond as well. Even the phosphate cements, as it has been found recently, may hybridize dentin to an extent, since they are self-etching due to the phosphoric acid.

Bruno Fissore

In the case that a well-bonded crown has to be removed, the procedure is quite complicated. This should make us consider if bonding is absolutely necessary.

Nitzan Fuhrer

Upon removal of an alumina or a zirconia crown, the bond on the tooth surface is found to be stronger than the bond on the ceramic surface. To cut a crown with an inner shell of zirconia is not a big issue. Bonding should be continued because it protects dentin from caries.

Didier Dietschi

Conventional cementation requires a tooth preparation with retention and resistance form. Bonded crowns rely less on this principle.

Stefano Gracis

Whenever you need to compensate for the lack of retention and resistance form in the preparation, there is a stronger indication to bond. While silica-based ceramics must always be bonded, the recommendation for alumina and zirconia is that the individual situation has to be evaluated by the clinician, who will make the final decision choosing between bonding and conventional cementation, taking into consideration the advantages and disadvantages.

Conclusions on bonding capacity of luting agents to alloys and ceramics

by Stefano Gracis and Aris Petros Tripodakis

The following statements can be drawn from the presenters' lectures and the discussion that followed:

1. Traditional alloy substructures of fixed partial dentures can be cemented with any luting agent, but it is suggested to lute them with $Zn_3(PO_4)_2$, glass ionomer (GIC) or resin-modified glass ionomer (RMGIC) that provide the minimum film thickness. The main reason for using composite/adhesive resin luting agents may be an inadequate form of resistance and retention.
2. Silica-based ceramic materials should be optimally bonded with a resin composite luting agent.
3. Silanization is important to improve wetting of the resin-luting agent to the substrate and to establish chemical bonding.
4. High strength ceramics can be cemented with any luting agent. Low-pressure air abrasion (1-1.5 bar) is recommended for bonding. While actual roughening of alumina surfaces cannot be expected, alumina splinters implanted on the surface upon sandblasting seem to increase the bond strength. High-pressure air abrasion (3 or more bar) should be avoided on zirconia surfaces in order to prevent the eventual monoclinic phase transformation.
5. Field isolation is mandatory for bonding: ideally, it should be done under rubber dam, as a minimum, with retraction cord and proper saliva control.
6. Total field isolation is not mandatory if the luting cement is water based ($Zn_3(PO_4)_2$, GIC or RMGIC), but saliva and fluid control are still necessary.

Table 1 A prosthesis made of different substrates can be luted with different types of cements. The table summarizes the possible choices for each substrate.

Prosthesis substrate	Zn-P	GIC	RMGIC	DC-RC	LC-RC	CC-RC
Precious alloys	✓	✓	✓	X	X	✓
Non-precious alloys	✓	✓	✓	X	X	✓
Titanium	✓	✓	✓	X	X	✓
Glass ceramics						
Crowns	X	X	X	✓	X	✓
Inlays/onlays	X	X	?	✓	X	✓
Veneers	X	X	X	?	✓*	X
Alumina	✓	✓	✓	?	X	✓
Zirconia	✓	✓	✓	?	X	✓
Resin composites						
Crowns	X	X	X	✓	X	✓
Inlays/onlays	X	X	?	✓	X	✓
Veneers	X	X	X	?	✓*	X

Zn-P: zinc phosphate; GIC: glass ionomer; RMGIC: resin-modified glass ionomer; RC: resin composite; DC: dual cured; LC: light-cured; CC: chemically cured X: contraindicated;?: possible, but not ideal; ✓: ideal; *: thickness <2 mm (for transparent materials).

Table 2 If a prosthesis is to be luted with a resin composite cement, its surface should be treated as follows:

Substrate	Surface treatment	With what	Pressure	Activator
Precious alloys Non precious alloys Titanium	Air-particle abrasion	30 µm silica-coated alumina particles	~2.8-3 bar	Silane coating
Glass ceramics lithium disilicate based leucite based feldspathic	Acid etching	9% hydrofluoridric acid for 60 seconds -5% hydrofluoric acid for 20 seconds for lithium disilicate G.C. 60 seconds for leucite G.C. 120 seconds for feldspathic ceramics	=	Silane coating
Glass-infiltrated alumina	Air-particle abrasion	50–100 µm alumina particles OR	~2.8-3 bar	Phosphate adhesive resin luting agent OR
		30 µm silica-coated alumina particles		Silane coating
Densely sintered alumina	Air-particle abrasion	Alumina particles	~2.8-3 bar	Phosphate adhesive resin luting agent
Densely sintered zirconia	Air-particle abrasion	<50 µm alumina particles OR	~1.5 bar	Phosphate adhesive resin luting agent OR
		30 µm silica-coated alumina particles		Silane coating
Resin composites	Air-particle abrasion	30 µm silica-coated alumina particles	~2.8-3 bar	Silane coating

Note: Commercially available silica-coating systems that include air-particle abrasion with silica-coated alumina are typically offered in different particle sizes (eg, 30 µm and 50 µm). The 30 micron particle size is recommended for chair-side air abrasion units. Recommended pressure is around 2.8 bar, but some materials may require lower pressure. Therefore, it is important to verify and adjust the pressure of laboratory air-particle abrasion units and chair-side microetchers, which may differ.

2. Exploring the interface and the reliability of ceramic veneers on metal and ceramic substrates

The Essays

Essay 2a: Clinical interpretation of the scientific evidence

Essayist, Prof Markus B. Blatz

Silica-based ceramics, also termed feldspathic porcelains, reveal excellent optical properties due to their high translucency and variety of shade options. Therefore, they are the materials of choice for highly esthetic indirect restorations. Their low flexural strength and inherent brittleness, however, require support from a coping or framework fabricated from either a metal alloy or a high-strength ceramic material. The bond of the veneering ceramic to the core is characterized by the following mechanisms: mechanical interlocking, chemical bonds, and compressive forces.¹ Numerous studies have investigated the metal-ceramic interface and respective bond strengths.¹⁻¹²

The mechanical retention requires a certain roughness of the substrate surface, typically achieved through air-particle abrasion and the ability of the ceramic to adequately wet this roughened surface during the firing process.⁵ Chemical bonds are facilitated through the presence of adherent oxides and diffusion of atoms from both the coping material and veneering ceramic into this oxide layer.^{1,2,5} Non-precious metal

alloys readily form such oxides on the surface, while in noble and high-noble alloys, trace elements migrate to the surface during the firing process, form oxides, and bond to similar oxides in the opaque layer of the ceramics.⁶

The selected alloy should have a slightly higher coefficient of thermal expansion (CTE) than the veneering ceramic. This causes a “draw” of the veneering ceramic towards the coping after firing and puts it under compressive stress, which increases the overall strength of the restoration.⁵

Likewise, this concept has been applied to all-ceramic restorations, especially zirconium oxide ceramics, which have become quite popular.¹³⁻²⁶ Some *in vitro* studies demonstrate that the use of veneering porcelain with a CTE higher than that of the zirconia framework results in delamination of the veneer and formation of massive microcracks.²⁰ In another study, the shear bond strengths of zirconia/ceramic veneers showed no difference within a CTE mismatch of 0.75 to $1.7 \times 10^{-6}^{\circ}\text{C}$.²¹

The high bond strength values found in these studies suggest that chemical bonds are established between the two materials. As previously shown for ceramo-metal systems, ceramo-zirconia bond strengths are mainly attributed to the following factors: micro-mechanical and chemical adhesive bonds between core and veneer, CTE values, cooling rate, and geometry of veneered ceramic.^{15,21,25,26} Similarly, the CTE of the veneering ceramic should be slightly lower (about 10%) than that of the core material to create compressive stresses in the veneer during cooling.^{25,26} Recent studies have used veneering ceramics

that were specifically developed for zirconia copings and frameworks.^{25,26} Interestingly, many of these studies demonstrate even higher bond strengths of these veneering ceramics to zirconia, as compared to ceramo-metal systems. These findings indicate that the actual bond strength may not be the reason for some of the reported “chippings” and fractures of zirconia-based restorations.

Factors often overlooked when examining bond strength as an isolated parameter are modulus of elasticity and flexural strength of the veneering ceramic, in comparison to the coping material. It seems that a “stronger” and more “rigid” veneering ceramic better complements the physical properties of a high-strength ceramic material, causing less chipping and/or fractures.^{15,25}

Metal alloys used in dentistry also have a high thermal conductivity, which greatly prolongs the porcelain-cooling rate at the interface and potentially alters the CTE. Applying the exact same firing and cooling parameters may introduce residual thermal stresses in the zirconia and the veneering ceramic, which may

translate into cracks and, consequently, failures. Zirconia has very low thermal conductivity and, therefore, requires a significantly adjusted firing and cooling cycles when the veneering ceramic is applied.^{21,25}

Lastly, the actual thickness of the veneering ceramic plays an important role in its fracture behavior.²⁶ Traditionally, high-strength ceramic copings had an even thickness, which may not adequately support the veneering porcelain. The modulus of elasticity and fatigue behavior of zirconia under functional load makes adequate veneer thickness even more important. Therefore, an anatomic coping/framework design that provides ideal thickness of the veneering ceramic has been suggested and has been shown to improve reliability of bilayer all-ceramic restoration. Modern CAD/CAM systems provide excellent tools to appropriately design and verify the most supportive, yet esthetic coping/framework.

Recent clinical reports indicate that successful implementation of the above parameters translates into significantly improved clinical success.^{27,28}

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Essay 2b: Experimental evidence

Essayist, Prof George Eliades

Introduction

For decades, porcelain-fused to metal restorations have been the materials of

choice for esthetic prosthodontic restorations. Extensive investigations of the porcelain-metal interfaces have disclosed three major mechanisms involved in metal-ceramic bonding: (a) micro-mechanical retention of porcelain with the rough metal substrate; (b) secondary bonding (wetting) of porcelain paste on the substrate and primary bonding

through establishment of surface adherent oxides, that upon porcelain firing react with oxides of the porcelain melt; and (c) compressive forces developed at the metal surface after porcelain cooling due to the tailored mismatch in thermal expansion coefficients (CTE) between porcelain and metal, the former being slightly higher.¹ Recent developments have introduced porcelain application onto high strength ceramic substrates, including glass-containing, glass-infiltrated and densely sintered ceramics. The information on the interfacial reactions involved in such systems is limited.

Porcelain bonding to alloys

The interfaces of noble alloys with porcelain have been the subject of many studies with a variety of analytical techniques to explore the metal-ceramic bonding mechanism. Migration of alloy trace elements (ie, In, Ga, Sn) towards the interface and formation of adhesive oxides with porcelain has been identified as the principal chemical bonding mechanism.²⁻⁴

On basic alloys, where bulk alloy elements may oxidize as well, a balance between adhesive and spontaneously formed non-adhesive surface oxides is required. For this reason, light elements, highly reactive to oxygen, are incorporated into the alloy to preferentially consume reactive oxidizing species. The thermally controlled balance of all these reactions is very sensitive to temperature fluctuations, leaving a narrow effective temperature range. On Ni-Cr alloys, the surface oxides formed are NiO, NiCr₂O₄ and Cr₂O₃ (Cr <30% wt) or mainly Cr₂O₃ (Cr: 30–40%wt). On

Co-Cr alloys, the predominant oxide is Cr₂O₃.⁵⁻⁸ On Ti, to overcome the problem of excessive oxidation, bonding agents are applied containing elements of higher chemical affinity to O than Ti.⁹ At the interface, Ti reduces SiO₂ forming oxides (Ti₂O₃, TiO₂, TiO) and complex Ti-Si compounds (ie, Ti₅Si₃).^{10,11} For electroformed gold substrates, no chemical bonding exists with porcelain.¹²

Although bonding capacity is usually evaluated by bond strength tests, there is still no consensus on the proper testing methodology, rendering direct data comparison from various studies invalid. Nevertheless, noble alloys seem to offer the highest metal-ceramic strength, followed by base-metal and titanium alloys.^{13,14}

Porcelain bonding to glass-containing, glass-infiltrated and densely sintered ceramics

In feldspathic glass-containing (leucite, lithium disilicate, fluorapatite) and lanthanide glass-infiltrating systems, a continuous interface rich in O, Si, Na, K, Ca and La is created during porcelain firing, forming a rather amorphous phase that extends from the veneering material into the inter-granular spacing of glass-ceramics. This layer establishes the primary chemical bonding between core and veneering materials, providing interfacial strength, as confirmed by the frequently mixed type of failures in bond strength tests.¹⁵ Nevertheless, the cohesive strength of these core materials is weak, in comparison with modern high strength ceramics.¹⁶ The latter exhibits a densely sintered polycrystalline structure, free of silica-glass. Consequently,

chemical bonding is mostly limited to secondary reactions, with no ionic migration at the interface.

For zirconia, there is lack of evidence on the bonding mechanism with dental porcelain.¹⁷ In industrial applications, though, it has been postulated that melted silica phases may attack Y-TZP intergranular sites and create secondary bonding conditions that facilitate excellent wetting of porcelain on zirconia frames.¹⁸ As these sites are yttria segregation points, reaction with melted silica may destabilize the tetragonal phase dependent on crystal orientation.¹⁹

A tetragonal to monoclinic zirconia phase transformation after porcelain firing has been confirmed in one study, mainly attributed to the water content of the “wash” porcelain layer applied onto Y-TZP frameworks.^{20,21} This phenomenon is actually the onset of zirconia low temperature degradation. Taking into account that some of the currently employed CAD/CAM manufacturing methods have been shown to induce monoclinic transformation in Y-TZP frameworks (not reversible by the porcelain firing temperatures), it may be concluded that at least part of the surface veneered by porcelain is already destabilized.

The relation of this transformation with the clinically documented porcelain failures is unknown. It has been reported that transformation may strengthen the interface (ie, after sandblasting).²² Nevertheless, the destabilized surface regions may act as a loci of transformation propagation. Due to the resultant volumetric expansion, the stresses may be more easily distributed towards the weaker overlying porcelain than the

densely sintered polycrystalline substrate. The tensile components of these stresses may be implicated with bulk porcelain fractures. Besides, evidence of high interfacial residual stresses associated even with the tetragonal phase has been recently reported, which further complicates the detrimental stress-patterns at porcelain-zirconia interfaces.²³

The higher modulus of the densely sintered alumina and zirconia results in much higher flexural strength of porcelain layered beams, than other core ceramic materials. However, the core thickness may affect veneer fracture. Alumina core, being stiffer, with almost twice the elastic modulus of zirconia, demonstrates less dependence on frame thickness.¹⁶ To improve the performance of Y-TZP, alumina-toughened Y-TZP composites have been designed. Recently, a ceria-doped alumina toughened zirconia nanocomposite has been introduced, with improved mechanical strength and exceptional stability of tetragonal to monoclinic transformation. Porcelain bonding to this substrate is mediated by the same mechanisms as in Y-TZP, with no evidence of chemical interactions so far.²⁴ The same applies also for ceramics pressed on alumina and zirconia.

In several comparative bond strength studies performed with the same methodology, the results of porcelain bond strength with zirconia were found to be lower than noble alloys.^{25,26}

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Discussion on exploring the interface and the reliability of ceramic veneers on metal and ceramic substrates

Editing by Aris Petros Tripodakis and Stefano Gracis

Stefano Gracis

The second issue to be discussed deals with the interface between ceramic veneers and framework substrates. The message that I got from the lecture of Markus Blatz is that he is convinced that CAD-CAM technology is here to stay. On the other hand, the message from George Eliades' lecture is that zirconia as it is now (yttrium reinforced) is not necessarily the end product to be used with CAD-CAM technology, and that there will be further developments.

George Eliades

CAD-CAM is promising not only for ceramics, but also for metals. For example, the casting of cobalt-chrome alloys has always been problematic. CAD-CAM offers tremendous advantages because a framework, which is milled, is much stronger than when cast.

Markus Blatz

That is why, when talking about digital milling, the discussion should not be limited to a specific material, but it should be extended to all the possibilities that CAD-CAM offers today. We can even mill the frameworks for removable partial dentures. The obvious advantage is that the material is much more homogeneous than when cast.

Stefano Gracis

My question is: can all these materials be used to make a substructure that has to be veneered? We have seen more problems with zirconia-supported restorations than we have seen with alumina-supported and, certainly, metal-ceramics restorations. So, one of the issues is whether we should go to full contour restorations.

Tidu Mankoo

No, this is not actually true, at least not any more. What has happened with zirconia is that the profession has been the testing ground in the development of zirconia-based ceramics. Now there is a clear understanding that both the design of the framework and the thickness of the veneering ceramic are critical. The layer of veneering ceramic should be thinner than the one applied to metal-ceramics. The early zirconia frameworks that we designed were like metal-ceramic frameworks: they were too reduced with big chunks of porcelain on top.

Stefano Gracis

I agree with what you just said, but the evidence in the literature is giving a different message.

Tidu Mankoo

We cannot go with just the evidence in the literature. All of the on-going clinical trials that I have seen recently, and the publications of many universities, say the same thing: that the frameworks should be thicker and that the amount of porcelain on top should be decreased.

Stefano Gracis

So here we are: substructure design is a big issue to prevent or reduce the incidence of ceramic chipping.

Tidu Mankoo

The coefficient of thermal expansion (CTE), how the ceramic is heated and cooled, and other factors, also all contribute to the incidence of chipping. When all is under control, it seems that the clinical performance of the zirconia material is the same as metal-ceramics. Many of the studies that have shown a high incidence of chipping used experimental CAD-CAM systems, and materials that have not become commercially available and their framework design is not clear. So, these studies are meaningless from a clinical standpoint. This is the problem with all scientific data that doesn't have relevance to everyday dentistry.

George Eliades

I agree with Tidu only partially. Initially, the zirconia studies were limited to three years and demonstrated a high success rate. Now that the studies have reached nine years of follow-up, many problems have been pointed out. The chipping incidence, for example, arose from the clinical studies and was not predicted from the material standpoint. I want to see which are the specific developments now and how these developments are going to be included in the new clinical trials. My point is that, as a dentist, I do not want to contribute to the development of a system through the failures that I face in my clinical practice.

Tidu Mankoo

I agree, but that doesn't negate the fact that the material, if we can find out how to use it optimally, has a clinical potential.

George Eliades

Of course. However, as a dentist, I am not going to do that clinically. I want a material to reach my hands, especially these types of materials, which are very different from composites, after proper development.

Markus Blatz

This is a major problem. Don't forget that it took us fifteen to twenty years to figure out how to deal with PFM and nowadays we want zirconia to be fool-proof overnight!

Nicola Pietrobon

The big difference today, as a laboratory technician, is that I have to invest about 100,000 Swiss Francs or 100,000 US dollars (80,000 Euros) to get new equipment. I have to buy now, for the sixth time, a new system while I am still fighting with the others. I am not willing to do this any more. All the problems we are facing now are due to the fact that gold has become so expensive. But you cannot give the public the message: "Face the future! We can go for it!," and then add: "We don't care about failures." We cannot do that!

Aris Petros Tripodakis

Yet, George in his lecture only mentioned half of the problem. A major aspect that he didn't touch upon is zirconia's hydrolytic degradation that happens as aging takes place. I think that he should address this and make us aware about the

influence of water on zirconia frameworks not only 2 to 3 years after insertion, but after 5 or 10 years.

Stefano Gracis

This is a very good issue that we should address. As a matter of fact, I too have a question on this phenomenon, because I have been using zirconia abutments for many more years than I have been delivering zirconia crowns and fixed dental prostheses. In my personal clinical cases, I have never witnessed a zirconia abutment fracture that could be linked or explained by this degradation, even though they are never veneered. So, I would like to ask both of you whether this process has an effect on the material in a clinically significant way and, if so, after how many years should we be expecting to see something.

George Eliades

Zirconia may change phase, from tetragonal to monoclinic, at ambient temperatures or in the presence of water, a phenomenon known as low temperature degradation. This induces surface and subsurface damage, which along with the loading conditions may create problems. Today, veneering ceramic chipping is the predominant failure. Phase transformation may be implicated in such failures, by producing tensile stresses towards the veneering material. To face this problem, monolithic zirconia has been introduced and advertised as problem-free, provided that occlusal surfaces with mirror-like smoothness are produced. Of course, the intraoral stability of such a surface is put in question. We must consider that the primary industrial use of zirconia is for oxygen sen-

sors and fuel catalysts, due to its inherent affinity to oxygen. Then, the question is how reliable can such a material be in the complex intraoral environment?

Andrea Ricci

As clinicians, our approach to the use of zirconia has been wrong. I think that universities and the industry need to test the material and I think that strict protocols should be applied. Nowadays, whoever talks about zirconia has a different approach in using it and treating it. We need long-term studies and sound research centers that can test the material with protocols like Markus's. Until I see those results and I read those publications, I will not use zirconia again.

Stefano Gracis

I would like to ask Markus whether, from his position as a clinical researcher who has been using zirconia for a long time, he recommends using this material to our audience. George was very clear about the fact that he would not recommend zirconia right now.

Markus Blatz

It is work in progress. In our practice, working with our CAD/CAM Center and the select dental laboratories that have gained significant experience with the material, we don't see any greater chipping rates than with PFMs. A lot depends on the laboratory. A critical thing, for example, is the calibration of the milling machines as well as the calibration of the firing ovens. If the oven for sintering is 50 degrees Celsius lower or higher than the optimal temperature, you get a totally different material. So, if you ask me whether I can recommend it to

everyone, I would say no. I would recommend it only to technicians who are familiar with the important handling, design, and firing parameters mentioned before. Some of the early studies that presented a lot of chipping analyzed the behavior of materials, which were experimental. However, more recent studies found fracture rates of zirconia fixed dental prostheses similar to those of porcelain-fused-to-metal (PFM) fixed dental prostheses. They also pointed out that all of these fractures occurred in areas where there was occlusal roughness after occlusal adjustments or wear. This is why polishing is very important. That is true for every ceramic, not just for zirconia; but in the case of zirconia, it may be even more important because of the possible degradation.

Stefano Gracis

The chipping that I observed in my early experiences with zirconia-supported restorations I believe could be ascribed to the fact that dental technicians were not aware that they had to apply different heating and cooling rates compared to metal-ceramics. In this way, a lot of stress was built into the structures. However, there is a range of opinions among dental technicians about what the optimal heating and cooling rates are, and that is another matter of confusion.

Nicola Pietrobon

When you buy a system, the companies do not tell you how to heat or cool zirconia. How can the technician know what he is supposed to be doing?

Stefano Gracis

My last question is whether, to prevent low temperature degradation, it is enough to cover the entire surface of zirconia with the veneering ceramic. Will that help?

George Eliades

No, It may reduce the degradation, but it will not be sufficient. As soon as you fire porcelain on the substrate, the mechanism is initiated and the degradation is there. It is like having a metal that starts oxidation at the interface.

Conclusions on exploring the interface and the reliability of ceramic veneers on metal and ceramic substrates

by Stefano Gracis and Aris Petros Tripodakis

The following statements can be drawn from the presenters' lectures and the discussion that followed:

1. CAD-CAM is the promising technology of the present both for ceramics and metal alloys.
2. Zirconia-based restorations may be recommended as an alternative to metal-ceramic restorations for fixed partial dentures and crowns, taking into account that the relevant material science is still under development. Low temperature degradation is a phenomenon to be considered. Further scientific evidence should be provided relating to the long-term durability of the restorations exceeding

- the five years of successful clinical application.
3. Chipping of the veneering ceramic in zirconia fixed dental prostheses is still a clinically relevant problem; however, some factors are better understood today, such as framework design, heating and cooling cycle-protocols during porcelain firing and thus, the incidence is expected to decrease.
 4. Porcelain bonding to high-noble alloys has proven to be reliable.
 5. Porcelain bonding to non-precious alloys has been improved and is considered reliable as well, although lesser than on high-noble alloys.
 6. Porcelain bonding to titanium is the least reliable and inadequate in certain commercially available systems.

Table 3 How to minimize or prevent ceramic chipping on zirconia.

Involved factors	Proposed procedure
Substructure design	It should be shaped to support the veneering ceramic, which should be of limited thickness (<1.5 mm).
Veneering surface roughness	Avoid mechanical damage to the intaglio surface and polish any roughness in the veneering ceramic (ie, occlusal adjustments).
Coefficient of thermal expansion (CTE)	Veneering ceramic has to have CTE optimized for zirconia.
Heating and cooling rates	Lower than for metal-ceramics; need for ovens to be calibrated for zirconia.
Modulus of elasticity of veneer	Veneering ceramics with e-moduli closer to zirconia are preferred.
Low temperature degradation (LTD)	Need for covering all zirconia surface with veneering ceramic.

