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Laboratory Aspects of Zirconia Restorations

Abstract: Zirconia restorations are now accepted and commonly prescribed in dentistry. However, these materials undergo hydrothermal ageing which can reduce their clinical performance. Appropriate handling is essential to limit the restorations' susceptibility to low temperature degradation/ageing. Through appropriate clinical prescribing and laboratory manufacture, an aesthetic, strong and long-lasting restoration can be fabricated.

Clinical Relevance: This article will inform the reader about zirconia as a dental material as well as how best to handle a zirconia restoration.

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What is zirconia?

In ancient history zircon was known to be a gem. The name zirconium comes from *Zargon* which translates from Arabic to golden in colour. *Zargon* is a composite of two Persian words; *Zar* meaning gold and *Gun* meaning colour. Zirconium dioxide (ZrO_2: zirconia) was first identified by a German chemist in 1789. The compound was used for a long time as part of a rare earth oxide mix to pigment ceramics. In its pure form, it is a white crystalline material and has three crystallographic forms, monoclinic, tetragonal and cubic. Monoclinic is the most naturally occurring form, while 'cubic zirconia' is rarely found in nature and is best known as a diamond simulant owing to a structural chemistry similar to cubic carbon and a high index of refraction. This is referred to as zircon by jewellers; however zircon is actually the mineral name for naturally occurring zirconium silicate.

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Zirconia ceramic was first introduced to the medical profession in 1969 in the field of orthopaedics as a proposed material for hip replacements.[1] Since then it has been described as 'ceramic steel'[2] and is widely used in both dentistry and medicine.[3] Owing to its impressive flexural and compressive strengths of 900–1200 MPa and 2000 MPa, respectively,[4] zirconia has developed into an efficient core material for all-ceramic restorations.

Many different methods of constructing an all-ceramic restoration have been developed, including sintering, cast glass and glass infusion. Contemporary methods include vacuum-pressing and milling via CAD/CAM methods. CAD/CAM zirconia restorations are now considered by many dentists to be the top of the range restorative treatment for a patient. However, despite the increase in size of the digital workflow, both the dentist and the technician must appreciate how to handle the materials appropriately.

Crystallographic structure

Pure ZrO_2 has a monoclinic crystal structure at room temperature which transitions to tetragonal and cubic at increased temperatures. It transforms into a tetragonal phase between 980°C and 1173°C and moves to cubic above 2370°C. A volume expansion of approximately 4.5%[5] occurs on cooling from the tetragonal to monoclinic phase. This transformation induces very large stresses and will cause pure ZrO_2 to crack upon cooling from high temperatures. Several different oxides can be added to zirconia to stabilize the tetragonal and/or cubic phases; magnesium oxide (MgO), yttrium oxide, (Y_2O_3), calcium oxide (CaO), and cerium (III) oxide (Ce_2O_3) allow these phases to remain at room temperature without catastrophic crack propagation.[2,4,5] Despite more difficult sintering, zirconia stabilized with yttria has better mechanical properties than other combinations.[1,2]

The addition of stabilizing oxides results in a multiphase material known as partially stabilized zirconia (PSZ). A paper in *Nature*, aptly named 'Ceramic Steel?' was the first to record how a phase shift from tetragonal to monoclinic can result in improved mechanical strength and toughness of zirconia.[2] If sufficient quantities of the metastable tetragonal phase are

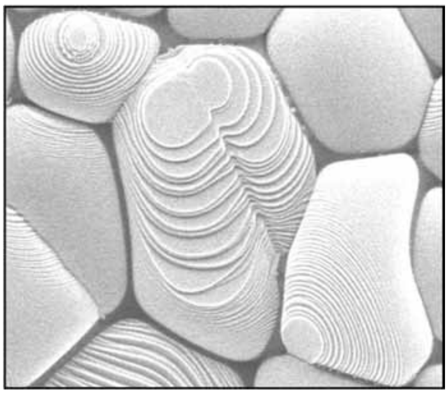
Figure 1. This SEM picture demonstrates grains of zirconia which have bulged in size as a result of transformation toughening (courtesy of 3M ESPE).

present, then an applied stress, magnified by the stress concentration at a crack tip, causes the tetragonal phase to convert to monoclinic. This phase transformation can then put the crack into compression, retarding its growth and enhancing the fracture toughness of the material. This mechanism, known as transformation toughening, significantly extends the reliability and lifetime of products made with stabilized zirconia compared with other ceramics (Figure 1).

Ageing of zirconia

The ageing of zirconia, known as low temperature degradation (LTD) has been studied extensively.[3,5–8] It is exacerbated by water, water vapour and increased temperatures.[8] Ageing is associated with surface roughening and microcracking of the material in which phase changes from tetragonal to monoclinic occur. The initiation and progression of ageing are influenced by many factors. Aside from environmental factors, grain size, phase assemblage, density and concentration of stabilizing agent, all play a role.[6,8]

Larger grain sizes are less stable and more susceptible to ageing. It has been shown that grain size can be controlled by sintering methods; higher sintering temperatures and longer sintering times lead to larger grains.[9] Critical grain size increases with increasing concentration of stabilizing agent, resulting in a greater resistance to ageing, ie grains no longer need to be so small to resist ageing. This happens as a result of cubic content increasing at the expense of the metastable tetragonal phase. However, this has resultant detrimental effects on the properties of the ceramic. Most studies concerning ageing have been conducted on yttria stabilized zirconia. However, magnesium oxide stabilized zirconia shows a similar susceptibility to hydrothermal ageing. Calcium oxide and cerium (III) oxide, on the other hand, do undergo phase changes, but at a slower rate than yttria. Should CeO or CaO be of a relatively high concentration, the material becomes significantly resistant to ageing.[8]

It has been demonstrated that deep scratches can be introduced into the ceramic during machining or polishing. These scratches are areas of monoclinic transformation that grow in height and diameter with time, eventually coalescing[6] and theoretically increasing the likelihood of cracking.

Annealing at 900 °C for one hour has been shown to induce reverse transformation.[10] This also results in a relaxation of surface stresses and subsequent decrease in strength, but will also act to increase ageing resistance.[5] This may be accomplished during the firing of veneering ceramic on to a zirconia coping. Another method shown to combat LTD is coating the zirconia, thus preventing its attack by solvents and protecting the weak surface flaws. It is assumed that veneering ceramic functions in this way.

Despite the perceived need to cover zirconia restorations to prevent ageing, a recent communication described making axial and occlusal surfaces of unveneered zirconia ceramic.[11] This option is attractive as it allows for a more conservative tooth preparation on the palatal and lingual aspects of the teeth where the width of the finish line could be reduced from 1.3 mm to 0.8 mm; however, these recommendations have yet to be reported in an *in vivo* trial.

The literature in this area is extensive and is well covered in a recent review article by Lughi and Sergo.[12]

Formulations

One of the most commonly used zirconia formulations is stabilized with yttria in the form of 3Y-TZP (3**Y**ttria – **t**etragonal stabilized **z**irconia **p**olycrystals). This particular formulation is used in 3M ESPE's LAVA® and Ivoclar Vivadent's E-max ZirCAD®. Zirconia toughened alumina ZTA is another way in which the advantageous properties of zirconia can be used for dental restorations. In-Ceram® (Vita) ZTA uses 12Ce-TZP to toughen its core at a volume of approximately 33%. It is manufactured through soft machining or slip-casting. Unfortunately, however, ZTA shows porosity of between 8 and 11%, which adversely affects the mechanical properties of the ceramic.[5] Partially stabilized zirconia (Mg-PSZ) is also currently marketed for dental purposes as Denzir-M® (Dentronic AB). It has generally been unsuccessful owing to large grain sizes, porosity and unfavourable wear characteristics.[4] It also requires a high sintering temperature and must be controlled precisely.[4]

Tooth preparation and clinical considerations

Zirconia may be used to construct copings and frameworks for full coverage single crowns and fixed partial dentures (FPD). A veneering ceramic is then layered and sintered on to this surface. These restorations require similar preparation to conventional porcelain fused to metal crowns (PFM).[1] The preparation follows principles which were established for cast restorations in the early-to-mid twentieth century. Despite closely following these principles, preparations for zirconia vary from cast restorations in one important respect, preparation depth.

Porcelain fused to metal restorations can be produced with a palatal chamfer of 0.5 mm thickness which allows adequate strength and a margin constructed in metal. However, zirconia restorations cannot have such conservative preparations and currently must be veneered with porcelain to protect the coping. This results in a relatively constant preparation depth palatally and labially. The minimum labial and palatal preparation depth for an anterior zirconia restoration is 1.3 mm, which is far from conservative.

Marginal configuration

During tooth preparation, a dentist must select the marginal design which results in the best or most predictable outcomes for a patient. This is influenced


Figure 2. Marginal fit (courtesy of 3M ESPE).


Figure 3. LAVA chairside intra-oral scanner (courtesy of 3M ESPE).

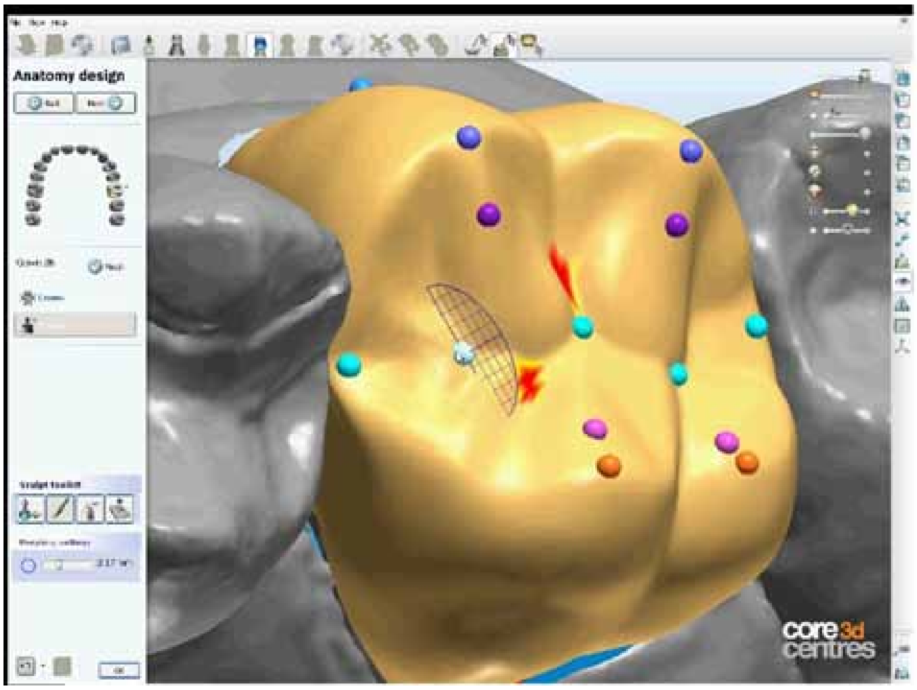

Figure 4. Design software is used to design the full contour to a customized shape such that appropriate cut-back can be done to generate the coping design (courtesy of DTS, Glasgow).

by the remaining tooth structure, aesthetic requirements and material choice for the restoration. Traditional all-ceramic porcelain jacket crowns required a circumferential shoulder preparation to produce marginal strength and easier manufacture. With cast alloy restorations, there is a greater flexibility and the dentist can afford to be more conservative.

Marginal opening of zirconia crowns has been assessed and it was found that, with cementation, a knife edge preparation resulted in the least amount of marginal opening.[13] However, the authors discuss the disadvantages of a knife edge preparation for a milled ceramic and the difficulties it produces in manufacture. For clinical use, the optimal marginal configuration is a shoulder or heavy chamfer. Figure 2 demonstrates that an excellent marginal fit is possible.

CADCAM impressioning

Manufacture of zirconia frameworks is via a CAD/CAM process. The data for the design of the framework therefore must be digitized at some stage in the workflow. This can take place at the chairside using an intra-oral chairside scanner (LAVA COS® 3M ESPE, CEREC Connect® Sirona) (Figure 3). Digitization at this stage is exciting and shows promise for the future but can be costly to set up and has a learning curve which may not easily fit into the busy life of the general dental practitioner.

Alternatively, a conventional elastomeric impression can be made and scanned, either in the laboratory or in the dental surgery (3Shape®). Finally, casting the impression in type IV dental stone and scanning of the model is also an appropriate method (LAVA Scan ST®, 3M ESPE). Whichever method is used, once the die is digitized, the technician/dentist can begin design of the framework.

Design of the restoration

CAD/CAM techniques used in the fabrication of zirconia copings and frameworks allow the technicians complete flexibility. With a 'virtual wax knife' the technician can cut-back a digitally generated full contour design, allowing anticipation of the final restoration contour (Figure 4).

Coping design

The design of metal-ceramic copings has been well established for many years.[14] Despite a lack of studies, some authors have commented on the need for porcelain fused to metal (PFM) coping design rules to be followed when using zirconia.[15] Greater tensile stresses have been shown to exist in ceramic copings which do not adequately support the overlying porcelain[16] (Figure 5).

Comparative studies have been conducted between all-ceramic and metal-ceramic crowns on implant abutments to assess geometric requirements. Two different framework designs with two different incisal thicknesses of veneering porcelain were

Figure 5. These zirconia copings will clearly not support the overlying porcelain.

	Zirconia	Slip cast glass infused zirconia	Lithium disilicate
3-unit bridge	2.5 mm	4.1 mm	4.9 mm
4-unit bridge	3 mm	4.9 mm	5.9 mm
5-unit bridge	3.5 mm	5.7 mm	6.9 mm

Table 1. Minimum connector diameter for all-ceramic bridges.[16]

a
b
c

Figure 6. (a–c) Two central incisors restored with zirconia crowns. Note the different axial heights of the preparations but the identical heights of the copings, providing support for the ceramic. Also note the excellent aesthetic outcome of this case, despite the post and core and discoloured root of UL1. The replication of the hypomineralization and surface characteristics were achieved with the use of a feldspathic veneering ceramic.

used for each alumina all-ceramic and high noble metal ceramic crown systems with identically-shaped crowns. Thermocycling and unidirectional loading were used to fatigue the specimens. Interestingly, geometry was a significant factor for PFMs but not for all-ceramic crowns.[17] Thickness of the ceramic coping, on the other hand, has a significant influence on the resulting stresses in the coping and veneering porcelain of an axially loaded crown by being inversely proportional.[18]

It would seem practical, based on the available evidence, to recommend that basic principles of coping design established for the PFM crown are applied to zirconia copings. Therefore, the veneering ceramic should be adequately supported at all times (Figure 6 a–c).

Framework design for fixed prostheses

The minimum connector diameters for 3-, 4- and 5-unit fixed partial dentures constructed for different ceramics have been calculated.[19] These are summarized in Table 1. This clearly demonstrates the advantages of zirconia over other high strength ceramics. In a study assessing connector design,[20] three materials were tested, heat-pressed lithium disilicate glass ceramic, milled lithium disilicate glass and milled yttrium-stabilized tetragonal zirconia polycrystals. Two connector designs, round and sharp with similar diameters, were studied. Higher maximum failure loads were found for the round connector design when compared with the sharp design, with zirconia being highest. The authors also demonstrated that, although connector design can be changed to improve framework fracture toughness, the initial fracture load at which veneering porcelain fractured did not show significant differences between the different designs. However, other authors have questioned this and have recommended a connector diameter of 4 mm inclusive of veneering ceramic.[21] A connector diameter of 4 mm is large and would require crown height of some 6 or more millimetres to allow access for plaque control procedures. This is not often found in posterior teeth, thus making the ideal dimensions of a connector difficult to deliver in all clinical situations.

Manufacture of the restoration

Once the zirconia restoration has been designed, the data must be sent to the milling machine for fabrication. 3Y-TZP dental restorations are constructed in one of two ways: soft machining of pre-sintered blanks in their green state, followed by final sintering at high temperature or hard machining of fully sintered blocks. The first has the disadvantage of approximately 20% shrinkage during the final sintering process, which must be compensated for during milling (Figure 7). However, the latter approach is not only more costly in terms of milling machinery owing to the hardness of the fully sintered block, but the copings contain a far larger monoclinic concentration upon completion. Despite giving the ability to mill to a 1:1 ratio, this method leads to surface microcracking and a decreased resistance to LTD.

Handling of the restoration

Conflicting evidence has been published on the post-sintering treatment of zirconia ceramic. Manufacturers recommend that minimal grinding, polishing or sandblasting be carried out, despite some systems requiring a degree of grinding to fit the die. Deville *et al*[6] reported that rough polishing can produce a compressive surface stress layer, which is beneficial for ageing resistance. However, Kosmac *et al* revealed that surface grinding and sandblasting have differing effects on the strength of Y-TZP ceramics.[10] While grinding acted to lower the mean strength and Weibull modulus, sandblasting caused strengthening of the ceramic, but at the expense of somewhat lower reliability. By way of further contrast, other studies have shown that sandblasting has detrimental long-term effects.[22–24]

Following hard machining, a number of surface scratches and transformed areas will be present. These

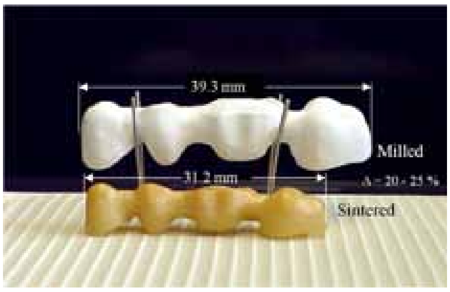

Figure 7. Each block of zirconia is accurately measured to determine its exact shrinkage. The milling software then compensates for this when milling in the green state (courtesy of 3M ESPE).

Figure 8. Zirconia copings have an obvious aesthetic advantage.

a

b

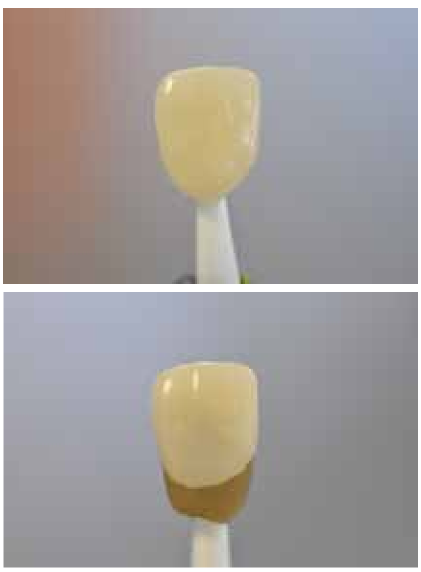

Figure 9. **(a, b)** Shade stumps can be used by the technician and are an important communication tool.

promote residual stresses, leading to greater susceptibility to LTD.[6] Smooth polishing, as opposed to rough grinding, was shown in this study to cause a preferential phase transformation around these scratches, which was beneficial.

Figure 10. Immersion of the framework to add chroma (courtesy of 3M ESPE).

Figure 11. Different colours of the zirconia framework (courtesy of 3M ESPE).

In summary, the sintered zirconia framework should be lightly ground with a fine diamond (≤30μm grit) prior to application of the veneering ceramic. Intense grinding should be avoided. Sandblasting of the zirconia should be avoided unless a digital veneering system is being used (see Veneering Material section). With respect to the fitting surface of the restoration, no grinding or sandblasting should be carried out unless the sandblasting is a part of tribochemical silicatization to improve bond strengths to resin cements (see Bonding and Cementation section).

Colouring of the framework

Metal-free all-ceramic restorations have been shown to influence soft tissue colour less than those made of porcelain fused to metal.[1] The reason for this and the consequent aesthetic advantage of zirconia over metal is plain to see when examining copings visually (Figure 8). In comparison with other all ceramic systems, zirconia is by far the most opaque.[25] Clinically, this opacity allows the relatively thin copings to be used to mask darkened tooth structure or metal cores. Despite this positive aspect of zirconia, a clinician should still be aware of, and communicate shade stumps to, his technician so that shade changes required at the chairside are kept to a minimum (Figure 9). However, should the white opacity of the material impart too high a value to the colour of the restoration, the core's chroma can be altered. Prior to sintering, the porous zirconia is immersed in a colouring liquid which penetrates the coping (Figure 10).

Following soft machining, copings can be coloured from a choice of eight different solutions of cerium, bismuth and iron (Figure 11). The concentration of the solution, as well as the final sintering temperature, influence the deposition of surface colour. This has no effect on the properties or microstructure of the ceramic.[5] However, it was discovered by SEM analysis that surface colourings crystallize during sintering and seem to lead to significantly poorer bond strengths of the veneering ceramic.[26]

Figure 12. A full contour zirconia restoration (courtesy of DTS, Glasgow).

Veneering

Material

A variety of methods is available when choosing how to veneer the coping:
- No veneering, ie full contour all zirconia restoration (Figure 12);
- Conventional layering with appropriate feldspathic porcelain;
- Pressing a glass ceramic on to the coping;
- Using CAD/CAM methods to mill the glass ceramic veneer which is then fused to the coping, as in the Digital Veneering System (DVS®) from 3M ESPE.

The material conventionally used for veneering zirconia cores is a feldspathic fluorosilicate porcelain which, following the application of a special liner, is incrementally layered and then sintered on to the coping

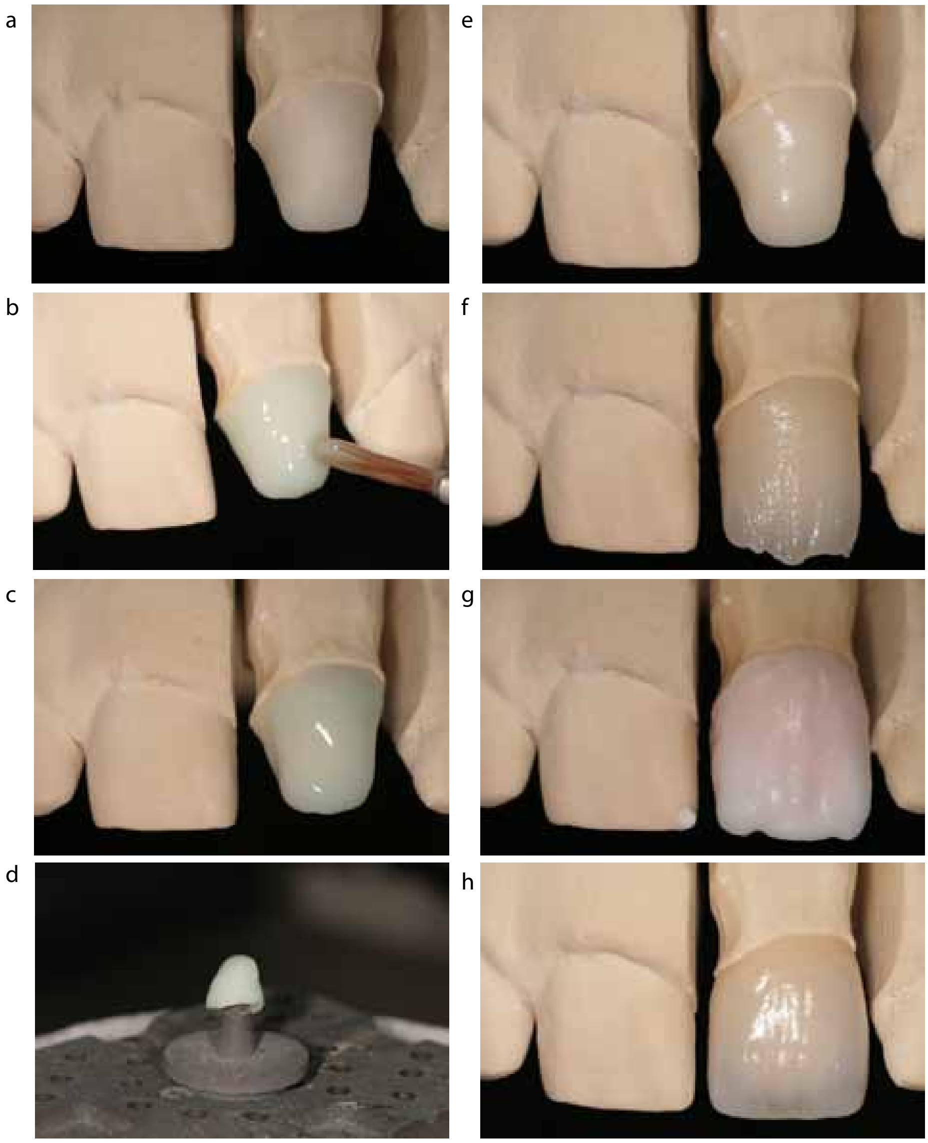

Figure 13. **(a–h)** Conventional layering of a zirconia coping showing application of liner followed by build up with dentine and enamel shades (courtesy of Wayne Fleck, Vision Dental Laboratory).

(Figure 13 a–h).

Other methods can be used:

- A fluorosilicate or a lithium disilicate veneer can be pressed over the zirconia. The latter has been shown to have significantly more favourable fracture toughness in comparison with the pressing or layering of any other type of ceramic.[27] Pressing the ceramic does not provide the opportunity for the technician to generate individualized aesthetics. However, the ceramic can be pressed and then, using a cut-back technique, subsequently veneered with feldspathic porcelain.[28] This double veneer does not alter the bond to the zirconia yet allows for improved aesthetics.
- A one piece milled veneer can be constructed using CAD/CAM techniques. The Lava™ Digital Veneering System uses the full contour feature of the design software so that the glass ceramic porcelain and the zirconia coping are both milled to fit together perfectly. The veneer and coping are subsequently bonded to each other using a low-fusing glass ceramic (Lava DVS Fusion Porcelain). The restoration can also be characterized with the system's stains, shades and glaze.

Firing procedure

The veneering process involves a firing procedure at high temperatures at least once and usually between two to five times. Technicians should also be aware of methods used in the handling of veneering ceramic as they can increase or decrease the susceptibility to crack formation, eg multiple firings causing increased numbers of high expansion leucite crystals and an increased tendency to cracks.

In a study assessing the influence of repeated firings on a zirconia core, both the flexural strength and microhardness were reduced after the first firing. However, after subsequent firings they were not significantly different from the values achieved after just one firing and were not detrimental to fracture patterns, dimensions or surface roughness.[29] It should be noted that firings should be carried out in a calibrated furnace, according to the manufacturer's recommendations, to limit large grain formation and produce a more homogeneous and smoother surface.

Bond of veneer to zirconia core

The bond between the veneering ceramic and zirconia core is extremely important as it will determine the overall strength of the restoration. The core is significantly stronger than the veneer and therefore can only impart support to the latter if a good bond exists.[30] Studies have shown that zirconia crowns have greater stress at the interface between core and porcelain than alumina crowns and fail earlier in loading tests.[16] Owing to these stresses, and the large differences in fracture toughness, veneer delamination fractures are likely to occur unless a good bond between the two components is achieved.[31]

Core liner

Prior to the application of veneering ceramic, some zirconia systems advise the application of a liner material. This is advocated to improve both the bond of the veneer to the core and the aesthetics of the core. Studies of this liner have shown that it can improve the bond strength of some veneering ceramics but can act as a weak point in others. A liner material should only be used with layered veneers, but not in combination with pressed veneers as it will result in weakening of the

	Survival of Conventional Fixed Partial Denture			Survival of Cantilever Fixed Partial Denture	Survival of Single Crowns		Complication Rates for FPDs
	MCC	AC	RRB		MCC	AC	
Tooth Supported	93.8%–94.4% (5yr); 89.2% (10yr); 85% (15yr)	88.6% (5yr); 97.8% (zirconia)	87.7% (5yr); 65% (10yr)	91.4% (5yr); 80.3% (10yr)	95.6% (5yr);	93.3% (5yr); 96.4% Densely sintered alumina; 95.4% Empress; 94.5% InCeram; 87.5% glass-ceramic	15.7% (5yr)
Implant Supported (96.8% implant survival at 5 years)	95.2% (5yr); 86.7% (10yr)			68.6%–94.3% (5yr); 88.9% (10yr)	94.5%–95.4% (5yr); 89.4% (10yr)	91.2%	38.7% (5yr)
Combined Tooth-Implant Supported	95.5% (5yr); 77.8% (10yr)			Not applicable	Not applicable		20.6% (5yr)

Table 2. Success rates for fixed restorations.

microtensile bond strength between the two.[32] This data, however, is at odds with the recommendations of some manufacturers, demonstrating that application of liner prior to pressing is a controversial issue.

Bonding and cementation of the restoration

Bonding to the fitting surface of a zirconia restoration would be invaluable as it would allow adhesive prosthodontic techniques to be used, potentially conserving tooth structure, ie onlays as opposed to full coverage crowns.[33] However, zirconia has a relatively inert surface and lacks silica which is required for bonding to the glass ceramics.

The use of airborne particle abrasion and a resin composite containing 10-methacryloyloxydecyl dihydrogen phosphate (MDP) [Panavia® F 2.0] is currently recommended.[34] A similar protocol has been advocated by other authors based on *in vitro* comparative studies of microtensile bond strength.[35] Abrading the surface of the zirconia through sandblasting or tribochemical coating (*Rocatec,* 3M ESPE) roughens the surface to increase the surface area for bonding. The phosphate ester group of MDP acts as an acidic monomer which chemically bonds to zirconia and other ceramics. This bond occurs with other metal oxides and it is assumed that it bonds to zirconia by the same method.

A form of tribochemical silica coating is available from 3M ESPE (CoJet®). This coats the surface of the ceramic in silica, thus allowing the use of a conventional silanating agent. In one study,[36] this method was controlled for and tested with and without MDP/silane. Results showed that the CoJet® system increased significantly the shear bond strength between zirconium-oxide ceramic and a resin luting agent. Application of an MDP-containing bonding/ silane mixture led to a further increase in bond strength. Bond strengths to zirconia can reach up to 22.9 +/- 3.1 MPa following ageing, whereas those commonly achieved with noble alloys are over 44 MPa following thermocycling.[37]

The current recommendations are clear. If there is adequate retention and resistance form of the tooth preparation, self-adhesive resin cement is recommended with light sandblasting of the zirconia fitting surface. If, however, resistance and retention form are poor, achieving the best bond becomes more critical. The zirconia fitting surface must undergo tribochemical silicatization, followed by application of an acidic primer, such as MDP, and finally a silane coupling agent. Resin cement can then be used in conjunction with appropriate bonding to tooth structure.

Reliable and improved bonding of zirconia ceramic would clearly be an advantage, but as yet there are no studies

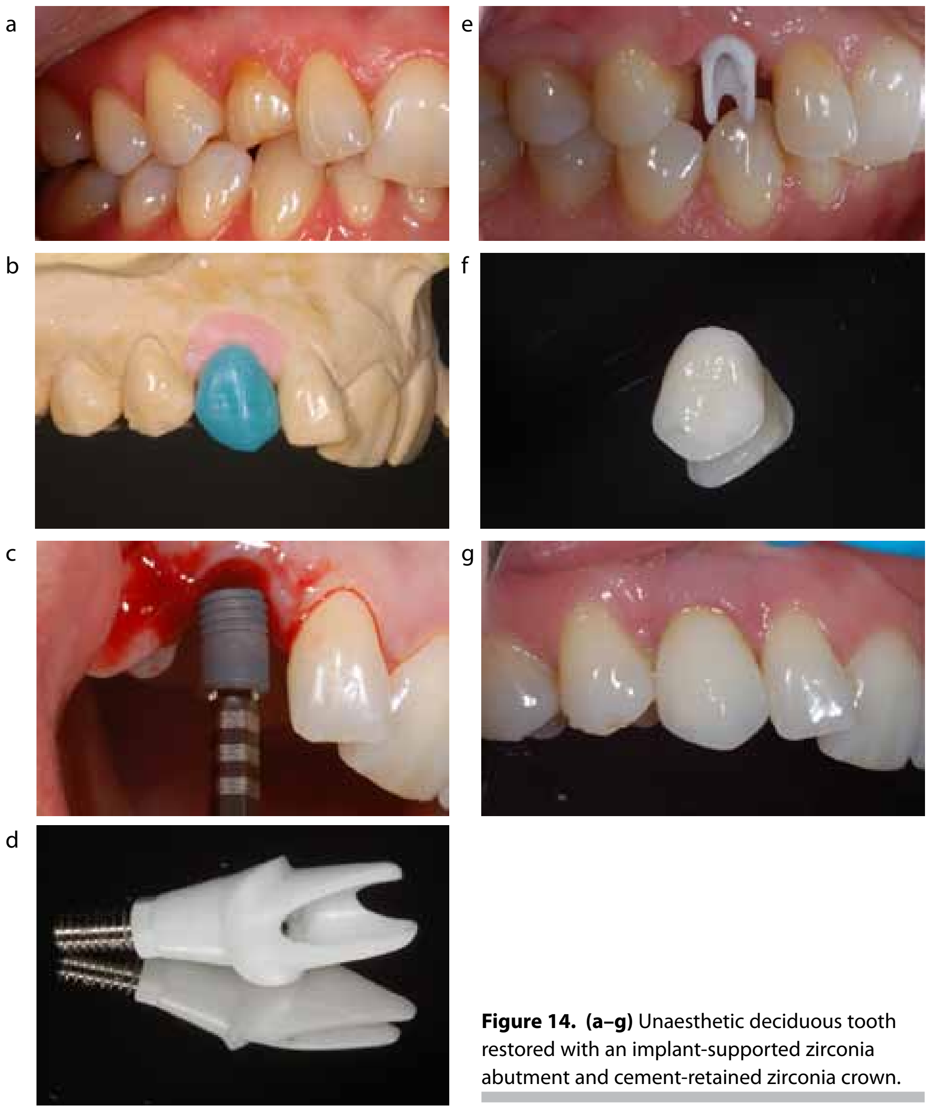

Figure 14. (a–g) Unaesthetic deciduous tooth restored with an implant-supported zirconia abutment and cement-retained zirconia crown.

assessing the effects of these surface alterations on the zirconia's resistance to LTD. The clinical implications of this could be significant. Despite shortcomings in the resin bonding capability of zirconia, both manufacturers and clinicians continue to publish cases of resin-retained bridges constructed from a zirconia framework,[38] albeit with limited success.[39]

Failure of zirconia restorations

A previously common cause of technical failure of all-ceramic restorations was bulk fracture. However this is relatively uncommon in zirconia prostheses. Review papers comment consistently that the most common cause of failure in zirconia restorations is veneer chipping or cracking.[5,40–43] Veneer chipping has been documented at 13% at only 3 years.[44] Many factors have been postulated as the cause of this chipping, such as:

- Flaws in the veneering ceramic;
- Differences in coefficients of thermal expansion;
- Firing shrinkage of ceramic;
- Poor wetting of the core by the veneer;
- Thickness ratios or framework design.

However, specific veneering ceramics have been designed in order to combat these issues.

A number of research groups has conducted systematic reviews and meta-analyses looking at the longevity of fixed prosthodontics.[40,42, 43,45–50] The results are outlined in Table 2. For restorations involving teeth, the most common complications were biological, such as secondary caries, 21.7%[44] and loss of pulp vitality.[42] This was similar for both metal-ceramic and all-ceramic fixed partial dentures. The technical complications told a different story, as framework or veneering ceramic fracture was significantly more common in all-ceramic restorations.[47] Although ceramic chipping of metal-ceramic fixed partial dentures was more common when supported by implants,[51] there are no studies which examine all-ceramic fixed partial dentures on implants, but it would seem reasonable to assume that these would have the highest rate of ceramic chipping. Framework fracture is uncommon in zirconia restorations.

The most frequent technical complications for all restorations were fractures of the veneer material, abutment or screw loosening and loss of retention.[42] The frequencies of ceramic fractures (framework and veneer) were significantly ($P < 0.0001$) higher for all-ceramic FPDs compared with metal-ceramic.[47] The fractures were mainly seen in the maxilla (75%), predominantly at the labial surface, and were associated with accidents, iatrogenic factors or surgical operations.[52] Stress distribution maps of 3-unit FPDs have demonstrated that tensile stresses accumulate adjacent to connectors on their lingual side, thus having direct relevance to the possible site of veneer fracture.[53]

Other and future uses in dentistry

Zirconia is currently being marketed heavily for use with dental implants. It has well researched use as an implant abutment, with obvious aesthetic advantages (Figure 14 a–g). It is also marketed as an integral component of newer implants, such as Straumann's Roxolid™. This alloy of zirconium and titanium takes advantage of excellent biocompatibility to increase bone-to-implant contact compared with pure titanium controls.[54] These may be the first steps towards a mainstream all zirconium dental implant. Such white implants are already marketed and clinical reports are available in the literature, however, they are still in their infancy compared with those made of titanium.

Summary

Zirconia restorations show great promise as the future for all ceramic restorations. They have demonstrated excellent biological, mechanical and aesthetic properties. However, it is evident from clinical studies that some challenges remain. Inferior bond strength to tooth structure in comparison with modern glass ceramics significantly limits their clinical versatility. Veneer chipping is also of concern; this may not catastrophically affect survival rates but is of significance when considering the success of these expensive restorations. Although contemporary research appears to be focused in these areas, it is essential that both clinician and technician treat the material properly so as to achieve best results.

Conclusions

The use of zirconia in dentistry is still in its relative infancy and it should be noted that more long-term clinical data are required to reinforce initial findings.

Sintering of the zirconia framework should be carried out in a calibrated furnace using the manufacturer's recommended temperatures and times to limit large grain formation.

Light grinding and polishing of zirconia copings is recommended as opposed to rough polishing and sandblasting.

Choice and handling of a veneer for the framework are important so as to limit failure of the restoration.

Although bonding to zirconia is not yet comparable with bonding to glass ceramics or noble metals, should bonding be desired, it is advised that the surface undergoes tribochemical silicatization followed by application of an MDP primer and silane. The restoration should be cemented with resin cement for best results.

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