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The Current Status of Materials for Posterior Composite Restorations: The Advent of Low Shrink

Abstract: Polymerization contraction, and the stresses associated with this, have presented problems with resin composite materials, particularly when used to restore cavities in posterior teeth. This paper summarizes the problems associated with polymerization contraction and examines methods used to overcome this, in particular, by the use of materials which have reduced percentage contraction when compared with traditional materials.

Clinical Relevance: Use of a material with reduced polymerization contraction should lead to simpler restoration placement.

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Since the ability to bond a restorative material to enamel was first described by Buonocore in 1955,[1] adhesion to tooth substance has become an integral part of restorative dentistry alongside the development of resin composite materials. These materials have become increasingly used worldwide,[2] principally because of patient concerns about the poor appearance of amalgam restorations and anxieties with respect to the use of a mercury-containing filling material. There is also evidence, from the early days of composite restorations in posterior teeth, that patients are partial to tooth-coloured restorations in their posterior teeth, and that, once they have received one such restoration, they will be unlikely to request a metallic restoration when a restoration is required.[3] There is also evidence, from Lynch and co-workers in 2006, of increasing teaching in dental schools on the use of tooth-coloured restorative materials, with the authors concluding 'that resin composite may soon equal or overtake amalgam as the material of choice when restoring posterior cavities in Irish and UK dental schools'.[4]

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Resin composite restorations and polymerization contraction stresses

The majority of conventional resin composite restorative materials shrink up to 3% on polymerization, resulting in stresses at the (bonded) restoration margin, or within the restorative material itself.[5] The result of these stresses may be:[5]

- Internal microcracks within the material bulk;
- Separation of the restoration from the cavity wall, with resultant post-operative leakage and sensitivity;
- Enamel microcracks, with a resultant white line around the restoration, although these may also be distant from the restoration. In the worst case, complete fracture of enamel can occur;
- Deformation of tooth, also leading to pain post-operatively, generally when the patient bites on a cusp.

The magnitude of the stresses depends on a number of factors, including:

- Volumetric shrinkage;
- The modulus of elasticity of the material;
- Its coefficient of thermal expansion;
- The bonding of the filler particles to the resin and their nature;
- Cure speed;
- The configuration of the cavity into which the restoration is placed; and
- Compliance of the remaining tooth structure.

In this respect, it has recently been demonstrated that it is in larger, rather than smaller, cavities that the effect of the so-called configuration factor is most relevant.[6]

A variety of methods have been utilized to reduce polymerization contraction stresses. These may be classified into:

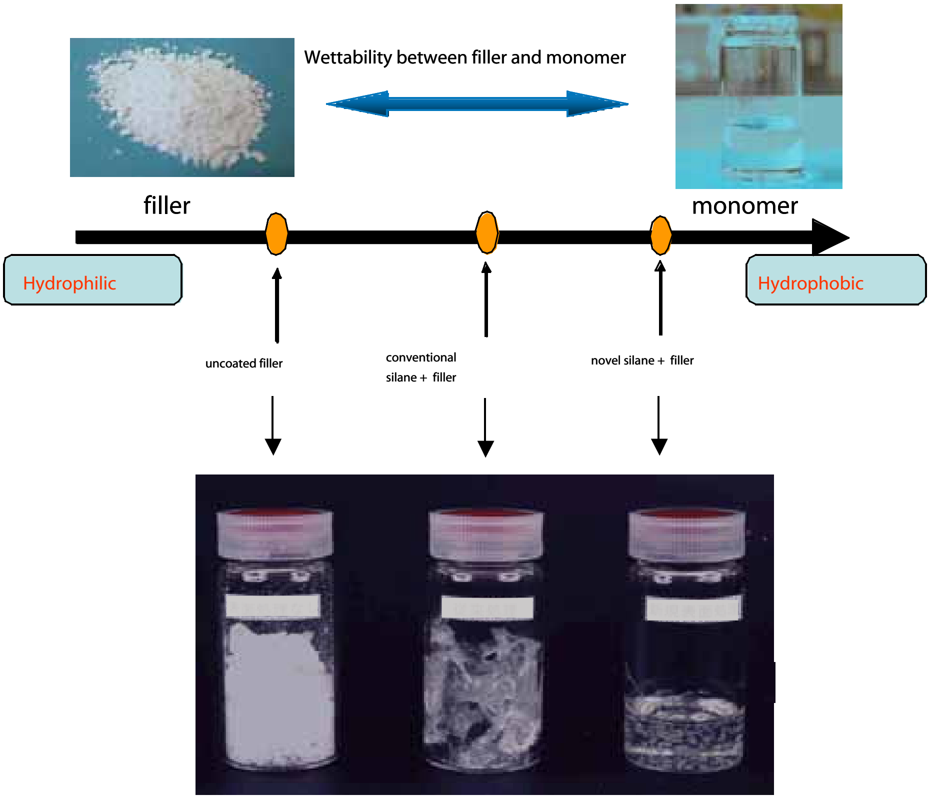

Figure 1. The use of a silane agent with increased hydrophobicity in *Clearfil Majesty Posterior* increases the wettability between filler particles and resin matrix which allows for a high volume fraction of filler within the composite. (Images courtesy of S Yamaguchi, Kuraray Dental.)

■ Urethane dimethacrylate (UDMA)
■ Triethyleneglycol dimethacrylate (TEGDMA)
■ Di- and trimethacrylate resins
■ Carboxylic acid modified dimethacrylate resin
■ Butylated hydroxy toluene (BHT)
■ UV stabilizer
■ Camphorquinone
■ Ethyl-4-dimethylamino benzoate
■ Silanated strontium aluminum sodium fluoride phosphate silicate glass

Table 1. Composition of *QuiXfil*.

- Clinical technique factors; and
- Material factors.

Clinical techniques employed to reduce the effect of polymerization contraction stresses

A number of clinical techniques have been suggested to reduce or overcome the effect of polymerization contraction stresses. The following techniques have been advocated, but in each case little evidence exists to suggest any beneficial effect in reducing shrinkage stress and eliminating marginal gaps. Moreover, the clinical relevance of *in vitro* microleakage tests, which are commonly used as markers of success for many studies investigating the following techniques, is not fully understood:

- Incremental placement, with one increment touching only one wall of the cavity and limiting the size of the increments;
- Ramped curing, in which the curing light does not reach its maximum intensity for up to 20 seconds;
- Pulse activation, in which the resin composite material is cured for 5 seconds and then left for up to 5 minutes;[7]
- Use of macro-fillers to reduce resin volume: however, this has not been shown to improve clinical effectiveness;[8]
- Placement of a flowable composite base layer which has been shown to reduce microleakage at the gingival margin in Class II cavities in a number of *in vitro* experiments;[9,10]
- Use of a chemically cured composite or glass ionomer base.

It could be considered that some or all of these additional stages lead to increased technique sensitivity during placement of resin composite restorations and, indeed, that these stages, which are designed to reduce polymerization contraction stress, could be a source of operator stress!

Material factors employed to reduce the effect of polymerization contraction stresses

These include the following:

- Increasing the filler loading of the material, with subsequent reduced volume of resin composite which may shrink; and
- Use of resins with reduced polymerization shrinkage. Ideally, its net volumetric shrinkage should be nil or capable of being balanced by the uptake of a similar %volume of moisture, and the resultant expansion in the mouth.

Materials with increased filler loading

Since the first use of polymethylmethacrylate (PMMA) as a direct restorative and subsequent development of dimethacrylate resins (bisGMA) by Bowen in the 1950s, one method of reducing polymerization shrinkage has been manipulation and improvement of filler particle morphology, which has led to improved hybrid, micro-hybrid and now so-called 'nano-hybrid' formulations.

Most manufacturers produce resin composites with two or more filler types and a range of filler sizes in order to improve particle size distribution and make higher filler loadings possible.

QuiXfil (Dentsply) (Table 1) is an example of a material in which the manufacturers have increased filler loading with the aim of reducing the overall polymerization contraction of the material. It contains filler particles of two different sizes and a defined particle size distribution to provide a high filler load (86% by mass and 66% by volume).[11] The manufacturers claim that *QuiXfil*, when cured, shrinks 33% less compared with similar restorative

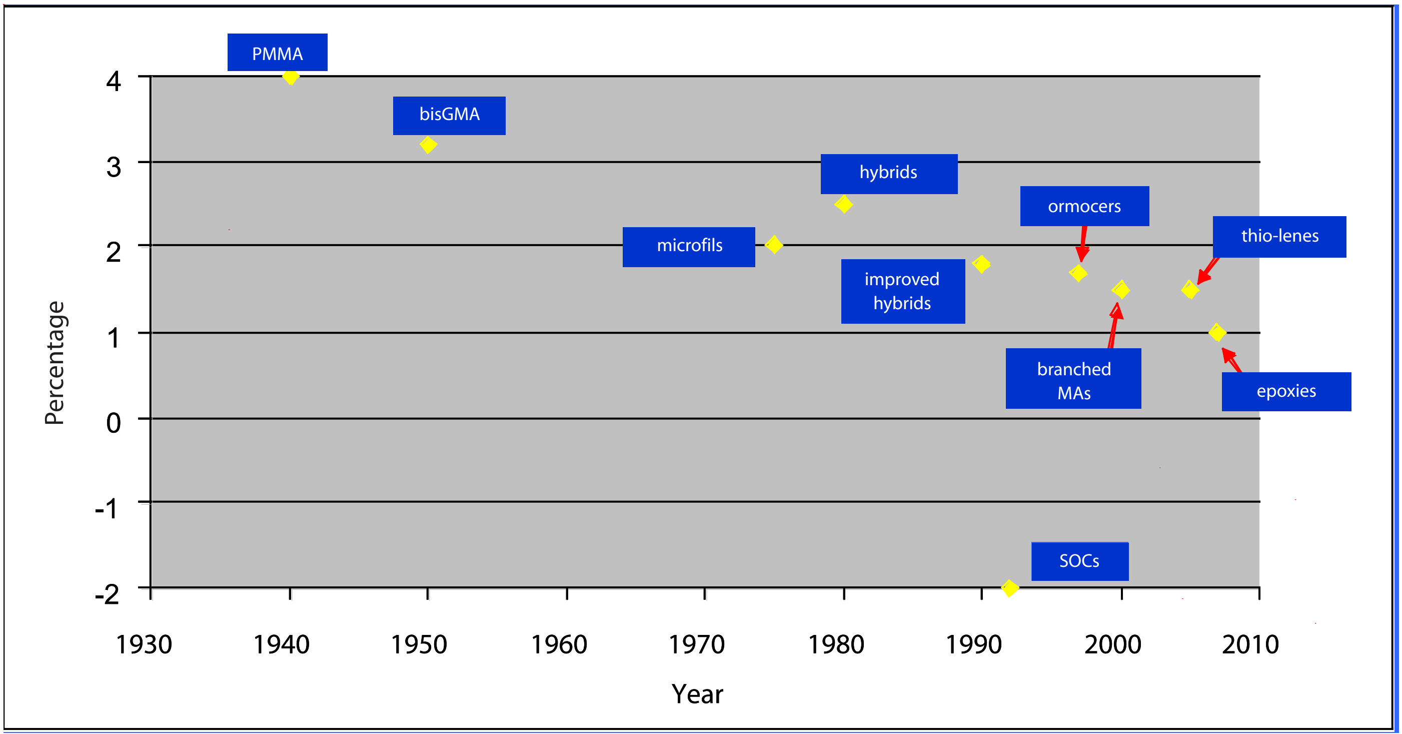

Figure 2. The decrease in total volumetric shrinkage over time of resins and resin composite systems.

materials, which may reduce shrinkage stress at the margin, to ensure better marginal integrity for long-term clinical success, and reduces the post-operative sensitivity of patients. However, a reduction in shrinkage stress has not been confirmed by independent workers, and it may be that the increased filler loading of the material leads to a higher modulus of elasticity, and that this will, to some degree, act against the higher filler loading as a means of stress reduction. *QuiXfil* is available in one universal shade. The principal clinical contra-indications are Class I and II cavities, the width of which exceeds 2/3 of the intercuspal distance.

Recently, one manufacturer has produced a material with filler loading of 82% by volume and 92% by weight (*Clearfil Majesty Posterior*, Kuraray, Japan).[12] The high filler loading of this material type has been realized using an innovative development in filler silanization (required to provide a bond between the inorganic filler and organic resin matrix). Here, a novel silane with increased hydrophobicity increases the affinity of the filler for the resin, allowing for an increased filler load without compromising viscosity for appropriate handling characteristics (Figure 1).

Although increasing the filler load of resin composites will reduce volumetric shrinkage, as the resin content is decreased the elastic modulus of the material will increase. Intuitively, both effects are counteractive for reducing polymerization shrinkage stress. Likewise, the production of so-called 'flowable' resin composites were designed, in part, to reduce shrinkage stress by using a lower modulus 'stress-absorbing' layer. However, the critical magnitude of stress required to create a gap at the tooth restoration interface is a complex multifactorial phenomenon which relies on many more factors rather than shrinkage and modulus alone.

It has been previously considered that commercial resin composites with lower volumetric shrinkage generally exhibit higher shrinkage stress, since materials with high filler loads exhibit increased elastic modulus[13] and an increased change in stiffness on cure. Consequently, low-shrinking materials do not necessarily provide lower contraction stress. However, the amount of contraction stress is also highly dependent upon compliance of the testing system *in vitro* (ie the load cell in shrinkage stress measurements) or remaining tooth structure *in vivo* (ie conformity of the tooth per unit stress). As the compliance approaches zero (a perfectly rigid construct), stress increases. For testing equipment which has a negative feedback mechanism to reduce or eliminate compliance, such as the aforementioned study by Kleverlaan and Feilzer,[13] the measured amount of contraction stress is governed by the elastic modulus of the material. However, for studies that use compliant testing systems such as Watts *et al*,[14] less shrinkage due to higher filler content resulted in less stress, despite higher elastic modulus of the material. This may explain, in part, why controversy exists for the use of flowable resin composites in reducing polymerization shrinkage stress and reducing marginal gaps. The clinical consequence of these findings is that, for cavity types with rigid (low compliant) surroundings (eg Class I restoration), a low modulus, flowable-type material would be beneficial. Conversely, if a prepared cavity were to exhibit higher degrees of compliance (eg a Class II MOD restoration, or larger cavities with less remaining tooth structure) then a material with lower volumetric shrinkage would favour stress reduction.

Resins with reduced polymerization shrinkage

Bisphenol glycidyl methacrylate (BisGMA) resin has been used as a resin in dental resin composite restoratives since its development and introduction by Bowen in 1958.[15] However, this is a viscous resin which would be unworkable as a dental restorative when filler particles are added and, accordingly, it is necessary to add a diluent resin to the material to allow the manufacture of a resin composite material which is readily handled by dental healthcare workers.[16] This diluent resin is, in many materials, triethylene glycol dimethacrylate (TEGDMA). Its polymerization contraction is *circa* 5%, thus increasing the overall polymerization contraction of the resin composite material to which it is added. Manufacturers have obviated the use of TEGDMA in materials introduced in the late 1990s by substituting BisGMA with less viscous resins, such as urethane dimethacrylate (UDMA) and bisphenol ethoxylated methacrylate (BisEMA), thereby reducing the polymerization contraction from 3% to 2%. The significant decrease in use of TEGDMA in commercial materials has played a role in reducing shrinkage stress and cuspal deflection of wide MOD cavities.[17] A similar reduction in cuspal movement was demonstrated when an Ormocer material (*Admira*: Voco, Cuxhaven, Germany) with a polymerizaton contraction of 2% was used.[18]

However, the resins used in the above materials are based upon methacrylate chemistry and it would appear impossible to reduce the polymerization shrinkage of these materials to much less than the values stated above because of the inherent nature of the resins and polymerization reaction involved. The use of alternative chemistries have been at the forefront of research and development for dental resin composites for many years. Figure 2 highlights some of the innovations of researchers and manufacturers over the last two decades. Researchers have investigated the use of spiro-orthocarbonate (SOC) resins which expand on polymerization,[19] however, less reactivity and decreased mechanical

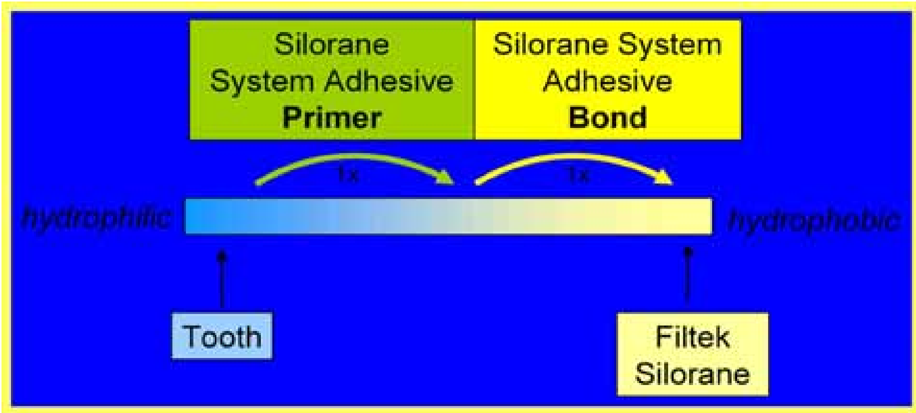

Figure 3. Diagrammatical representation of how a two-stage bonding process is needed to 'bridge the gap' between the hydrophilicity of the tooth and the hydrophobicity of the Silorane resin (Courtesy of 3M ESPE, Seefeld, Germany).

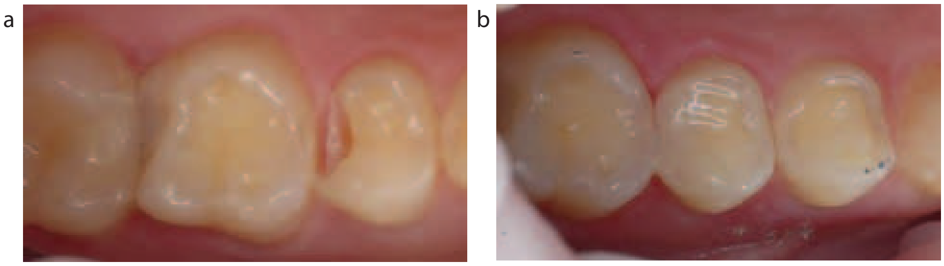

Figure 4. (a) Distal caries removed from UL second premolar tooth, resulting in a saucer-shaped cavity with little retention. **(b)** Cavity in (a) restored with Filtek Silorane™ (3M ESPE).

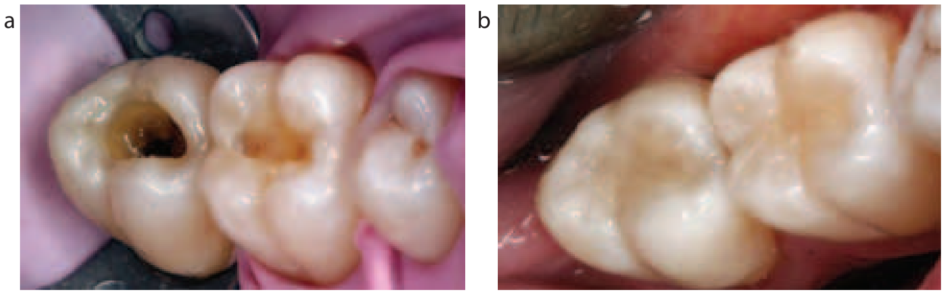

Figure 5. (a) Class I cavities in lower first and second molar teeth. **(b)** Cavities in (a) restored with Filtek Silorane™ (3M ESPE).

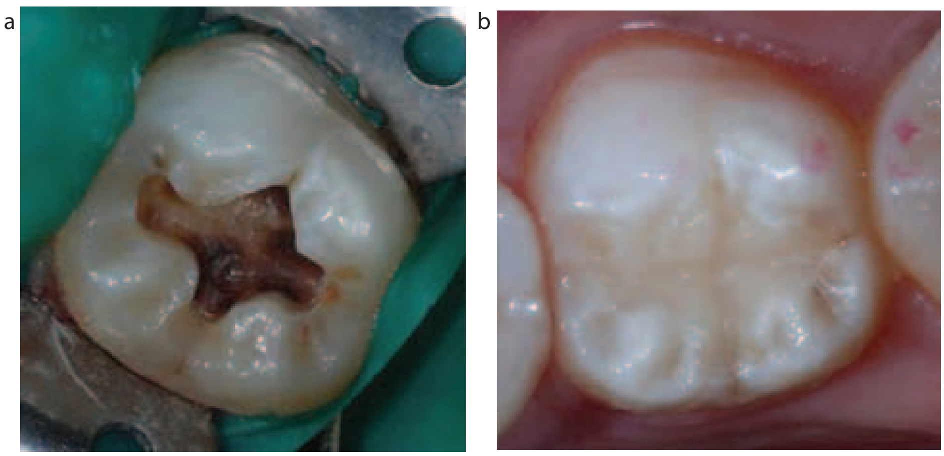

Figure 6. (a) Class I cavity. **(b)** Cavity in (a) restored with Filtek Silorane™ (3M ESPE).

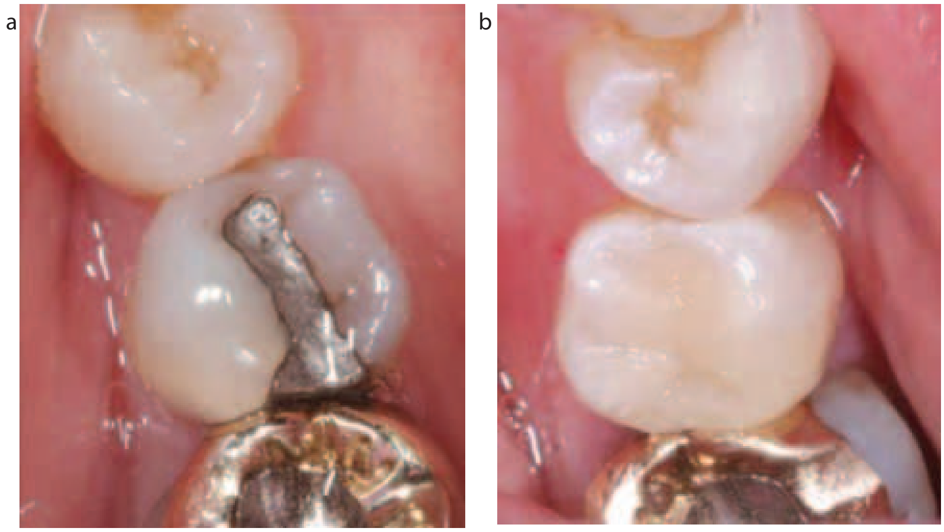

Figure 7. (a) Defective restoration in maxillary second premolar tooth. **(b)** Restoration in (a) replaced with Filtek Silorane™ (3M ESPE).

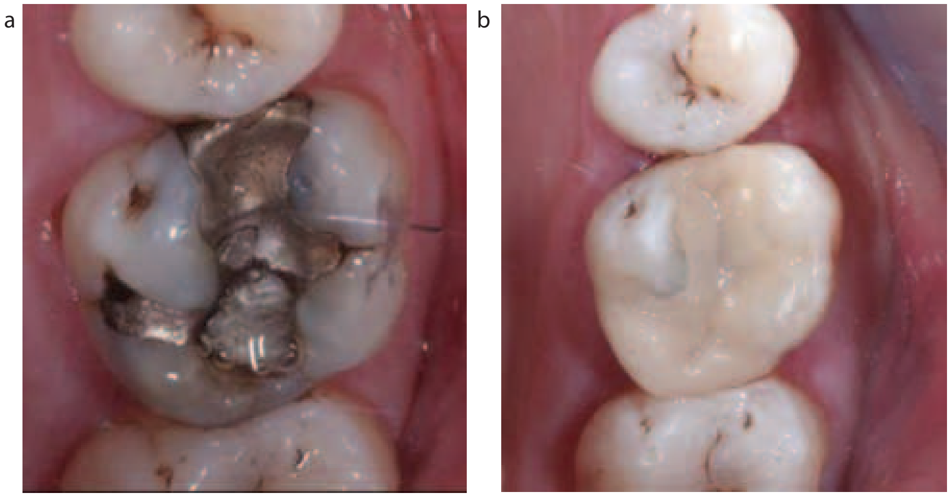

Figure 8. (a) Defective restoration in maxillary first molar tooth: distal caries also present. **(b)** Restoration in Filtek Silorane™ (3M ESPE).

properties have precluded their viability as a commercial material. Moreover, it might be argued that a net zero shrinkage or even expansion would be more detrimental than 1–3% shrinkage of methacrylates which allows for water uptake during service.

Existing bisGMA resins have been altered to include branched liquid-crystalline matrices which provide structural homogeneity and the possibility of producing decreased viscosities with similar molecular weight and decreasing shrinkage compared with bisGMA. Difficulties with filler incorporation and inferior strengths have prevented these resin types from commercial exploitation.[20]

The use of thio-lene resins may provide a suitable replacement for conventional resins and they have been the subject of modern resin research. The thio-lene chemistry offers a 'step-growth' rather than the 'chain-growth' curing characteristic associated with methacrylates. This has been reported to provide more control of the curing process and reduce polymerization shrinkage stress.[21]

Filtek Silorane™ (3M ESPE Dental Products, Seefeld, Germany) has recently been marketed and is based on an innovative resin matrix.[22] The epoxy-based resin contains an oxygen-containing ring molecule ('oxirane') which cures via a cationic ring-opening reaction rather than a linear chain reaction associated with conventional methacrylates and results in a volumetric shrinkage of *circa* 1%, which may reduce the deleterious effects of shrinkage stress at the tooth-restoration interface. In this respect, work by Watts has demonstrated substantially reduced polymerization shrinkage stress in comparison to other resin composite restorative materials.[23] The incorporation of a siloxane molecule (hence the term '**silo**(xane)(oxi)**rane'** was coined) has resulted in a material with comparable material properties,[24] increased hydrolytic stability,[25] reduced oxygen inhibition and improved ambient light stability compared with conventional materials.

Operative procedures

Filtek Silorane™ has its own dedicated bonding agent, because the hydrophobicity of the material makes it inappropriate for use with conventional methacrylate-based bonding agents. There are two stages in bonding:

- The application of a self-etch adhesive; and
- The application of a more hydrophobic resin.

These two materials are designed to 'bridge the gap' between the hydrophilic bonding resin and tooth and the hydrophobic resin in Silorane (Figure 3).

Clinical procedures employed for placement of restorations in Filtek Silorane™ are similar to those used for conventional materials.[26,27] Minimally invasive cavity designs should always be considered, although it is likely that many cavity preparations will be dictated by the outline of a previous restoration. Cavity outlines with minimal retention may also be employed (Figure 4), since the bond achieved at the cavity/restoration margins should not be stressed. The preparations, ideally, should have the following features:

- Rounded line and point angles;
- Resistance and retention form to be achieved in the usual way from remaining tooth tissues.

The tooth shade is selected using the Filtek Silorane™ shade guide, appropriate isolation obtained, and the restoration placed in accordance with the manufacturer's instructions in increments of a maximum depth of 2.5 mm, given that the product profile suggests a depth of cure of 2.5 mm.[22] In this respect, in contrast to 'traditional' resin composite materials, in which it has been advised that increments should touch only one cavity wall at a time,[27] increments in Silorane may be placed horizontally. It may be considered that the material is appropriate to a variety of cavity shapes and size s. (Figures 5, 6, 7 and 8).

Discussion

The use of a recently introduced material will necessarily be without the benefit of clinical trials since the 'evidence' that such trials produce takes time to accumulate. Clinicians may therefore commence use of a new material such as Filtek Silorane™ because they consider its benefits in terms of reduced polymerization contraction stress to outweigh the disadvantages of a paucity of research. Additional benefits include the simplified placement procedure, since the techniques utilized to negate the effects of polymerization contraction stress, such as placement of a flowable composite layer, increments touching only one wall, ramped curing and/or pulse activation, need not be employed.

In the case of the material described in this paper, the clinicians involved, all of whom were experienced users of previously-available resin composite materials for restoration of posterior teeth, considered the reduced shrinkage of Filtek Silorane™ to be a clinical advantage which justified its use. In this respect, results of a recent evaluation on the handling of the material have been positive.[28]

Conclusion

The introduction of a novel low shrink resin composite appears to provide clinicians with a simplified placement procedure when compared with conventional resin composite materials. Long-term clinical trials are required to assess the impact of this novel material fully.

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