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Polymer-based direct filling materials

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Synopsis

After a brief review of current restorative materials and classifications, this article discusses the latest developments in polymer-based direct filling materials, with emphasis on products and studies available in the last 10 years. This will include the more recent bulk-fill composites and self-adhesive materials, for which clinical evidence of success, albeit somewhat limited, is already available. The article will also introduce the latest cutting edge research topics on new materials for composite restorations, and an outlook for the future of how those may help improve the service-life of dental composite restorations.

Keywords

Dental composites; polymerization; clinical longevity; caries

Introduction

Since their introduction to the market over 60 years ago, modern resin composite restorative materials have undergone substantial development and improvement. Even larger posterior restorations now show good clinical performance when built with current materials [1–3]. More and more, amalgams are falling out of favor for such applications for a number of different reasons, but are composite materials truly a complete substitute? Most of the developments throughout the history of composites have concentrated on the inorganic filler portion, and the advent of micro- and nano-hybrid formulations has made it possible to obtain highly esthetic and wear-resistant restorations recommended for use as universal restoratives.

More recently, especially in the last 15 years or so, the technological advances have focused on the organic matrix, with a heavy emphasis on producing low-shrinkage and low stress materials. The rationale is that polymerization shrinkage and the consequent stress that develops at the tooth-restoration interface produces gaps, which in turn, make the restoration more prone to recurrent decay [4]. This premise has been challenged in the past few years, especially because materials that have been shown to present low shrinkage/stress in vitro

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testing were not able to outperform so-called conventional materials in clinical trials [5, 6]. More recent advances include bulk-fill composites and materials claiming to be self-adhesive to the tooth, with the main goal of simplifying the technique-sensitive restorative procedure to avoid inherent operative errors. As it stands, composite restorations present an average life-span of about 10 years or less, with the main reasons for failure being secondary caries and fracture [7–11]. Therefore, even with the tremendous advances made in the recent past, there is still room for improvement.

This article will examine the scientific evidence available in the last 10 years to provide insight into novel techniques and materials available to the clinician. From the over 3,000 papers published on dental composites and related techniques in that period, this review will focus on novel materials or restorative protocols developed, and on how those have influenced clinical practice. The term “conventional composite” in this chapter refers to composite materials with regular consistency (not flowable or packable) and whose placement protocol recommends increments no thicker than 2 mm, preceded by the application of an adhesive system.

The evolution of filler systems

Current commercially available composite materials can be classified according to their filler type, as summarized in Table 1. Excellent, in depth reviews focusing specifically on the filler technology can be found in the literature [12–14], and a summary is provided here. Microfill composites contain colloidal silica particles with average size of 50 nm. To enhance filler loading levels, monomers are highly filled with colloidal silica and polymerized by heat. These pre-polymerized composites are then ground to a relatively fine powder on order of 50 μm in size, and then re-dispersed in the final composite for a total filler content (including pre-polymers) of about 70 wt%, according to the manufacturers (<http://www.ivoclarvivadent.com/en/products/restorative-materials/composites/heliomolar>). These materials present excellent polishability [15], but do not perform well in more mechanically-challenging situations, so their main indication is for highly esthetic areas, and relatively small class III and class V restorations [16]. To try to overcome these challenges and expand the indications of esthetic direct restorations, the materials evolved into hybrids and midfills having glass fillers with variable sizes in combination with the 50 nm colloidal silica. This aimed to improve filler loading and, therefore, mechanical properties, while maintaining reasonable esthetic characteristics [17]. In fact, generally, midfills and hybrids have ranked among the materials with the highest fracture toughness, flexural strength and elastic modulus [18], which makes them very good choices for mid-size to larger posterior restorations [19]. However, loss of surface gloss and wear of the restorations was still a clinical concern, even within a relatively short time after restoration placement [20–22], and especially in larger posterior preparations. Wear and esthetics were the main driving forces for the development of even smaller sized filler technologies, in an attempt to combine smooth, esthetic surfaces with longer-lasting restorations, capable of withstanding occlusal challenges.

Micro-hybrid composites were then developed. Together with nano-hybrid materials, they comprise the most abundant categories of composite currently on the market. These

materials have also been extensively characterized in the literature, both in in vitro and clinical studies [23–28]. They are considered to be universal composites, recommended for use in anterior and posterior restorations. In vitro studies comparing the mechanical properties of micro- and nano-hybrid composites to those of hybrids and midfills concluded that, as general categories, and because of the great variations among different commercial brands, there is no difference between micro- and nano-hybrid materials [29, 30]. However, in terms of polishability and long-term gloss retention, micro- and nano-hybrids have demonstrated far superior performance both in in vitro [20, 31] and in clinical studies [32] compared to their predecessors. In general, their clinical performance is excellent with some examples of up to 10-year follow-up studies showing failure rates of less than 3% [1, 33, 34]. It is noteworthy that the differences between micro- and nano-hybrid materials are in fact very subtle. Because of the size distribution of particles, as shown in Table 1, the overall particle size is very similar for the two categories.

True nanofill composites contain filler particles with the smallest size available to date, ranging from 5–100 nm. These materials do not contain additional glass particles that exceed the nanoscale i.e. greater than 100 nm). Their obvious advantage is the excellent esthetic made possible by the fact that the dentist can obtain highly polished surfaces, which can retain their gloss even after long-term use [13]. Different manufacturers rely on different strategies to decrease the filler size and still keep the overall filler loading high, such as the clustering of nanoparticles via water dispersion and spray drying (Filtek Supreme, 3M-ESPE). Other nanohybrids have used different approaches to achieve low overall average particle size but high filler fraction, such as the use of pre-polymerized composite particles re-dispersed in the matrix (such as in Tetric Evo-Ceram – Ivoclar-Vivadent), or the solvent-driven dispersion of particles in the matrix, followed by atomization and pre-polymerization (CeramX, Dentsply-Sirona). One study has indeed demonstrated color stability and gloss retention for several nano-hybrid and nanofill materials after simulated clinical conditions [21]. A comprehensive literature review of in vitro studies, however, concluded that nanofill composites were no better than microhybrids in terms of surface smoothness and/or gloss, before and after surface challenges [13]. Nanofills have also been demonstrated to behave very similarly in vitro to nano- and micro-hybrids, both in terms of mechanical properties and depth of cure [35, 36]. Clinical studies with follow up times of up to 5 years have demonstrated an annual failure rate for nanofilled composites of less than 3%, deeming these materials clinically acceptable and within the range of survival of micro- and nano-hybrid materials [37–39].

Newer monomers and low-shrinkage/low-stress composites

While the evolution of fillers improved the wear and fracture characteristics of dental composites, most of the development in the organic matrix in the last 10–20 years has been dedicated to producing low-shrinking materials [40]. It has long been demonstrated that the composite polymerization shrinkage that takes place, when confined by the adhesion to the relatively rigid cavity walls, leads to stress development at the tooth-restoration interface [41]. This can have several deleterious effects on the restoration, such as de-bonding and formation of marginal gaps [42], and induction of cracks near the margin [43], as shown in Figure 1. Other than being responsible for postoperative sensitivity, it is logical to assume

that the formation of gaps facilitates bacterial re-colonization and secondary decay, a long held assumption [44]. At least one study was able to successfully demonstrate the formation of biofilm at the bottom of an artificially created gap in a restoration subjected to cariogenic and mechanical challenges [45]. Another study demonstrated that the presence of adhesive in the gap significantly reduced the formation of carious lesions [46, 47].

With that in mind, manufacturers developed new products based on a few different shrinkage and/or stress reduction strategies. Some products rely on the use of monomers of higher molecular weight compared to the conventional BisGMA/TEGDMA mixtures [48]. Larger monomers lead to less shrinkage because of the lower concentration of reactive functional groups (C=C) per unit volume. This is the same rationale for why the inclusion of pre-polymerized additives reduce shrinkage and stress, as has been recently demonstrated with nanogels in experimental dental composites [49]. Table 2 shows a comparison of molecular structures, molecular weights (sizes) and commercial brands for some of these new monomers. One other product is based on ring-opening polymerization (Filtek LS, 3M-ESPE, Table 2), with intrinsically lower shrinkage than conventional methacrylate polymerization [50, 51]. In vitro studies comparing “low-shrinkage” products have shown that they indeed present lower volumetric shrinkage, but not all of them result in lower stress [48, 52, 53]. This is because the stress, apart from the shrinkage, also depends on the final degree of conversion and elastic modulus of the composite [4], so comparisons among commercial brands is often difficult. In general terms, the stress increases for higher shrinkage, higher conversion and higher stiffness materials [4]. When experimental materials are used, under controlled conditions (geometry, photoactivation protocol) and known composition, those relationships are usually straightforward. However, for commercial materials, it is impossible to control all the variables simultaneously, because of the differences in type and concentration of initiators, type and concentrations of monomer species, filler type, etc. For example, one study demonstrated that the ring-opening-based material produced the lowest shrinkage while showing one of the highest elastic moduli among the materials tested, including the conventional control [53]. Interestingly, the stress values for that material were actually higher than the conventional control, likely due to the high modulus, and in spite of the lower shrinkage. Other composites showed lower stress than the control in that study, with comparable modulus, which is an encouraging result [53]. This demonstrates the complexity of the polymerization stress issue in commercial materials, even in controlled, in vitro studies, where biological factors such as the biofilm and complex occlusal loading do not come into play.

In spite of the encouraging in vitro evidence and in spite of the intuitive correlation between shrinkage/gap formation and secondary caries development, clinical studies have failed to demonstrate this effect, at least with the available “low-shrink” materials [5, 6, 44, 54]. This is due to the biological factors mentioned above (biofilm formation, dietary and hygiene habits of the patient and unique occlusal loading situations). For example, in studies evaluating one low-shrinking composite and a conventional control, the incidence of restoration failure and recurrent decay was similar for either material [5, 6, 55]. The reason for the lack of correlation between marginal gaps and secondary decay stem from the fact that biofilm formation and caries development are multi-factorial processes, and the presence of gaps alone do not guarantee that demineralization will take place. It is important

to note, however, that just because a direct correlation has not been found between improved clinical performance and the use of reduced stress materials, the presence of marginal gaps resulting from polymerization stress remains consequential. As mentioned before, at least in vitro, the presence of caries-forming bacteria has been identified at the bottom of gaps at the margin of restorations subjected to cyclic loading [45]. There are no clinical or in vivo studies correlating gap formation and the development of secondary decay.

Still, the subject of polymerization stress continues to be investigated. More recently, materials capable of directly reducing stress have been introduced. Examples range from thiol-ene-methacrylate formulations [56, 57] to covalent adaptable networks [58]. In the case of thiolene methacrylates, the presence of thiols leads to delay at the point in conversion when gelation and vitrification take place, i.e. the point where the liquid resin polymerizes sufficiently to form a network with substantial rigidity [59]. By delaying gelation, the impact of stresses is reduced, because they do not reach a high level until the network is mostly formed, and therefore, the overall stress is drastically reduced [59]. There are currently no commercial materials based on this technology, though it has been licensed by dental companies. Another example of stress-reducing material is based on the covalent adaptable networks concept [58]. These monomers contain allyl disulfide functionalities in their backbone, capable of recycling crosslinks (i.e. breaking them in response to internal stress and then reforming them) without decreasing the overall crosslinking density. The effect of this mechanism is that the network can adapt to dimensional changes and strain as it is forming, generating far less stress overall [58]. Its use for dental materials has been introduced with model molecules, later optimized for use in commercial materials. The only example of a commercial material containing this type of chemistry is Filtek Bulk Fill (3M-ESPE). This material has only been evaluated as part of bulk-fill studies, where the main focus was not the stress development aspect, but the depth of cure and the influence of the placement technique [60, 61]. However, in selected publications, this material showed decreased gap formation compared to that of a conventional composite of the same manufacturer when the material was placed in a single increment, presumably due to the reduced polymerization stress [62]. Finally, other materials contain proprietary compounds ("stress modulators") that are, according to the manufacturer, capable of stress relaxation. This is the case for SDR Flow (Dentsply-Caulk). This material has indeed shown low stress values [63] and adequate depth of cure [60], as will be discussed in the appropriate section.

Though the longevity of resin dental composites has been increasing, perhaps due to better materials, but also due to more acceptance and better training by practitioners, the current placement protocol is still considered time-consuming and technique sensitive compared to the placement of amalgam. Depending on the adhesive system selected, the number of application steps can vary from one (with universal, self-etching adhesives) to more than 3 (with etch-and-rinse, three-component adhesives). In every step, there is a possibility for error, especially when bonding to dentin, where the moisture content of the substrate, if not controlled, can affect clinical longevity [64–66]. The other main sensitivity issue involves the depth of cure of current composites. In general, the recommendation for conventional materials is to use increments no thicker than 2 mm [67]. But if the tip of the light source is not properly positioned, or for the material located at the bottom of a proximal box, there is the possibility for insufficient light to reach the full depth of even a 2 mm increment [68].

All of this has prompted manufacturers to develop materials that could be placed in one increment, and/or without the need for an adhesive step, as will be explored in the following sections.

Bulk-fill materials

The rationale for the use of bulk-fill materials is to streamline the restorative process in the operatory. However, the insertion of composites in a single increment has long been contraindicated for two main reasons: 1. Conventional materials need to be placed in increments no thicker than 2 mm to ensure proper monomer to polymer conversion at the bottom of the increment. This is even more critical at the bottom of, for example, a proximal box of a large class II restoration, where light access is often compromised [69]. 2. Especially for class I and class V restorations, the cavity configuration factor (C-factor, the ratio of surface area of bonded to non-bonded interfaces in a preparation) is high and this has been correlated, in general, with increase in stress [70]. This correlation is not without controversy, as it is often seen as an oversimplification of the subject, since it overlooks the volume of the restoration [70] and the condition of the remaining tooth structure [71–73]. However, at least for conventional composites, because of the C-factor vs. stress correlation, the use of incremental placement is still recommended to minimize the bonded surface on each increment, reducing the relative C-factor in each increment, and therefore, reducing overall stress [60]. This was indeed observed in several in vitro studies [60, 74]. In one of them, the deflection of aluminum molds of various thicknesses was measured for conventional composites placed in a single or multiple increments, with the results showing that the single increment technique always resulted in greater wall deflection [72]. There is also some clinical evidence that incremental technique improves the outcomes of restorations of conventional dental composites [2, 75]. In one clinical study, pre-molars scheduled for extraction for orthodontic reasons received standardized preparations and were restored with either a single or several increments. The results demonstrated a lower incidence of marginal gaps for restorations placed using the incremental technique [75].

In recent years, manufacturers have introduced modifications in the materials to try to overcome the two main drawbacks mentioned above and allow for bulk placement of restorations, including:

1. Use of flowable materials, with lower filler content;
2. Modifications to the filler type to improve light transmission in depth;
3. Use of more efficient initiators;
4. Modifications to the monomer system to allow for stress relief during curing.

These strategies are summarized in Figure 2.

For the materials that use the flowable strategy, the rationale is that the lower filler content (in general) would decrease the light scattering through the material and provide better degree of conversion in depth [76–78]. This is shown to be generally true for blue wavelengths, but shorter wavelengths in the UV range were shown to be significantly limited in terms of penetration depth despite the increased translucency of the material [79].

However, because of the low resistance to wear expected with lower filler contents, the clinical placement technique calls for bulk fill of the cavity preparation with the flowable material, except for the last 2 mm of the occlusal surface, which needs to be filled with a conventional, highly filled material. In other words, the restoration still has a “cap” made of a hybrid or micro-hybrid regular consistency composite to ensure sufficient mechanical strength to withstand occlusal loading and reduce the amount of wear [63, 80]. The degree of conversion of such flowable bulk-fill materials at the bottom of 4 mm increments was indeed shown to be similar to that of the top in some studies [81]. One potential added advantage observed with this technique is that the composite adaptation to the cavity walls may improve [60], as expected based on the low viscosity of the flowable materials. As for the polymerization stress, some studies actually found increased values with the use of bulk-fill flowable composites compared to a conventional ones depending on the C-factor [82], but since the degree of conversion was not measured in that study, it is not possible to determine whether greater conversion from the bulk fill materials, associated with the greater shrinkage obtained, played a role in determining the stress values. There is evidence, however, for increased gap formation at the base of such restorations due to the greater shrinkage observed [60, 82]. One other study used finite element analysis to evaluate stress and the strain gage method to evaluate post-gel shrinkage and concluded that teeth restored with the flowable bulk-fill followed by a micro-hybrid capping material led to reduced cuspal deformation, post-gel shrinkage, and shrinkage stress, and increased fracture resistance [83]. Therefore, in vitro evidence is still conflicting, and clinical studies are scarce. Two studies, however, seem to indicate that restorations placed with a bulk-fill material did not differ from those placed with conventional placement techniques, at least after a 5-year follow up [84, 85].

Other materials rely on optimization of the refractive index match between the inorganic filler and the organic phase, which is known to increase the depth of light transmission [86]. This is the case for at least one material (SonicFil, Kavo-Kerr) which, allied with higher concentration and/or different types of initiators, has been shown to produce hardness values at 4 mm not statistically different from the top of the increment [87]. One additional feature of this material is the use of vibration to decrease the viscosity of the composite at room temperature, improving the adaptation to the cavity wall [60]. One study, however, has demonstrated inferior mechanical properties and greater susceptibility to degradation by ethanol with this material compared to a conventional micro-hybrid [88]. Another example of modification of the initiator technology is Tetric EvoCeram Bulk Fill (Ivoclar-Vivadent). This material utilizes a germanium-based photoinitiator, with maximum wavelength of absorption at 420 nm [89]. This molecule presents a much higher quantum yield than the camphorquinone/amine system, and also results in the formation of two active radicals, which may facilitate propagation of reactive species even at depths where the light intensity is significantly diminished [89]. In vitro investigations have demonstrated that these materials may require at least 20 s of photoactivation to achieve levels of conversion comparable to incrementally placed conventional composites [90]. Clinical investigations have demonstrated that these bulk fill materials behaved similarly to the conventional composites they were compared to at a 5 year follow up [85].

Direct modifications to the chemistry of the monomer phase include the introduction of a methacrylate capable of undergoing free-radical addition fragmentation, as is the case for the Filtek Bulk Fill material (3M-ESPE, [Technical profile](#)). This is a mechanism that allows the forming crosslinked network to adapt to stress development during polymerization, significantly decreasing its final value [91]. This technology, allied with other high molecular weight monomers in the composition, have shown to reduce the polymerization stress in comparison with conventional composites, even though it was not the lowest among the bulk-fill materials tested [60]. The degree of conversion at 4 mm was not statistically different from that of the control, and it was comparable to the value obtained at 1 mm [60].

One aspect that cannot be overlooked is the issue of heat generation with a larger volume of composite being polymerized at once, as is the case for bulk-fill restorations. Studies have demonstrated that the temperature rise is greater for bulk-fill composites compared to conventional controls, as measured in the composite itself [92, 93], but the effects of this elevated heat generation on the dental pulp have yet to be investigated. In conclusion, clinical studies with these materials are still very scarce, but the first few reports demonstrate they are at least as effective as conventional materials in the short-term, as far as marginal integrity is concerned. However, in vitro studies seem to suggest that they require at least 20 s of photoactivation to produce these results.

Self-adhesive composites and resin-cements

Self-adhesive cements and composites have been developed to not only streamline clinical procedures, but also to hopefully eliminate the most technique-sensitive step in the restorative procedure: the application of the adhesive system. As already mentioned, the bonding to dentinal substrates is not particularly reliable, and many factors such as the degradation of the adhesive layer by the action of water percolation and of the collagen by matrix metalloproteinases contribute to decrease the long-term stability of the bonded interface [94]. In addition, potential errors in some of the clinical steps have been shown to critically affect the quality of the interface, such as the time for application of the acid (where applicable), the level of moisture of the substrate, the evaporation of solvent, the number and thickness of the bond layers, etc. [95]. Self-adhesive cements and composites rely on acidic functionalities, much as in self-etching adhesives [96], which are theoretically capable of interacting with the tooth substrate via its mineral content to not only mildly etch the surface but also form true chemical bonds [96]. The challenge with this type of material is to promote good adaptation to the cavity preparation, and this is the reason why the commercially available products all rely on low viscosity formulations [97]. According to the manufacturers, self-adhesive flowable composites are recommended for small pit and fissure lesions, small class I and II and, in limited cases, class V restorations, where the mechanical challenge is not very pronounced. In those situations, the use of self-adhesive materials can actually be advantageous because it theoretically eliminates the adhesive step, leaving more space in the very conservative cavity preparation for the insertion of the more highly filled material to be used. At least one in vitro study of the interface between these materials and enamel and dentin has demonstrated an absence of etching of the surface in either substrates, demonstrating a limited interaction with smear-covered surfaces and aprismatic enamel, with a thin interaction area of only about 200 nm [96, 98]. This agrees

with the findings of another in vitro study that demonstrated inconsistent resin tag formation with the use of two commercially available self-adhesive composites, as reflected in a decreased shear bond strength and increased microleakage [98, 99]. The prior application of acid etching seems to improve the microleakage resistance of these materials, at least in vitro [97]. Clinical studies with these materials are still scarce, but preliminary results seem to demonstrate that they are effective at reducing dental hypersensitivity, though not to any greater degree than conventional desensitizing agents [100]. When used to restore non-carious cervical lesions, one study found very poor results – of 40 restorations, 27 presented as clinically unacceptable after only 6 months follow up [101].

Toxicity and the BPA controversy

Bisphenol A (BPA) is a high production volume chemical, in use since 1957. It is present in polycarbonate bottles and is used in can and pipe linings to prevent rusting. BPA's molecular structure is very similar to that of certain hormones (Figure 3), and is therefore classified as an endocrine disruptor compound [102]. In adults, it becomes metabolized by a specific enzyme, which is not present/active in fetuses nor in small children. From animal studies it has been concluded that when large doses of BPA are administered to pregnant females, they produce offspring with developmental and behavioral issues [103, 104]. However, a toxicology panel organized by the National Institutes of Health in 2008 failed to find such a correlation in humans, which was credited to the relatively low levels of exposure from daily plastic sources (extensive information, including the conclusions of the 2008 panel can be found at [NIEHS-NIH 2008 study pannel](#)). The FDA and its counterparts in Europe and Canada have since released an update concluding that BPA levels occurring in foods are safe ([FDA - BPA recommendations](#)). There are two monomers used in dental composites and sealants whose molecular structure contains a BPA core: Bisphenol A diglycidyl dimethacrylate (BisGMA) and Bisphenol A dimethacrylate (BPDMA), as seen in Figure 3. Though these molecules used in dental sealants and possibly composites contain the BPA core, degradation studies have failed to detect the presence of BPA by-products from dental sealants [105]. The other degradation products can be toxic at the local level, but exposure to them is considered to be brief as they are quickly cleared by the saliva [106]. Several studies concluded that the cumulative exposure level to sealants and/or flowable composites was not associated with behavioral, psychosocial or neuropsychological alteration [107–109], and the American Dental Association has deemed sealants safe for use in children and adults ([ADA - FDA in dental sealants](#)).

Summary/Future directions

Until such time in the future when regenerative therapies have completely evolved to the point that damaged dental tissues or the entire tooth can be regenerated, direct and indirect restorations will continue to be a very important part of the clinician's armamentarium to repair the damage resulting from dental caries. Among direct restorative materials, dental composites will continue to replace amalgams, due to esthetic demands. The past couple of decades have seen an enormous amount of progress in terms of enhancing filler and organic matrix composition, with the result being that the average life span of a composite restoration has increased significantly compared to what was expected when they were first

introduced. However, as clinicians improve their techniques and researchers fine tune the composition of materials, more and more focus will likely be placed on the interaction of the material itself with its surroundings, including the mineralized tooth and soft periodontal tissues and the environment as a whole, including bacteria and components of the saliva. In other words, producing materials that can not only generate less interfacial stress and withstand the occlusal loading, but also that can resist chemical and biological degradation, will be the focus of future dental composite research. Significant efforts are currently underway to produce materials that are better able to resist enzymatic degradation, focusing on the elimination of ester-containing methacrylate monomers. In addition, materials with self-healing capabilities are also being studied. On the more biological side, re-mineralizing and antibacterial composites have been investigated for several years, and are getting closer to being commercially viable. Ultimately, the goal is to produce materials that are easier to use, and therefore are less technique-sensitive, and that will produce robust, long-lasting restorations. This will reduce costly replacements and will significantly advance oral health.

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Key Points

1. Review of the literature on conventional materials and current drawbacks, including wear and polymerization stress.
2. Summary of claims and properties of newer materials, and their relationship (or lack thereof) with the increase in clinical longevity in dental composite restorations.
3. Evidence from the last 10 years on novel materials and techniques, such as bulk-fill and self-adhesive composites.
4. Analysis of clinical trials available using most current materials and techniques.
5. Brief outlook to the future and latest research on materials intended to better withstand the environmental and bacterial challenges in the oral cavity.

Figure 1.
Schematic illustration of the deleterious effects of polymerization stress at the bonded interface.

Figure 2.

Different strategies to build bulk-fill restorations, as a function of the materials used.

Figure 3.
Molecular structure of bisphenol A, bisphenol A diglycidyl dimethacrylate (BisGMA), bisphenol A dimethacrylate (BPADMA) and their possible degradation products.

Table 1

Classification of conventional resin composite materials currently available on the market according to their filler type

Type of composite	Comparative filler size and distribution	Average filler size	Commercial examples
Microfill		40–50 nm	Durafill® VS (Heraeus Kulzer Inc), Renamel® Microfill (Cosmedent, Inc), Matrixx™ Restoratives Anterior Microfill (Discus Dental), and EPIC®.TMPT (Parkell, Inc.), Heliomolar®/Heliomolar® HB (Ivoclar Vivadent) and Virtuoso Sculptable® (Den-Mat)
Hybrid		10–50 µm + 40 nm	Herculite XRV™ (Sybron Dental Specialties Inc/Kerr Dental), Spectrum® TPH® (DENTSPLY Caulk), and Charisma® (Heraeus Kulzer Inc).
Midifill		1–10 µm + 40 nm	Z100 (3M-ESPE), Clearfil Photo posterior (Kuraray America, Inc)
Minifill or microhybrid		0.6–1 µm + 40 nm	Filtek™ Z250 (3M ESPE), Synergy® D6 (Coltène/Whaledent® Inc), Gradia™ Direct (GC America), Point 4™ (Kerr Dental), Renamel® Universal Microhybrid (Cosmedent), Tetric® Ceram (Ivoclar Vivadent, Inc), and Venus® (Heraeus Kulzer Inc)
Nanohybrid		0.6–1 µm + 5–100 nm	Premise (Kerr Dental), Aelite Aesthetic Enamel (Bisco, Inc), Clearfil Majesty™ Esthetic (Kuraray America, Inc), Artiste (MANUF) and Z250 XT (3M-ESPE).

Type of composite	Comparative filler size and distribution	Average filler size	Commercial examples
Nanofill		5–100 nm	Filtek Supreme Plus (3M-ESPE), Clearfil Majesty posterior (Kuraray America, Inc) and Estelite Sigma 1 (Tokuyama)

Modified from Ferracane JL. Resin composite--state of the art. *Dent Mater* 2011;27(1):29–38; with permission.

Table 2

Molecular structures of several examples of monomers used in modern dental composites

Monomer	Molecular weight (g/mol)	Commercial example
<i>BisGMA</i>	512	Present in several brands in different combinations – Filtek Supreme (3M-ESPE), Aelite (Bisco Dental Inc.), Tetric Evo Ceram (Ivoclar-Vivadent), etc.
<i>BisEMA</i>	540	
<i>UDMA</i>	470	
<i>TEGDMA</i>	286	
<i>DX-511 (DuPont monomer)</i>	895	Venus Diamond (Heraeus-Kulzer)
<i>Dimer-acid dimethacrylate</i>	870	N'Durance (Septodont-Confidential)
<i>TCD-urethane (tricyclodecane urethane)</i>	510	Kalore (GC America)
<i>Silorane</i>	470	Filtek LS (3M-ESPE)