Scientific Manual

SDR® flow+

Bulk Fill Flowable

Dentsply Sirona

Research

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1. Introduction

1.1 Background of resin composites

Light cure resin composites have been introduced into the field of conservative dentistry for the needs of cure on command from clinicians and esthetic appearance from patients. In general, dental composites encompass four main components: (1) the resin matrix or continuous phase comprising a combination of oligomer/monomer system, an initiator/co-initiator system and stabilizers; (2) filler consisting of inorganic particulates such as glass, and/or fused silica or mixed oxides such as silica-zirconia, with certain composites also comprise macro-filler based on pre-polymerized ground composite; (3) the coupling agent, usually an organo-silane that chemically bonds the reinforcing filler surface to the resin; (4) iron oxide pigments and sometimes radio-opacifier dispersed into the mixture of the resin matrix and surface modified filler to provide natural tooth colors and radio-opacity.

The resin matrix of composites represents the continuous phase and can be viewed as the backbone of the inorganic/ organic composite system. The filler or dispersed phase is designed to enhance the strength of the softer organic polymer phase and usually consists of glass particles of different compositions, sizes, and size distributions. Filler size is only one of several parameters that affect the overall properties of a composite resin. The filler type, shape, and amount, as well as the filler/resin coupling agent contribute to the material and handling performance.

1.2 Flowable composites

High-viscosity composites (universal or posterior resin composites) are commonly used to restore teeth due to their high filler load, high mechanical strength, strong wear resistance, low shrinkage and good handling such as sculptability. However, due to the high viscosity and high stiffness of the paste, high-viscosity composites are not easily to adapt to the internal cavity wall or small cavities.

Flowable restoratives are used to compensate the adaptation challenges of high viscosity resin composites. Due to their low filler load and high flowability, flowable resin composites can easily adapt to the cavity with less or no manipulation. Dentists commonly use flowables as the first base layer or liners in posterior restorations. Due to the low mechanical strength, weak wear resistance and lack of sculptability, flowables are not used on load bearing occlusal surfaces. Especially due to their low filler load and high shrinkage, flowables are commonly considered as unsuitable for bulk placements.

1.3 Polymerization shrinkage and stress

When exposed to light, the resin monomers link together to create large molecules (polymers), which, in turn, link together to form a continuous network. The polymerization process requires that monomers physically move closer together to chemically react via a free radical process. This process results in a volumetric shrinkage referred to as polymerization shrinkage if not restricted by e.g. bonding to a cavity. When the shrinkage process is restricted, stress builds up. Not only will this polymerization stress be concentrated inside the composite itself, but it will also exert forces on bonded interfaces to which the composite is attached. The term, C-Factor (Configuration Factor) was used to describe this effect and relates the area of bonded surfaces to the area of unbonded surfaces (Feilzer et al. 1987). The lowest C-Factor values are obtained with class IV cavities because the composite has enough unbonded surfaces to flow. As the area of bonded surfaces increases, the C-Factor increases, resulting in a greater polymerization stress. This relationship is demonstrated in Figure 1. However, it is worth mentioning that the complexity of the clinical situation does not allow for the prediction of polymerization stress based solely on the C-Factor.

In a well-bonded composite restoration, the polymerization stress is transferred through the interface with the tooth. This may result in enamel cracks, white lines, cusp deflection, and cracked cusps. In less-bonded restorations, polymerization stress has the potential to initiate failure of the composite-tooth interface (adhesive failure) if the

forces of polymerization stress exceed the bond strength. The resulting gap between the composite and cavity walls may produce post-operative sensitivity, microleakage, and/or secondary caries.

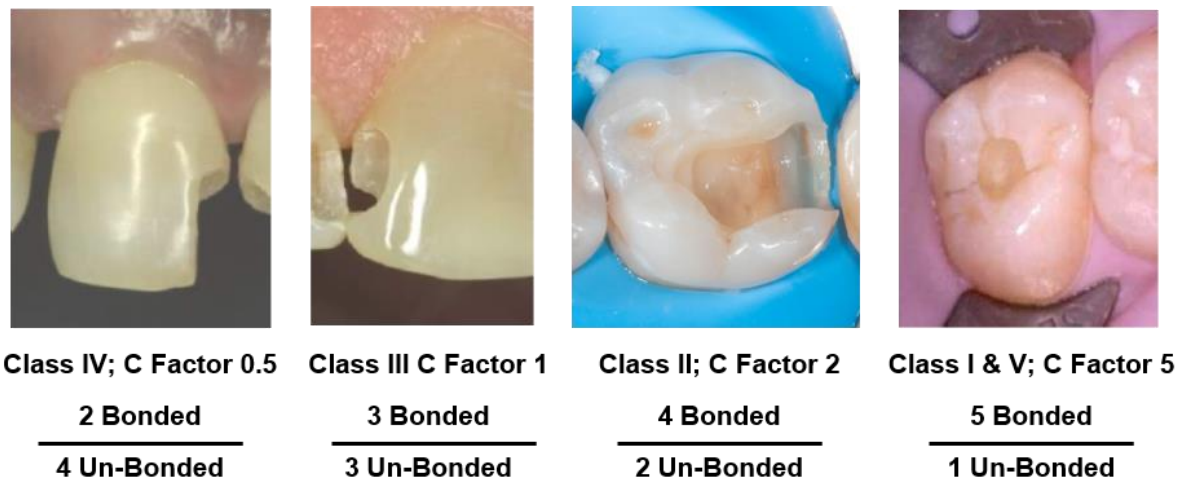

Figure 1 As the area of bonded surfaces increases relative to unbonded surfaces, the C-Factor increases (Clinical pictures Class I, III, IV, V courtesy of Dr. Jeff Blank; Clinical picture Class II courtesy of Dr. Walter Dias).

1.4 Bulk-Fill Composites

To reduce the polymerization stress, composite restorations have to be light-cured in increments. The maximum thickness of each increment, which provides adequate light penetration and polymerization of conventional composites, has been generally defined as 2 mm. However, since this results in a complex and time-consuming layering technique, easier and faster placement of composite restorations is highly demanded by dentists (van Dijken & Pallesen 2015, Manhart et al. 2010). In 2003, Dentsply Sirona introduced a new approach to the application of posterior composite restorations in thicker layers, which involved the use of a high viscosity and highly translucent composite. This first bulk-fill composite, named QuiXfil® posterior restorative, has a low polymerization shrinkage and a high depth of cure that allows a simplified placing technique with 10 seconds light-curing of increments up to 4 mm. During the following years, several clinical studies have been completed on the QuiXfil composite showing its suitability for bulk-filling posterior cavities (reviews in Van Ende et al. 2017). Recently, the ten-year follow-up of a randomized clinical trial showed no

significant difference in the long-term clinical success between QuiXfil restorations and a regular hybrid composite material placed in 2 mm increments (data on file 2017).
In 2009, Dentsply Sirona launched the first bulk fill flowable composite, SDR®, to the global market. With the incorporation of Stress Decreasing Resin (SDR™) technology[1] and high depth of cure, SDR has exhibited exceptional clinical performance and great commercial success due to their excellent physical properties, remarkable handling characteristics, and outstanding quality control. Following SDR, other major dental product manufacturers started researching and developing similar products. Bulk-fill composites as a product category have become widely accepted by both academic researchers and clinicians. In 2014, the indications of SDR were extended to include posterior restorations in deciduous teeth (Class I and II) without an additional capping layer. Based on the clinically well-proven SDR™ technology, Dentsply Sirona has now introduced the next generation of this bulk-fill flowable composite. SDR® flow+ Bulk Fill Flowable was developed to meet additional clinical needs such as improved mechanical strength, wear resistance and radiopacity which can greatly improve the efficiency and productivity of clinician's ever-increasing composite restorations.

1.5 SDR technology

The SDR technology is a patented urethane dimethacrylate structure that is responsible for the reduction in polymerization shrinkage and stress. SDR has minimal overall shrinkage (3.5%) compared to other conventional flowable composites. Lower volumetric shrinkage contributes to overall lower polymerization stress. SDR provides an approximate 20% reduction in volumetric shrinkage and almost an 80% reduction in polymerization stress compared to conventional methacrylate resins as shown in Figure 2.

[1] SDR™ technology is included in several products such as SDR®, SureFil SDR® flow, SureFil SDR® flow+ and also the new SDR® flow+. It is self-levelling for excellent cavity adaptation, it enables dentists to bulk-fill up to 4 mm and exhibits extremely low polymerization stress.

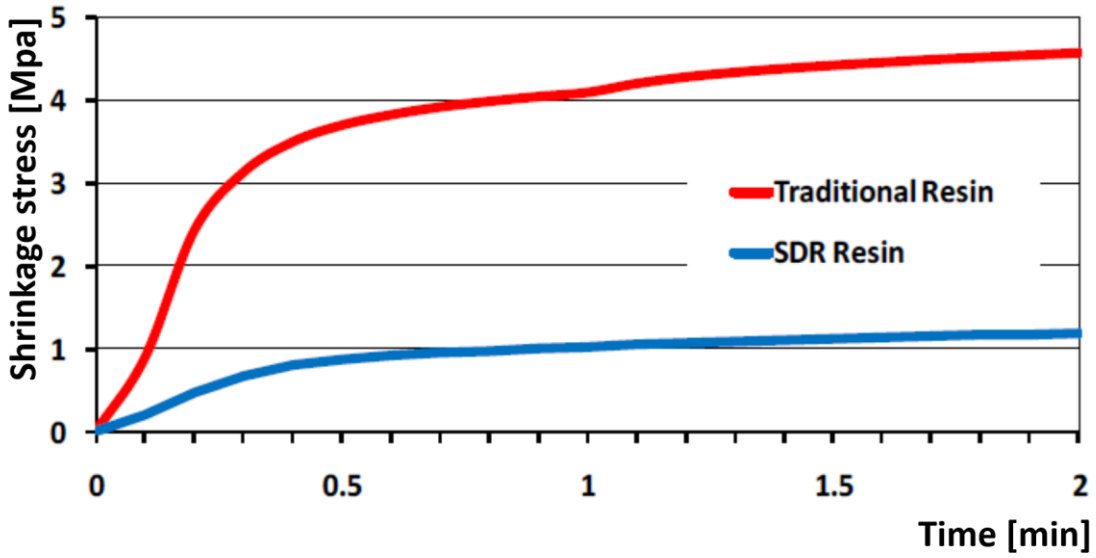

Figure 2 Development of shrinkage stress for traditional methacrylate resin compared to SDR technology. (Data on file, 2017).

The low stress is due in part to the larger size of the SDR resin compared to conventional resin systems (molecular weight of 849 g/mol for SDR resin compared to 513 g/mol for Bis-GMA). The SDR technology comprises the unique combination of such a large molecular structure with a chemical moiety called a “Polymerization Modulator” chemically embedded in the center of the polymerizable resin backbone of the SDR resin monomer (Figure 3).

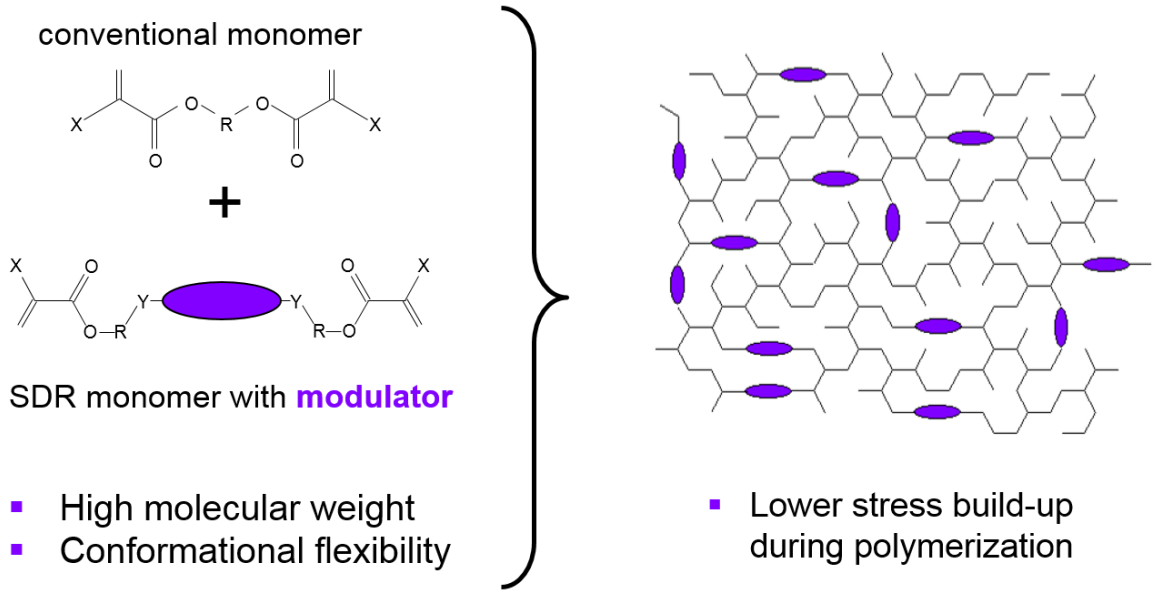

Figure 3 Chemistry of SDR technology.

The high molecular weight and the conformational flexibility around the centered modulator impart optimized flexibility and network structure to SDR resin. Dynamic mechanical analysis (DMA) can be used to characterize visco-elastic materials. Figure 4 shows the tan Delta over temperature curve comparing SDR resin and SDR composite to Esthet•X flow and the respective neat resin after curing. The peaks in the graph represent the glass transition temperature (Tg). Both, SDR resin and SDR composite show not only a lower Tg but also a higher tan Delta. Simplifying, the tan Delta expresses the ratio between dissipation (resulting from viscous behavior) and storage (resulting from elastic behavior) of energy induced into the material. Higher tan Delta is related to higher dissipation of induced energy. As a result SDR is able to dissipate more energy (and store less) when energy is induced, e.g. during polymerization.

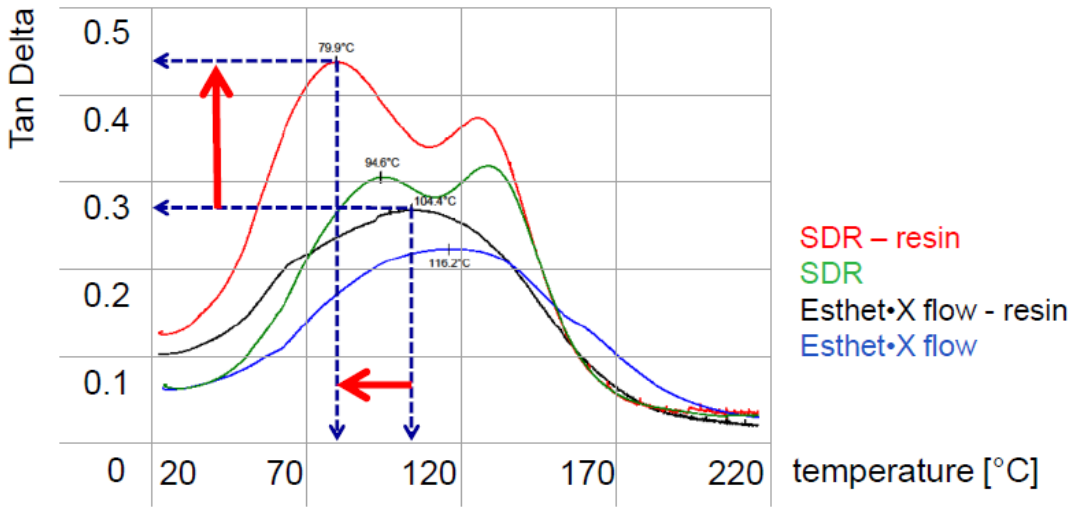

Figure 4 Tan Delta versus temperature from DMA for neat resin or formulated product comparing Esthet•X flow to SDR. (Data on file, 2017).

Another point is that the curing rates and overall conversion are not sacrificed with SDR. As shown in Figure 5, FTIR analysis of double bond conversion during curing of SDR resin and formulated SDR show very similar conversion rates to conventional resin and conventional composites such as Esthet•X flow.

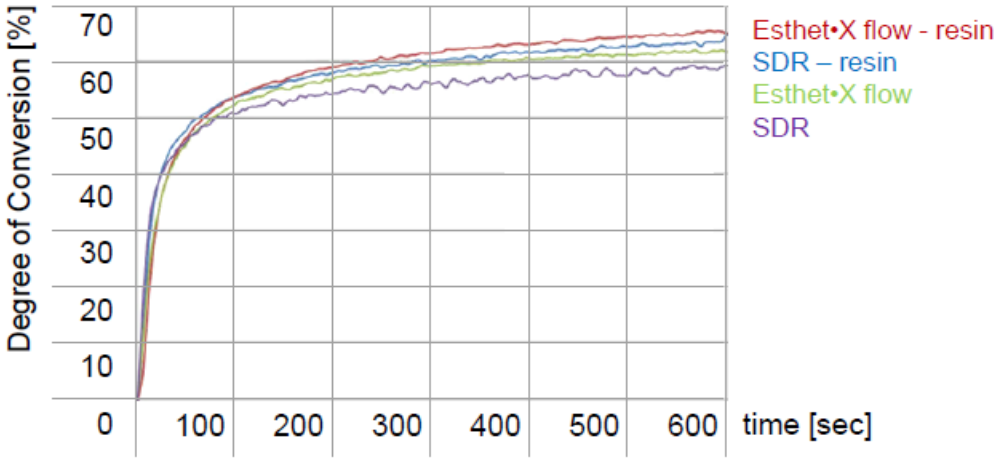

Figure 5 Degree of double bond conversion versus time comparing neat resin or formulated product of Esthet•X flow to SDR. (Data on file, 2017).

Further, the high degree of double bond conversion ensures the development of the physical and mechanical properties required for the use of SDR as a posterior bulk fill material. As shown in Figure 6, photo-rheology studies of the modulus development during curing illustrate the rapid network formation and strength development achieved with SDR. The rate of modulus development of SDR is quite similar to a conventional flowable composite such as Esthet•X flow.

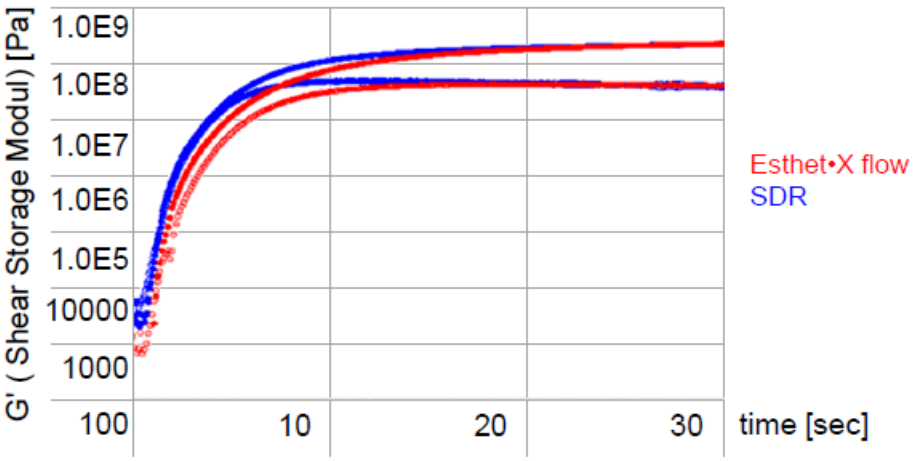

Figure 6 Storage modulus development versus time for traditional flowable (Esthet•X flow) compared to SDR. (Data on file, 2017).

In summary, the unique structure of the Stress Decreasing Resin provides low stress to the composite system. The optimized balance of properties exhibited by the SDR technology is a result of the combination of SDR resin with fillers and other formulation components.

1.6 SDR flow+ features and benefits

SDR flow+ is a one-component, fluoride-containing, visible light cured, radiopaque composite. SDR flow+ has handling characteristics typical of a flowable composite, but can be placed in 4 mm increments with minimal polymerization stress. SDR flow+ has a self-leveling feature that allows intimate adaptation to the prepared cavity walls (Figure 7). When used used as a base/liner material in Class I and II restorations, it is designed to be overlayed with a methacrylate-based universal/posterior composite for replacing missing occlusal/facial enamel. It is also suitable as a stand-alone restorative material in Class III and V restorations without a separate capping being applied on top. To ensure esthetic appearance in Class III and V restorations, the shade range has been expanded to A1, A2 and A3 shades in addition to the universal shade. SDR flow+ restorative's major features and benefits are summarized in Table 1:

Feature	Benefit
Bulk Fill	• Simplified placement technique
Self-leveling handling	• Excellent cavity adaptation • Minimizes need for manipulation of material
SDR Technology	• Low stress
High radiopacity	• Visibility on x-rays
Increased wear resistance	• New indications for Class III and V in addition to Class I and II restorations
Different shades	• Esthetic appearance

Table 1 SDR flow+ restorative's major features and benefits.

Figure 7 Sectioned sample showing the excellent adaptation of SDR to the cavity preparation.

1.7 Composition of SDR flow+

In the transition from SDR to SDR flow+, the composition of both the resin matrix as well as the filler paste has been modified. In order to strengthen the material, improve its radiopacity and reduce its wear, the filler load has been increased by 2.5% pts and the previous glass filler of SDR has been partially replaced by an alternative filler which provides higher strength. In order to retain key characteristics of SDR, such as flowability and self-leveling handling, the resin was also re-formulated to adjust to the overall consistency of the new filler loading. Overall, this reformulation was successful in retaining these key characteristics of SDR while increasing the wear resistance of SDR flow+ to the level of standard flowable composites and the radiopacity by approximately 20% to 2.6 mm Al.

SDR flow+ has incorporated 70.5 wt% / 47.4 vol% filler. The resin matrix contains proprietary modified urethane dimethacrylate resin; TEGDMA; polymerizable dimethacrylate resin; polymerizable trimethacrylate resin; camphorquinone (CQ) photoinitiator; ethyl-4(dimethylamino)benzoate photoaccelerator; butylated hydroxy toluene (BHT); fluorescent agent, and UV stabilizer. The filler contains silanated

barium-alumino-fluoro-borosilicate glass; silanated strontium alumino-fluoro-silicate glass; surface treated fume silicas; ytterbium fluoride; synthetic inorganic iron oxide pigments, and titanium dioxide.

2. Indications for use

2.1 Indications

- Base in cavity Class I and II direct restorations
- Liner under direct restorative materials – Class II box liner
- Pit & Fissure Sealant
- Conservative Class I restorations
- Core Buildup
- Class III and V restorations

2.2 Contraindications

- Use with patients who have a known hypersensitivity to methacrylate resins

2.3 Light-curing

Each bulk increment of SDR flow+ is light-cured with a suitable curing light such as SmartLight Focus. SDR flow+ must be used with a compatible curing light. The curing light must be able to cure materials containing camphorquinone (CQ) initiator and the peak of its spectrum has to be in the range of 440-480 nm.

Depending on shade the curing time for 4 mm increments is 20 and 40 seconds, respectively. A curing time table SDR flow+ also appears on all outer packages to facilitate sufficient light curing.

	Shade	sec 2 mm	sec 4 mm
mW/cm² ≥ 550	Universal	20	20
	A1, A2, A3	20	40

Table 2 Curing time table for SDR flow+. Check minimum light.

3. In vitro investigations

3.1 Stress reduction

3.1.1 Investigations on a methacrylate-based flowable composite based on the SDR technology

Ilie N, Hickel R. *Dent Mater* 2011; 27:348-55

OBJECTIVE: To analyze the polymerization shrinkage stress and gel point as well as mechanical properties of different flowable composites.

METHODS: The bulk-fill composite SDR was compared to four conventional composites (Filtek Supreme Plus Flow, Esthet•X Flow, Filtek Supreme Plus, Esthet•X HD) and a silorane-based composite with low-shrinkage behavior (Filtek Silorane). Each of the composites was bulk-cured for 20 seconds in a simulated cavity using a LED curing unit (Freelight 2, 1226 mW/cm^2 irradiance). Shrinkage stress and time until gelation (gel point) was continuously measured within the first 5 minutes after light-curing using a stress-strain analyzer. Maximum shrinkage stress during the recorded time and time needed to exceed a force threshold of 0.5 N (arbitrarily defined as the time until gelation) were also compared. To analyze the mechanical properties (Vickers hardness, modulus of elasticity, creep behavior, and elastic-plastic deformation), measurements were conducted at the top and bottom of 2 mm thick composite samples with a micro-hardness indenter. Prior to testing, the composite samples were polished and stored in water for 24 hours.

RESULTS: SDR achieved the significantly lowest shrinkage stress followed by the silorane-based composite, whereas the highest stress was induced in the conventional flowable composites. SDR achieved also the lowest shrinkage stress rate and, together with Filtek Silorane, the longest time until gelation. For all composites tested, no significant difference in the mechanical properties between top and bottom were found. Within the flowable composites, SDR achieved the lowest Vickers hardness,

the highest modulus of elasticity, the highest creep and showed the significantly lowest elastic deformation.

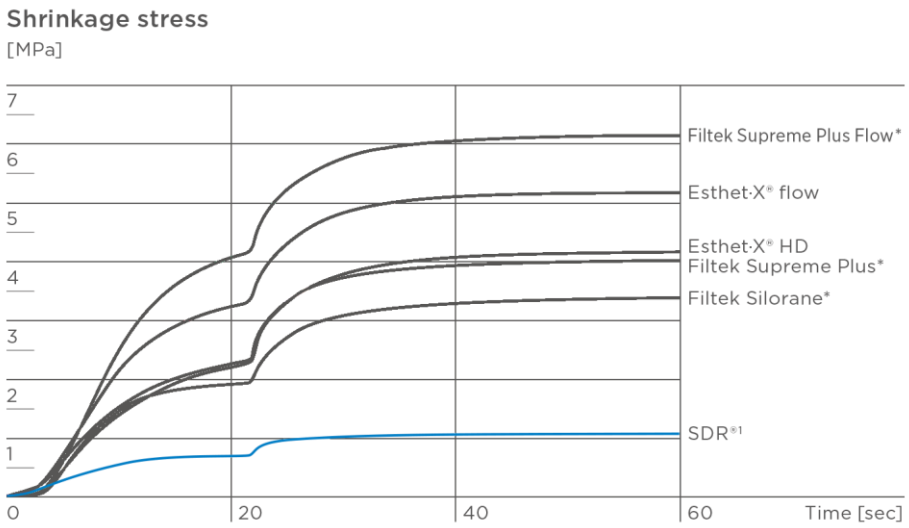

Figure 8 Mean polymerization shrinkage stress curves of the tested composites as a function of time.

CONCLUSION: SDR revealed the lowest polymerization shrinkage stress and shrinkage stress rate in comparison to conventional composites and a silorane-based composite.

3.1.2 Monomer conversion and shrinkage force kinetics of low-viscosity bulk-fill resin composites

Marovic D, Tauböck TT, Attin T, et al. *Acta Odontol Scand* 2015; 73:474-80

OBJECTIVE: To investigate the polymerization shrinkage force and the degree of conversion of different flowable composites by using Fourier transform infrared (FTIR) spectroscopy.

METHODS: Three bulk-fill composites (Surefil SDR flow, Venus Bulk Fill, x-tra base) were compared to a conventional composite (Esthet•X flow), which served as control. Each composite was bulk-filled and light-cured for 20 seconds in a simulated cavity with a C-factor of 2 using a LED curing unit (Bluephase G2, 1170 mW/cm^2 irradiance).

A transparent Mylar strip was positioned between the curing tip and the specimen to prevent oxygen inhibition. The shrinkage force was continuously recorded by a load cell over a period of 15 minutes from the start of curing using a custom-made stress analyzer. Additional composite specimens were prepared to measure remaining double bonds with FTIR spectroscopy at the near surface (0.1 mm) and at 1.5 and 4 mm bulk thickness 15 minutes after light-curing. Curing was performed as for shrinkage force measurements. A total of 20 scans per specimen were measured with a resolution of 4 cm^{-1}. Uncured composite served as reference. For each composite, the percentage degree of conversion was calculated using the ratio between the cured and uncured specimens.

RESULTS: The significantly lowest shrinkage force was generated by Surefil SDR flow, followed by the other bulk-fill composites, and finally the conventional composite. At 4 mm thickness, the conventional composite reached the lowest conversion degree, which was not significantly different to one of the bulk-fill composites (x-tra base).

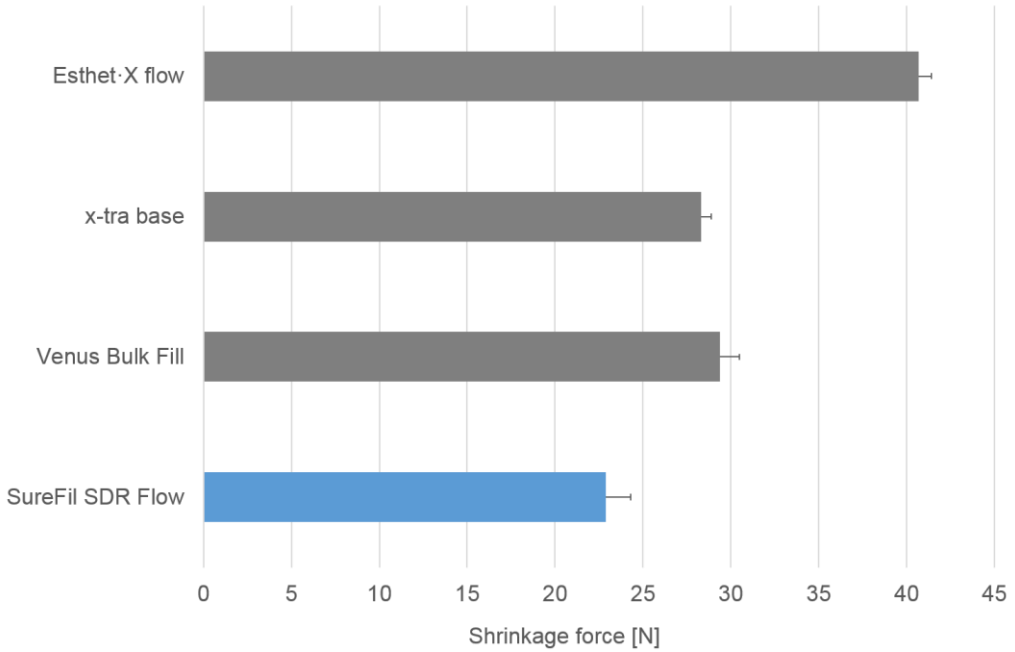

Figure 9 Mean polymerization shrinkage force (N) and standard deviation of the four composites tested.

CONCLUSION: Surefil SDR flow achieved the significantly lowest shrinkage forces at high levels of degree of conversion in up to 4 mm thick composite bulks.

3.1.3 Polymerization shrinkage, modulus, and shrinkage stress related to tooth-restoration interfacial debonding in bulk-fill composites

Kim RJ, Kim YJ, Choi NS, Lee IB. *J Dent* 2015; 43:430-9

OBJECTIVE: To evaluate the polymerization shrinkage (stress), dynamic modulus, and tooth-to-composite debonding during light-curing of conventional and bulk-fill composites.

METHODS: Polymerization shrinkage (stress) of conventional (Filtek Z250, Filtek Z350 XT Flowable) and bulk-fill (Filtek Bulk Fill, SonicFill, SureFil SDR flow, Tetric N-Ceram Bulk Fill) composites were measured within the first 10 minutes after light-curing using custom-made instruments. Additionally, standardized Class I cavities of extracted human molars were etched with phosphoric acid, bonded, and then filled with one of the six composites in bulk. The same etch&rinse adhesive was used in all groups and the curing time for each restoration was 40 seconds (LED unit Elipar S10, 750 mW/cm^2 irradiance). Acoustic emission (AE) signals generated as a result of debonding at the tooth-to-composite interface were recorded for 33.3 minutes during polymerization of the composite restorations.

RESULTS:

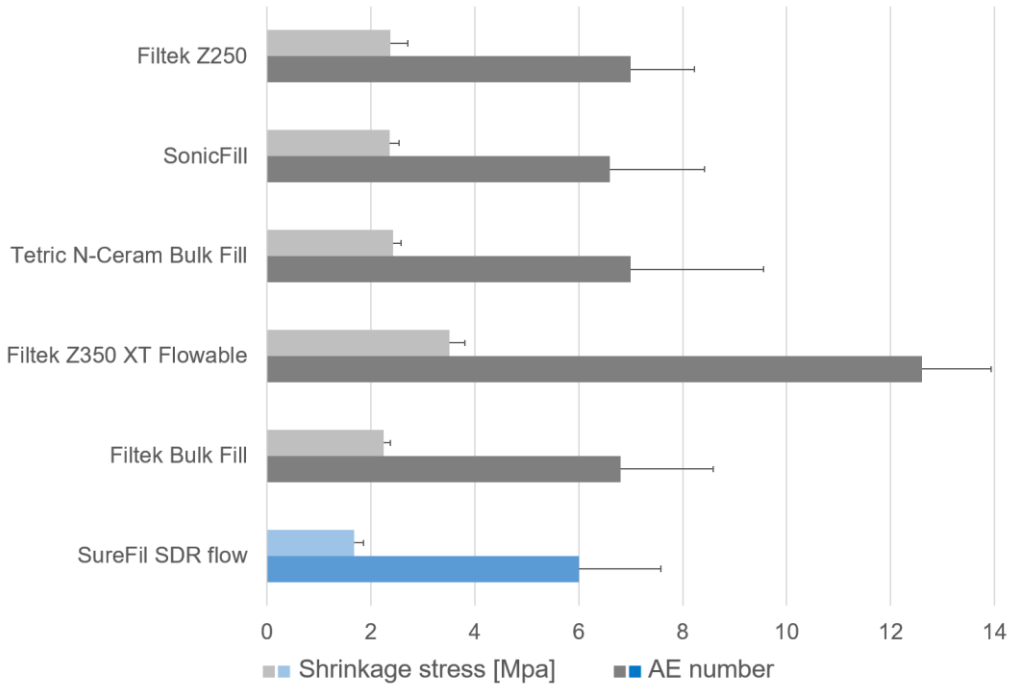

Figure 10 Mean polymerization shrinkage stress (MPa) and mean number of acoustic emission (AE) signals for each of the six composites tested.

CONCLUSION: Composites that exhibited greater polymerization shrinkage stress generated more debonding at the tooth-to-composite interface. SureFil SDR flow demonstrated significantly lower shrinkage stress and produced less debonding in Class I composite restorations than the other light-cured composites.

3.1.4 Influence of the compliance and layering method on the wall deflection of simulated cavities in bulk-fill composite restoration

Kim YJ, Kim R, Ferracane JL, Lee IB. *Oper Dent* 2016; 41:e183-94

OBJECTIVE: To examine the relationship between the wall deflection of Class II cavities and the polymerization shrinkage (stress) of conventional and bulk-fill composites.

METHODS: Standardized mesio-occluso-distal (MOD) cavities with three different wall thicknesses (1, 2, and 3 mm) were made of aluminium blocks. Bonding to the

model cavity surfaces was achieved by sandblasting and adhesive application. The cavities were filled either with conventional (Filtek Z250, Filtek Z350 XT Flowable) or bulk-fill (Filtek Bulk Fill, SonicFill, SureFil SDR flow, Tetric N-Ceram Bulk Fill) composites. All the composites were tested using two filling techniques: either they were filled in bulk and light-cured for 80 seconds or layered in four horizontal increments, of which each layer was light-cured for 20 seconds (LED unit Elipar S10, 1200 mW/cm^2 irradiance). Wall deflections in µm were measured for 33.3 minutes during polymerization of the composites by using linear variable differential transformer probes. The polymerization shrinkage (stress) and flexural modulus of the composites were also determined.

RESULTS: Surefil SDR flow showed significantly lower polymerization shrinkage stress than the other composites investigated. Wall deflection correlated strongly with the polymerization shrinkage stress.

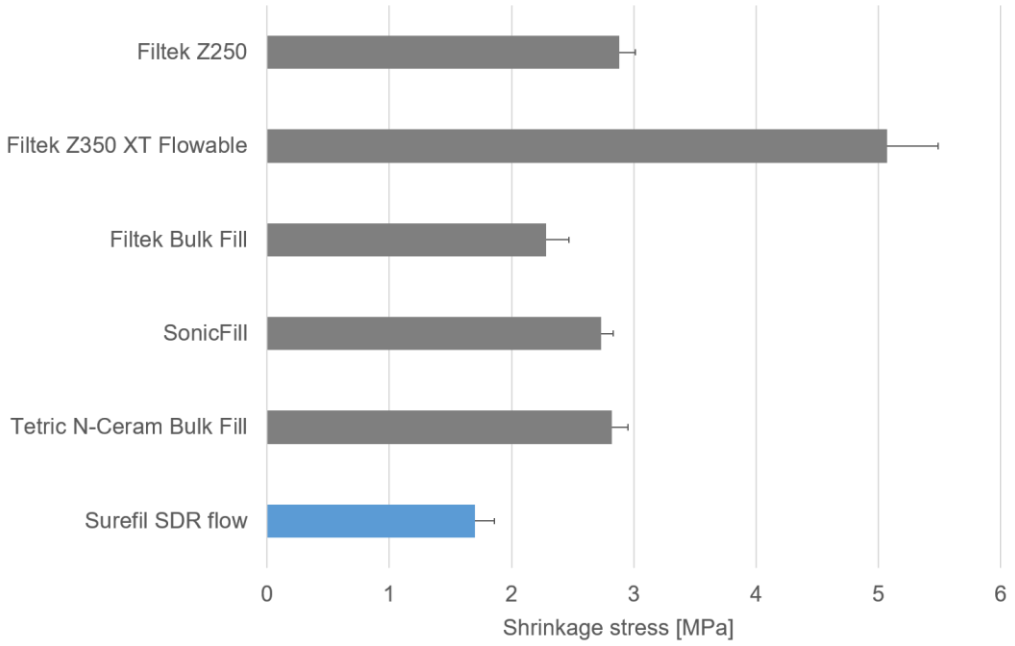

Figure 11 Mean polymerization shrinkage stress (MPa) and standard deviation of the six composites investigated.

CONCLUSION: Bulk-filling MOD cavities with the low-stress composite Surefil SDR flow yielded lower wall deflections than incremental layering of conventional composites with high stress, for example Filtek Z350 XT Flowable.

3.1.5 Microcomputed tomography evaluation of polymerization shrinkage of Class I flowable resin composite restorations

Sampaio CS, Chiu KJ, Farrokhmanesch E, et al. *Oper Dent* 2017; 42:E16-23

OBJECTIVE: To visualize and quantify the volumetric polymerization shrinkage of conventional (Permaflo), bulk-fill (Filtek Bulk-Fill, Surefil SDR flow), and self-adhesive (Vertise Flow) flowable composites using three-dimensional (3D) micro-computed tomography (micro-CT).

METHODS: Standardized Class I cavities of extracted human molars were filled with one of the four composites in bulk. With exception of the self-adhesive composite group, preparations were etched with phosphoric acid and bonded with the specific adhesive corresponding to each composite. All the restorations were light-cured for 40 seconds with a polywave LED unit (Bluephase 20i). The cavities were scanned three times using a µCT, namely after preparation, immediately after cavity filling, and after light-curing of the composite. Correlated micro-CT images were evaluated with a 3D rendering software to analyze both the shrinkage pattern and the volume of polymerization shrinkage.

RESULTS: The micro-CT revealed that the shrinkage patterns were similar for all groups, which presented higher shrinkage along the unbonded occlusal surface relative to the bonded interfaces of the cavity. SureFil SDR flow showed significantly less volumetric polymerization shrinkage compared with the other composites between which no significant differences were found.

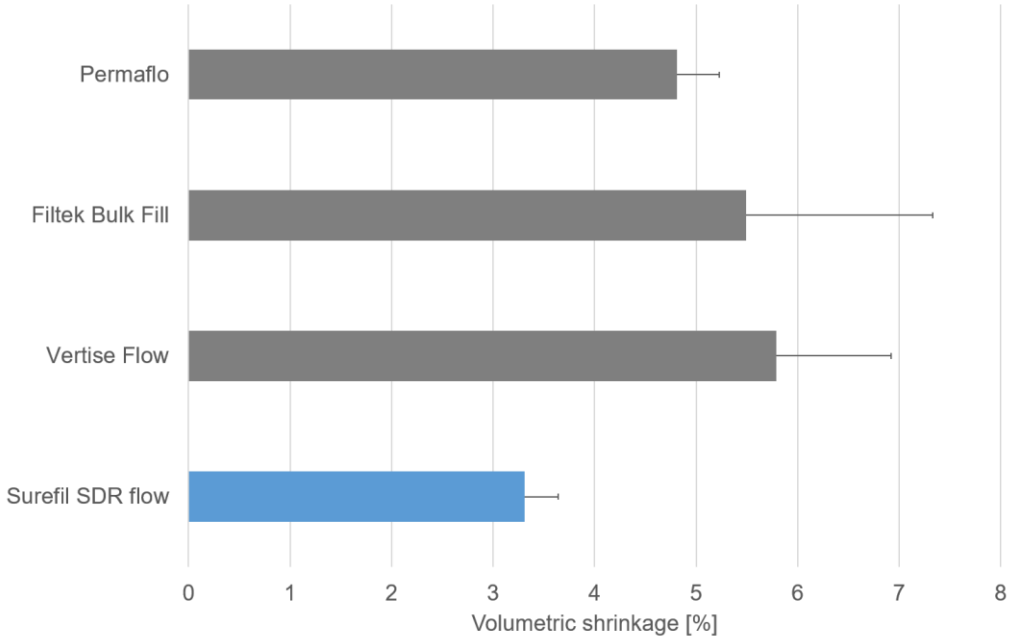

Figure 12 Percentages (mean and standard deviation) of volumetric polymerization shrinkage of the four composites investigated.

CONCLUSION: The study confirmed that Surefil SDR flow counteracts the volumetric loss and unwanted interfacial gap formation following light-curing of the composite restoration.

3.2 Marginal and internal adaptation

3.2.1 Marginal quality of flowable 4-mm base vs. conventionally layered resin composite

Roggendorf MJ, Krämer N, Appelt A, et al. *J Dent* 2011; 39:643-7

OBJECTIVE: To examine both the marginal and internal adaptation of composite restorations with and without SDR using different adhesives.

METHODS: MOD Class II cavities were prepared in human molars with proximal boxes located cervically in enamel and dentin, respectively. The restorations were done with etch&rinse (XP Bond, Syntac) and self-etch (Xeno V, Prompt L-Pop, iBond SE) adhesives. After light-curing for 40 seconds, half of the cavities were filled

in horizontal layers of 2 mm thickness using the respective recommended composites (Ceram X mono, Tetric EvoCeram, Filtek Supreme XT, Venus Diamond). The other half were restored with SDR as first 4 mm bulk increment, in combination with the tested composites on top. Light-curing was performed for 40 seconds per increment and an additional 20 seconds from the buccal and oral side of each restoration (Translux CL, 650 mW/cm^2 irradiation). After water-storage for 21 days, replicas were made for SEM. Chewing loading was performed against a steatite antagonist with 50 N load for 100,000 cycles at a frequency of 0.5 Hz. This was accompanied with 2500 thermocycles at 5-55 °C. After loading, the teeth were replicated again for SEM. The percentage gap-free margin was calculated in relation to the entire margin. Teeth were further cross-sectioned in order to investigate the internal adaptation.

RESULTS: Before loading, high percentages of gap-free margins were found in enamel and dentin for all adhesives. After loading, etch&rinse adhesives performed better than self-etch adhesives for both marginal and internal adaptation. The replacement of incremental layers with a 4 mm bulk of SDR had no negative influence on the composite restorations.

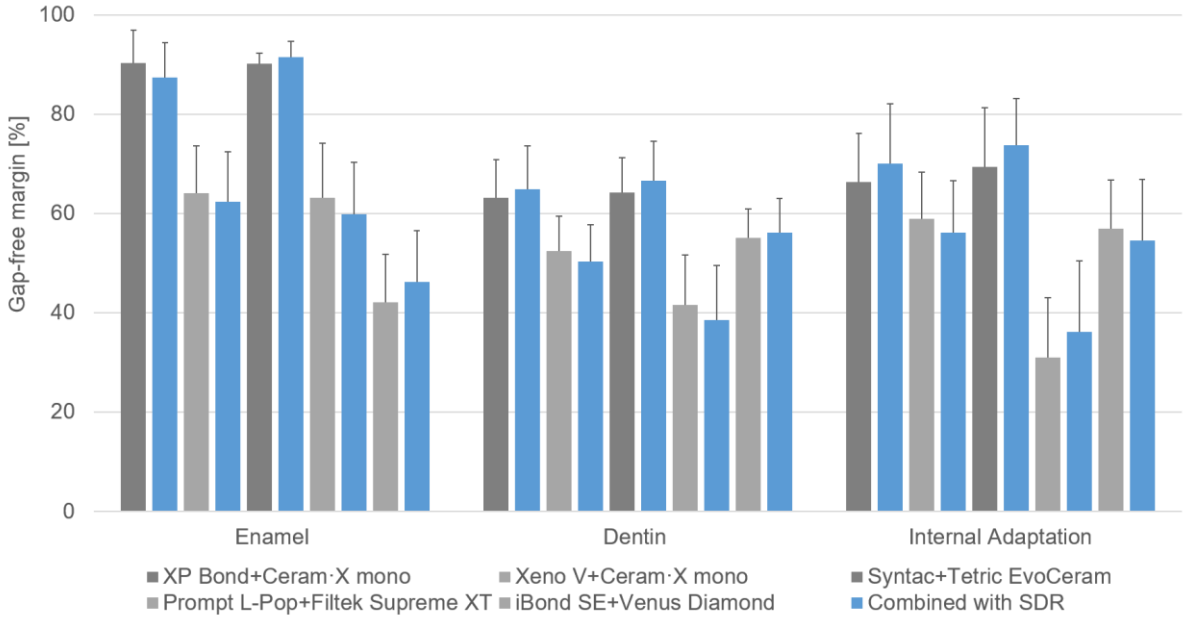

Figure 13 Percentages (mean and standard deviation) of gap-free margins for composite restorations using different material combinations, in each case with and without SDR.

CONCLUSION: The study demonstrated that procedural simplicity can be possible without any significant differences in marginal and internal adaptation of composite restorations further suggesting the effectiveness of SDR application technique saving chairside time of the clinician.

3.2.2 3D assessment of void and gap formation in flowable resin composites using optical coherence tomography

Nazari A, Sadr A, Shimada Y, et al. *J Adhes Dent* 2013; 15:237-43

OBJECTIVE: To evaluate both the internal adaptation and the void formation of two flowable composites at clinically relevant cavity depths by using swept-source optical coherence tomography (OCT).

METHODS: Standardized Class I cavities of two depths (2 and 4 mm) were prepared in extracted human molars and bulk-filled with either Surefil SDR flow or a conventional composite (Clearfil Majesty LV). The same self-etch adhesive was used in all the groups. The bulk increments were light-cured for 20 seconds (Surefil SDR flow) and 40 seconds (Clearfil Majesty LV), respectively. After 24 hours, the occlusal surfaces of the 4 mm deep restored teeth were trimmed by 2 mm to accommodate the depth limitations of light penetration by OCT. The area of interest (5 mm x 5 mm) was scanned to create cross-sectional images and stacked to generate 3D scans. OCT tomograms obtained from the 3D scans were evaluated with regard to the internal dentin adaptation and voids within the composite restorations. The percentages of sealed interfaces and voids were calculated. After the scans were obtained, specimens with and without gaps and voids were selected, cross-sectioned and observed under confocal laser scanning microscopy (CLSM) followed by SEM evaluation of the interfacial area.

RESULTS: At each cavity depth, both the microscopic and the OCT images showed better adaptation of Surefil SDR flow to the cavity walls and floor compared to the conventional composite. Regardless of the bulk volume, Surefil SDR flow showed a significantly lower percentage of voids than the conventional composite.

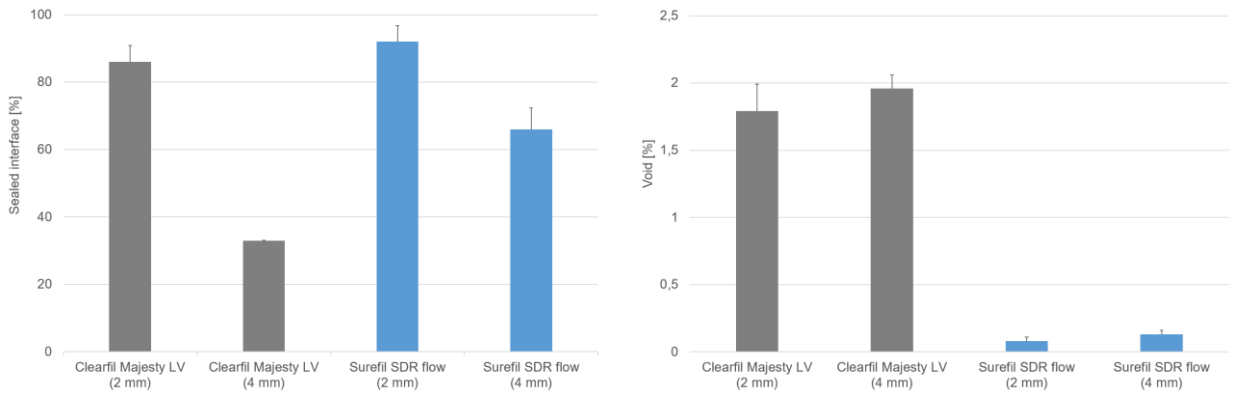

Figure 14 Percentages (mean and standard deviation) of sealed interface for the entire interface length (left) and voids within 2 mm and 4 mm thick bulk restorations.

CONCLUSION: Surefil SDR flow showed homogeneous bulk-filled restorations with significantly lower incidence of voids within the bulk and better internal dentin adaptation at both 2 mm and 4 mm depths compared to a conventional flowable composite.

3.2.3 Monomer conversion, microhardness, internal marginal adaptation, and shrinkage stress of bulk-fill resin composites

Fronza BM, Rueggeberg FA, Braga RR, et al. *Dent Mater* 2015; 31:1542-51

OBJECTIVE: To study the degree of conversion, hardness, shrinkage stress, and internal adaptation of bulk-fill composites in comparison with an incrementally layered composite.

METHODS: Standardized Class I cavities were prepared in extracted human molars and restored with one of five composites (Herculite Classic, Surefil SDR flow, Filtek Bulk Fill, Tetric EvoCeram Bulk Fill, everX Posterior) along with their respective recommended adhesives. Herculite Classic served as control and was placed both in 4 mm thick bulk and incrementally in four oblique layers, of which each one was light-cured for 40 seconds. The bulk increment was light-cured for 40 seconds only once. For all bulk-fill composites, the curing time was 20 seconds. A polywave LED unit (VALO, 995 mW/cm^2 irradiance) was used for the curing procedures. After one

week of water-storage, the restored teeth were sectioned bucco-lingually and polished. One half side was subjected to confocal Raman spectroscopy and Knoop hardness test to determine the degree of conversion and hardness at four cavity depths (1, 2, 3, and 4 mm). The other half was replicated in epoxy to evaluate the internal dentin adaptation under SEM. The percentage of internal gap in relation to the entire interface length was calculated. Additionally, shrinkage stress was measured using a tensometer.

RESULTS: Surefil SDR flow and Filtek Bulk Fill demonstrated uniform polymerization at all depths of the restoration. Hardness did not significantly differ among depths, except for Tetric EvoCeram Bulk Fill, which exhibited lower values at increased depth. When placed in bulk, internal adaptation correlated strongly with the shrinkage stress of the composite.

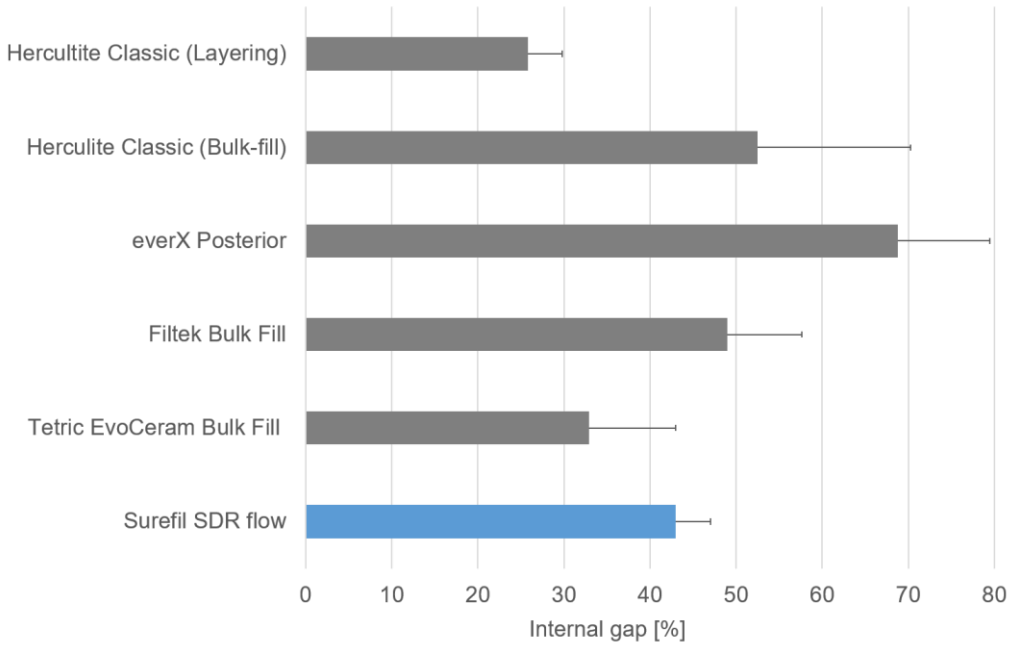

Figure 15 Percentages (mean and standard deviation) of internal gap for incrementally layered and bulk-filled composite restorations.

CONCLUSION: Surefil SDR flow and Tetric EvoCeram Bulk Fill restorations showed the best internal dentin adaptation, which was not significantly different from that of incrementally layered composite restorations.

3.2.4 Effect of bulk-filling on the bonding efficacy in occlusal Class I cavities

Van Ende A, De Munck J, Van Landuyt K, Van Meerbeek B. *J Adhes Dent* 2016; 18:119-24

OBJECTIVE: To compare the interfacial bonding of bulk-filled composite restorations to Class I cavity floor in dentin and onto flat dentin surfaces.

METHODS: A conventional composite (Filtek Z100) and three bulk-fill composites (SDR, Filtek Bulk Fill, Tetric EvoCeram Bulk Fill) were either bulk-filled into standardized 4 mm deep Class I cavities of extracted human molars or built-up in bulk on flat dentin surfaces using silicone molds with the same dimensions as the cavity preparation. A self-etch adhesive was used in all groups. Each of the composites was light-cured for 40 seconds with a polywave LED unit (Bluephase 20i, 1100 mW/cm^2 irradiance). After one week of water storage, the restored teeth were sectioned in four rectangular micro-specimens per tooth and subjected to a micro-tensile bond strength test in a universal testing machine with a load cell of 500 N and a crosshead speed of 1 mm/min. Bond strength values of specimens that failed before testing were recorded as zero. The mode of failure was analyzed light microscopically and representative fracture surfaces were further processed and imaged under SEM. Additional 4 mm thick samples were prepared to measure the light penetration in mW/cm^2 at the bottom of each composite with a spectrometer. The measurement was started when the composite was light-cured following the same curing protocol as before.

RESULTS: On flat dentin surfaces, no significant differences in bond strengths were found between the four composites and no pre-test failures occurred. When the cavities were bulk-filled, SDR showed significantly higher bond strengths than the other composites. Failure analysis revealed predominantly adhesive failures. The incidence of mixed failures increased on flat surfaces. With the conventional composite, all the specimens failed prior to bond strength testing, while SDR showed no pre-test failures. The highest light penetration was measured for SDR, followed by the other bulk-fill composites and, finally, Filtek Z100.

Composite	4 mm bulk on flat surface		4 mm cavity filled in bulk	
	Bond strength [MPa]	Pre-test failure [%]	Bond strength [MPa]	Pre-test failure [%]
SDR	26.7 ± 9.8	0	16.6 ± 7.7	0
Filtek Bulk Fill	19.7 ± 7.8	0	4.0 ± 7.8	75
Tetric EvoCeram Bulk Fill	21.4 ± 9.0	0	3.9 ± 7.5	73
Filtek Z100	26.0 ± 13.9	0	0.0 ± 0.0	100

Table 3 Mean micro-tensile bond strength (MPa) and standard deviation of the four composites onto flat dentin surfaces as well as to the cavity floor in dentin. Pre-test failures are given in percentage.

CONCLUSION: In this study, SDR was the only composite that did not cause premature debonding to dentin at the cavity floor when deep Class I cavities were filled in bulk. Moreover, the highest light irradiance at the bottom of the restoration was measured for SDR.

3.2.5 In vitro evaluation of marginal adaptation of direct Class II composite restorations made of different ‘‘low-shrinkage’’ systems

Shahidi C, Krejci I, Dietschi D. *Oper Dent* 2017; 42:273-83

OBJECTIVE: To evaluate the marginal adaptation of bulk-filling when subjected to chewing simulation in comparison to composites placed in incremental layering.

METHODS: Standardized MOD cavities were prepared in extracted human molars with proximal boxes located cervically in enamel and dentin, respectively. After selective enamel etching with phosphoric acid and application of a self-etch adhesive, the cavities were either filled incrementally in layers (Tetric, ELS) or in bulk (SonicFill, Surefil SDR flow). ELS was used with and without a 1 mm thick flowable layer

(ELS flow). Surefil SDR flow was covered with a 1 mm layer of Ceram X mono+ composite. Each layer or composite bulk was light-cured for 20 seconds (Bluephase, 1200 mW/cm^2 irradiance). Epoxy resin replicas were made before and after chewing loading against a stainless steel antagonist with 100 N load for one million cycles at a frequency of 1.5 Hz in saline. Scanning electron microscope (SEM) was used to analyze the proximal marginal quality.

RESULTS: Before and after loading, high percentages of continuous enamel margins were found among the composites, with the exception of SonicFill restorations after loading. In the critical cervical dentin, bulk-filling showed better marginal adaptation both before and after loading than incrementally placed composites with or without flowable base.

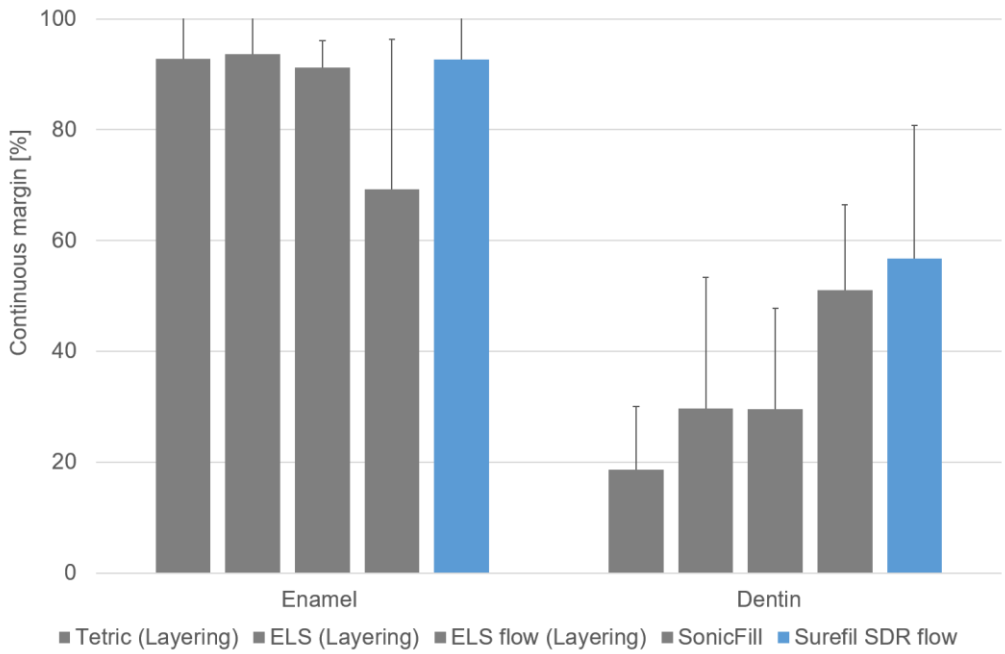

Figure 16 Percentages (mean and standard deviation) of continuous margin in enamel and dentin for incrementally layered and bulk-filled composite restorations.

CONCLUSION: Overall, Class II restorations using Surefil SDR flow as the bulk-fill composite showed the best marginal adaptation along the composites and filling techniques under investigation.

3.3 Depth of cure and degree of conversion

3.3.1 Polymerization shrinkage stress kinetics and related properties of bulk-fill resin composites

El-Damanhoury HM, Platt JA. Oper Dent 2014; 39:374-82

OBJECTIVE: To evaluate the polymerization shrinkage stress, polymerization efficiency, and related mechanical properties of different bulk-fill composites.

METHODS: Shrinkage stress of the bulk-fill composites was measured within the first 30 minutes after light-curing using a tensometer. A conventional composite (Filtek Z250) served as control. Using the tensometer software, maximum stress rate and time to achieve maximum stress rate were calculated. Polymerization efficiency was determined by measuring Knoop hardness on the top and the bottom surfaces of 4 mm thick bulk increments of each composite 24 hours after light-curing. The curing time was always 20 seconds (LED unit Demetron A.1, 1000 mW/cm^2 irradiance). The curing tip was placed in contact with a transparent Mylar strip covering the top of the composite. Bottom-to-top hardness percentages were calculated. Flexural strength and flexural modulus of the composites were measured according to the ISO 4049 standard. A crosshead speed of 1 mm/min was applied in a universal testing machine until failure occurred.

RESULTS: SureFil SDR flow and Venus Bulk Fill showed the highest polymerization at 4 mm bulk thickness with bottom-to-top hardness ratios above 90%. The lowest shrinkage stress was recorded for Surefil SDR Flow, Venus Bulk Fill and the experimental bulk-fill composite.

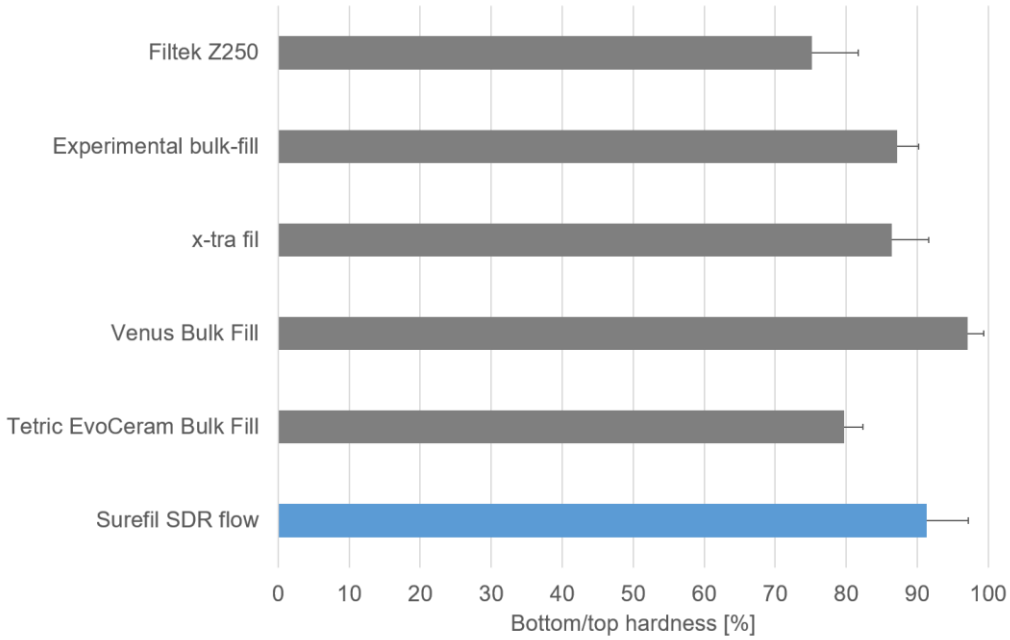

Figure 17 Percentages (mean and standard deviation) for bottom-to-top hardness of the six different composites tested.

CONCLUSION: A significant reduction in polymerization shrinkage stress while achieving high polymerization at 4 mm depth was achievable for some bulk-fill composites, including SureFil SDR flow.

3.3.2 Polymerization efficiency and flexural strength of low-stress restorative composites

Goracci C, Cadenaro M, Fontanive L, et al. Dent Mater 2014; 30:688-94

OBJECTIVE: To assess the depth of cure, degree of conversion, and flexural strength of different composites.

METHODS: The bulk-fill composites SonicFill, everX Posterior, and Surefil SDR were compared to composites that are not indicated for bulk-filling, but also claiming low-shrinkage behavior (Filtek Silorane, Kalore). The composites were placed and polymerized in bulk to prepare cylindrical specimens. Light-curing was performed for 20 seconds using a LED unit (Demi, 1100 mW/cm^2 irradiance), placing the curing tip on the top of each composite specimen. A transparent Mylar strip was positioned

between the curing tip and the specimen to prevent oxygen inhibition. Specimens were subjected to the Acetone Shake test where the uncured material was dissolved in acetone. The remaining thickness of the cured material was divided by two to calculate the depth of cure according to the ISO 4049 standard. Additional 4 mm thick specimens were prepared to measure the degree of conversion on top and at the bottom of the composites using FTIR spectroscopy with attenuated total reflectance (ATR) equipment (4000-500 cm^{-1} wavelength and 6 cm^{-1} resolution). Bottom-to-top ratios of degree of conversion percentages were calculated. Flexural strength of composite bars was evaluated after 24 hours water storage using the three-point bending test based on ISO 4049. A crosshead speed of 0.75 mm/min was applied in a universal testing machine until failure occurred.

RESULTS: The results of both the conversion degree and the depth of cure showed that all bulk-fill composites provide uniform curing through 4 mm thickness. Filtek Silorane and Kalore had significantly lower conversion degrees. Regarding the depth of cure and flexural strength results, Surefil SDR and everX Posterior achieved significantly higher values than Filtek Silorane and Kalore.

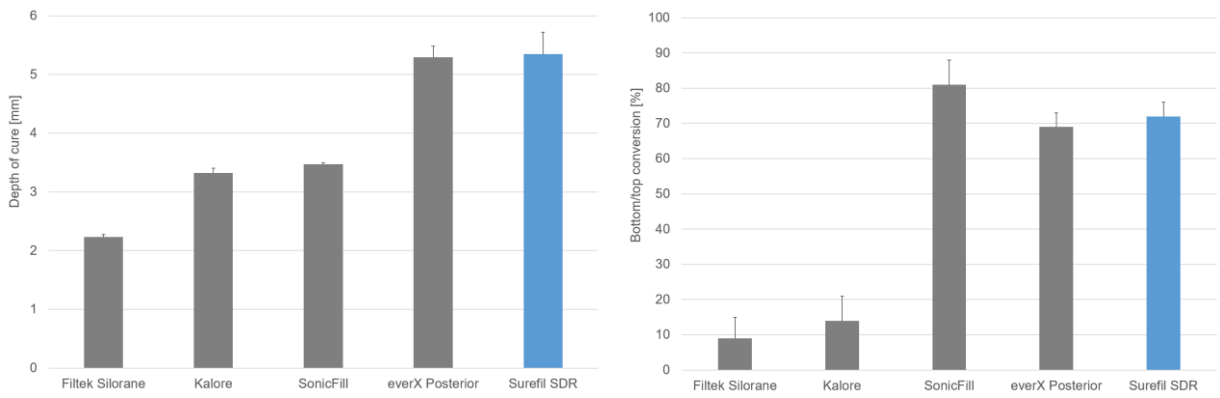

Figure 18 Mean depth of cure (mm) and standard deviation (left) as well as percentages (mean and standard deviation) for bottom-to-top conversion degree of the five composites.

CONCLUSION: Surefil SDR and everX Posterior cured properly in 4 mm thick bulk increments, while the depth of cure for SonicFill was much lower than the value stated by the manufacturer (up to 5 mm increments).

3.3.3 Bulk-fill resin composites: Polymerization properties and extended light curing

Zorzin J, Maier E, Harre S, et al. Dent Mater 2015; 31:293-301

OBJECTIVE: To compare the degree of conversion, hardness, and polymerization shrinkage (stress) of bulk-fill and conventional composites.

METHODS: Two conventional (Filtek Z250, Filtek Supreme XTE flow) and five bulk-fill composites were bulk-filled in molds of 2 or 4 mm in depth. Light-curing was performed in the manufacturers' light-curing time (10, 20 seconds) or for 30 seconds (Bluephase 20i, 1200 mW/cm^2 irradiance) through a transparent Mylar strip covering the composite. After polishing and water-storage of the composites for 24 hours, the degree of conversion and hardness was determined on the top and 2 mm or 4 mm deep bottom surface of each specimen. To measure the remaining double bonds, FTIR spectroscopy with attenuated total reflectance (ATR) accessory was operated under the following conditions: 4000-650 cm^{-1} wavelength, 4 cm^{-1} resolution, and 64 scans. Uncured composite served as the reference. Hardness was measured using a Vickers indenter. Bottom-to-top ratios of degree of conversion and hardness percentages were calculated. Additional specimens were prepared to measure the polymerization shrinkage (stress). Volumetric shrinkage was determined by density measurements of light-cured and uncured composites according to Archimedes principle. Shrinkage stress was measured within the first 5 minutes after light-curing using an extensometer.

RESULTS: Except SDR and x-tra base, all bulk-fills displayed a significant decrease in hardness while maintaining high conversion degree at 4 mm. Higher radiant exposure (30 seconds at 1200 mW/cm^2) improved the polymerization but resulted in the case of Tetric EvoCeram Bulk Fill and x-tra base in significantly higher shrinkage stress.

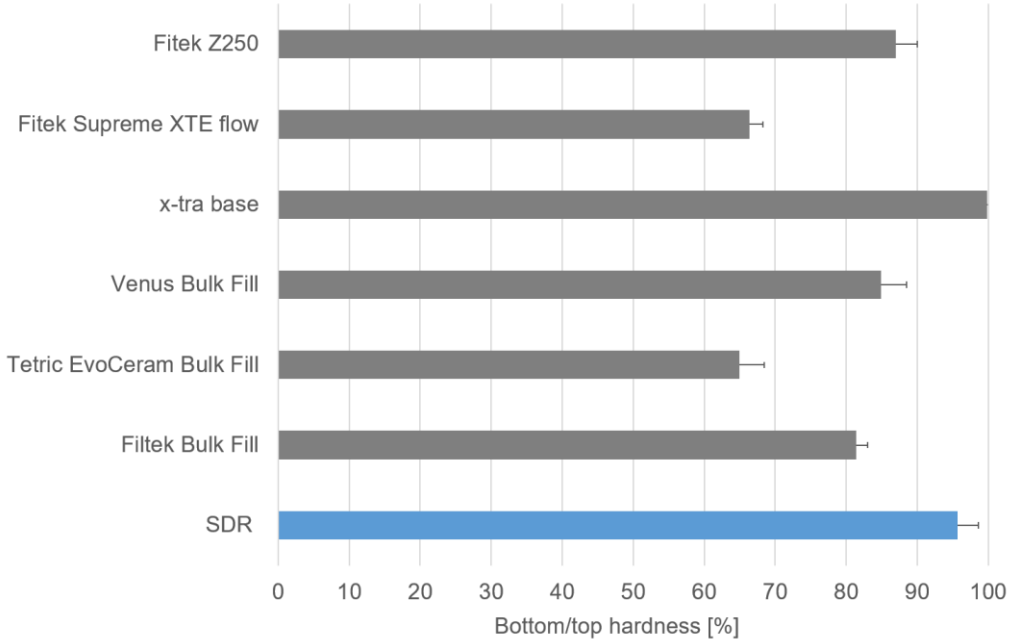

Figure 19 Percentages (mean and standard deviation) for bottom-to-top hardness of the different composites tested in 4-mm thickness.

CONCLUSION: SDR in the manufacturer's light-curing time cured properly in 4 mm. Higher radiant exposure of SDR had no adverse effect on its polymerization shrinkage stress.

3.3.4 Degree of conversion and BisGMA, TEGDMA, UDMA elution from flowable bulk fill composites

Lempel E, Czibulya Z, Kovács B, et al. Int J Mol Sci 2016; 17:732

OBJECTIVE: To assess the degree of conversion and the amount of released monomers of bulk-fill composites. A comparison was made with a conventional composite.

METHODS: Standardized 4 mm deep molds were placed on a glass slide and filled either with flowable bulk-fill composites (Filtek Bulk Fill, x-tra Base, Surefil SDR flow) or a conventional composite (Filtek Ultimate Flow). As positive control, Filtek Ultimate Flow specimens were also used in 2 mm thickness. Specimens were light-cured for 20 seconds with a LED unit (LED.C, 1100 mW/cm^2 irradiance) through a transparent Mylar strip covering the composite. In the case of Filtek Bulk Fill and x-tra base, the effect of a 10 seconds cure was also investigated. After 24 hours, the specimens were measured with micro-Raman spectroscopy for the calculation of double bond content on the top and bottom surface and the uncured composite was used as reference. The specimens were further placed in 75% ethanol for dissolution of the unreacted monomers. The amount of eluted monomers was analyzed with high-performance liquid chromatography (HPLC) from the ethanol solutions and calculated by the calibration curves of concentration versus peak area produced by the three monomers.

RESULTS: Surefil SDR flow showed significantly higher conversion degrees at the bottom and top surface than the other composites tested. Shorter curing times (10 seconds) significantly reduced the polymerization of Filtek Bulk Fill and x-tra base by 41% and 16%, respectively. The conventional composite showed a higher rate of monomer elution than the bulk-fill composites.

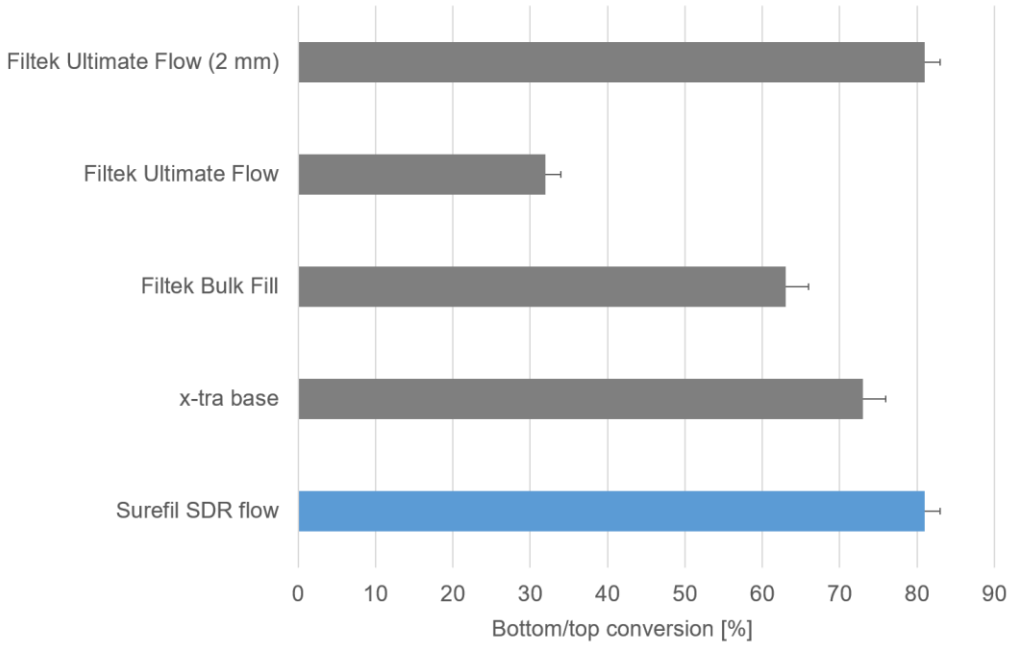

Figure 20 Percentages (mean and standard deviation) for bottom-to-top conversion degree of the different composites tested in a 2 mm (positive control) and 4 mm thickness.

CONCLUSION: Surefil SDR flow demonstrated high polymerization in 4 mm thick bulks reaching the conversion degree of 2 mm thick composite layers.

3.3.5 Curing characteristics of flowable and sculptable bulk-fill composites

Miletic V, Pongprueksa P, De Munck J, et al. Clin Oral Invest 2017; 21:1201-12

OBJECTIVE: To evaluate the degree of conversion of five bulk-fill composites and one conventional composite and correlate with depth of cure, hardness and translucency.

METHODS: Each composite was placed in standardized molds either in two 2 mm thick layers (each light-cured for 10 seconds) or in bulks of 4 mm (cured for 10 or 20 seconds) and 6 mm (cured for 20 seconds), respectively. Light-curing was performed with a polywave LED unit (Bluephase 20i, 1337 mW/cm^2 irradiance) through a glass slide covering the composite. For each of the four filling techniques the degree of conversion and hardness was measured 24 hours after polymerization. FTIR-ATR spectroscopy (4500-400 cm^{-1} wavelength, 4 cm^{-1} resolution, and 32 scans)

was used to measure the polymerization on the top and bottom surface of each composite specimen with uncured composite as the reference. Vickers hardness was measured on the top and bottom of each specimen using a Vickers indenter. Depth of cure was measured with the Acetone Shake test. Specimens were bulk-filled in cylindrical molds and light-cured for 20 seconds. After 5 minutes, the composite cylinder was removed and mixed in acetone dissolving the unset composite. The residual specimen thickness was measured and divided by two in order to calculate the depth of cure. The translucency parameter was measured by 4 mm thick specimens using a spectrophotometer against a black and white background.

RESULTS: SonicFill, Tetric EvoCeram Bulk Fill, and Xenius Base required a higher radiant exposure (20 seconds at 1337 mW/cm^2) than SDR and Filtek Bulk Fill to reach at least 80% bottom-to-top hardness ratios. SonicFill and the conventional composite could not be properly cured in 4 mm, while the other bulk-fill composites showed sufficient depth of cure at more than 4 mm.

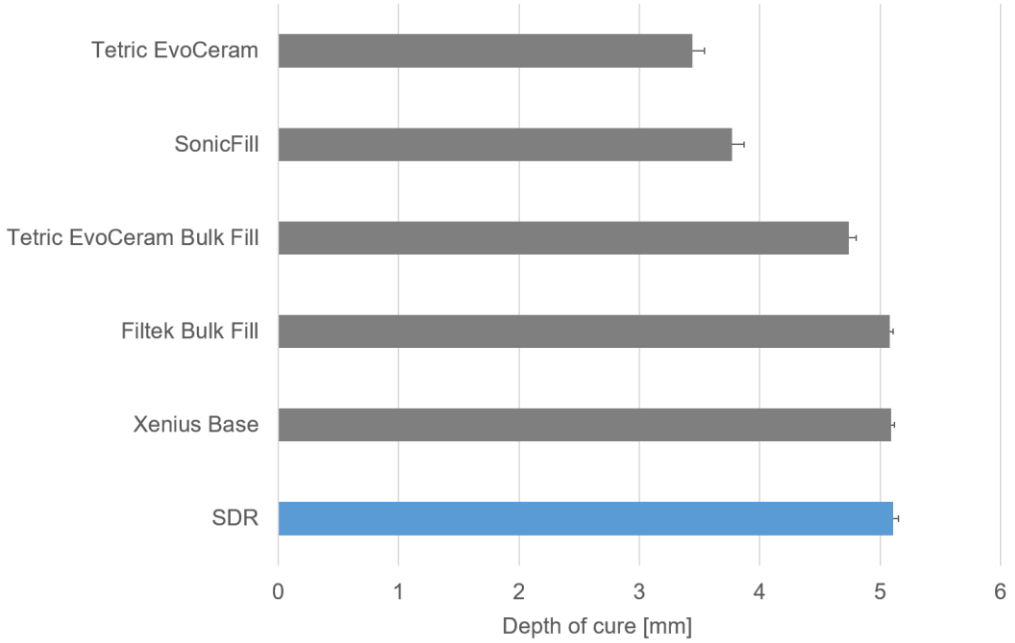

Figure 21 Mean depth of cure (mm) and standard deviation of the six composites tested.

CONCLUSION: Flowable bulk-fill composites like SDR performed better regarding polymerization efficiency compared to high viscosity bulk-fill composites like SonicFill.

4. Clinical studies

4.1 A three year clinical evaluation of Class II composite resin restorations using Surefil SDR and an experimental composite resin or Esthet•X HD

Burgess J, Munoz C. University of Alabama, USA. *Internal report* 2010

OBJECTIVE: A three-year clinical trial to evaluate the in vivo performance of Surefil SDR flow as bulk-filled base in posterior composite restorations.

METHODS: Eighty-seven patients were enrolled into this clinical trial in US dental schools, receiving a total of 170 Class I and II restorations. In all cavities, the etch&rinse adhesive Prime&Bond NT was applied. SureFil SDR flow was placed in bulks of 4 mm thickness as needed to fill the cavity to the level of the dentin-enamel junction. An experimental micro-hybrid composite or Esthet•X HD composite was then layered onto the bulk-filled base to complete the occlusal surface of the restoration. Light-curing of adhesive and composite was performed with a LED unit (Freelight 2, >800 mW/cm^2 irradiance). Restorations were evaluated within one week (baseline) as well as six months and then annually after placement of the restoration. At each recall, clinical parameters relevant to the bulk-fill composite were evaluated. A gingival index was also noted to measure any inflammation of the gingiva adjacent to the restoration.

RESULTS: After three years, 86 restorations in 49 patients were available for evaluation. In total, six fractures within the capping composite required repair. One restoration was replaced. There was no post-operative sensitivity related to the use of Surefil SDR flow, and the response of the gingiva in contact with the bulk-filled base was within normal limits. There were no observations of secondary caries associated with the bulk-fill composite and there were no reports of adverse events throughout the duration of the trial.

Criteria	SureFil SDR flow Baseline (n = 170)	SureFil SDR flow 3 years (n = 86)
Retention	100%	99%
Proximal contact	99%	90%
Secondary caries	100%	97%
Fracture	100%	98%

Table 4 Percentage of composite restorations with an acceptable rating at baseline compared to the recall data after three years.

CONCLUSION: Surefil SDR flow when used as bulk-filled base in Class I and II restorations with a conventional composite as occlusal capping layer exhibited highly acceptable results after three years.

4.2 Posterior bulk-filled resin composite restorations: A 5-year randomized controlled clinical study

Van Dijken J, Pallesen U. J Dent 2016; 51:29-35

OBJECTIVE: To compare in a randomized controlled study the clinical performance of SDR based restorations to conventionally layered composite restorations after five years.

METHODS: In total, 86 patients with one or two pair similar Class I or II cavities received 200 composite restorations by two dentists. The majority of the cavities were deep and had extended size. The SDR cavity of each pair was filled in bulks of 4 mm up to 2 mm short of the occlusal surface and covered with the hybrid composite Ceram X mono+. The other cavity was conventionally filled with Ceram X mono+ in 2 mm layers. In all cavities, the self-etch adhesive Xeno V+ was applied. Light-curing of adhesive and composite was performed with a LED unit (SmartLite PS,

950 mW/cm^2 irradiance). All restorations were in occlusion. The restorations were evaluated using slightly modified USPHS criteria at baseline and then annually during five years. Caries risk and bruxing habits of the participants were estimated.

RESULTS: No post-operative sensitivity was reported. At five years, 183 restorations, 68 Class I and 115 Class II, restorations were evaluated. Ten restorations failed, four SDR and six conventionally layered restorations, all of which were Class II. The main reason of failure was tooth fracture and secondary caries resulting in annual failure rates of 1.1% for SDR and 1.3% for conventionally layered restorations. No significant differences were observed between bulk-filled and conventionally layered composite restorations for the evaluated criteria at the recall.

Criteria	**SDR restoration** (n = 92)	**Conventional restoration** (n = 91)
Anatomical form	96.7%	94.5%
Marginal discoloration	100%	100%
Marginal adaptation	96.7%	95.6%
Color match	100%	98.8%
Surface roughness	100%	100%
Secondary caries	97.8%	97.8%

Table 5 Percentage of SDR based restorations with an acceptable rating compared to incrementally layered composite restorations after five years.

CONCLUSION: This study showed good clinical results for the recalled SDR based restorations after five years, similar to the failure rate for composite in the layering technique.

4.3 Bulk-filled posterior resin restorations based on stress-decreasing resin technology: a randomized, controlled 6-year evaluation

Van Dijken J, Pallesen U. Eur J Oral Sci 2017; 125:303-9

OBJECTIVE: To report on the six-year recall data of SDR based composite restorations that were intraindividually compared with a conventionally layered composite.

METHODS: Thirty-eight patients with a total of 53 paired restorations, 30 Class I and 76 Class II restorations, were treated with either conventionally layered or bulk-filled composite restorations by one dentist (the first author). The cavity pairs were similar in size and location. The SDR cavity of each pair was filled in bulks of 4 mm up to 2 mm short of the occlusal surface and covered with the hybrid composite Ceram X mono. The other cavity was conventionally filled with Ceram X mono in 2 mm layers. In all cavities, the self-etch adhesive Xeno V was applied. Light-curing of adhesive and composite was performed with a LED unit (SmartLite PS, 950 mW/cm^2 irradiance). All restorations were in occlusion. The restorations were evaluated within one week of placing restorations (baseline) and then annually during six years.

RESULTS: One conventionally filled molar restoration showed post-operative sensitivity during the first three weeks. After six years, 49 paired restorations, 26 Class I and 72 Class II restorations were evaluated. Six Class II molar restorations failed, three SDR and three conventionally layered restorations, which resulted in annual failure rates of 1% for both groups. Reasons for failure were fractures of the composite (four cases) or tooth cusp (one case) or secondary caries in another case. No significant differences were observed between bulk-filled and conventionally layered composite restorations for the evaluated criteria at the recall.

Criteria	SDR restoration (n = 49)	Conventional restoration (n = 49)
Anatomical form	96%	98%
Marginal discoloration	100%	100%
Marginal adaptation	94%	94%
Color match	100%	100%
Surface roughness	100%	100%
Secondary caries	98%	100%

Table 6 Percentage of SDR based restorations with an acceptable rating compared to incrementally layered composite restorations after six years.

CONCLUSION: The six-year recall data continue to support that using SDR as a bulk-fill base results in a clinical performance of the composite restoration equivalent to conventional layering.

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Glossary and Abbreviations

BHT	butylated hydroxy toluene
CLSM	confocal laser scanning microscopy
CQ	camphorquinone photoinitiator
DMA	Dynamic mechanical analysis
FTIR	Fourier transform infrared
OCT	optical coherence tomography
SEM	Scanning Electron Microscope

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Demetron A.1, Demi (Kerr)

ELS, ELS flow (Saremco Dental)

Elipar S10 (3M Espe)

everX Posterior (GC)

Filtek Bulk Fill, Filtek Silorane, Filtek Supreme Plus Flow, Filtek Supreme Plus, Filtek Supreme XT, Filtek Supreme XTE flow, Filtek Ultimate Flow, Filtek Z100, Filtek Z250, Filtek Z350 XT Flowable, Freelight 2 (3M Espe)

Herculite Classic (Kerr)

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Tetric, Tetric EvoCeram, Tetric EvoCeram Bulk Fill, Tetric N-Ceram Bulk Fill (Ivoclar Vivadent)

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VALO (Ultradent)

Venus Bulk Fill, Venus Diamond (Kulzer)

Vertise Flow (Kerr)

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x-tra base, x-tra fill (VOCO)