Polymerization Shrinkage of Dental Composites Registered by a Video-imaging Device. A pilot study

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ABSTRACT

The use of composite materials for dental fillings has become more common due to demands for more esthetic filling materials and a national ban against using mercury-containing products, among others dental amalgam. However, one of the drawbacks with composites is their polymerization shrinkage. Filler particles are incorporated into composites among other things to minimize the shrinkage. The sizes of the filler particles have in recent years become smaller and most composites have nano-particles incorporated.

The aims of the study were to investigate if a) the filler load, b) the curing time and c) tested after "best-before date" will affect the polymerization shrinkage of commercial dental composites. The hypotheses are that high filler loads will result in low shrinkage, and that different curing times and tested after "best-before date" will not significantly affect the shrinkage.

The polymerization shrinkage of ten commercial composites was studied and three different curing times were used. 150 specimens were manually formed and AcuVol was used to register the volumetric shrinkage.

The mean volumetric polymerization shrinkage values of the composites ranged between 1.8% and 5.0% for the recommended curing times. The composite with the highest filler load (Kalore) had the lowest mean shrinkage, and the composite with the lowest filler load (SDR) had the highest mean shrinkage.

The video-imaging device could be used to register the polymerization shrinkage of dental composites. The composites polymerization shrinkage was related to the filler loads when the composites were arranged in groups based on their type. No conclusion could be made about the effect of different curing times and "best-before date".

INTRODUCTION

The use of dental composites for filling materials have become more common due to demands for a more esthetic filling material and legislations prohibiting amalgam in some countries. Amalgam, as a filling material, has been used for more than 150 years and it is still in use in many parts of the world. It is an alloy of mercury and other metals such as silver, tin, and copper. Whether amalgam is toxic or not, has been debated over the years without reaching consensus (Mutter, 2011). One of the advantages of using dental composite materials is their micromechanically retention to the tooth surfaces, which makes undercuts unnecessary for composite fillings but not when using amalgam.

Amalgam fillings have lower failure rates and less secondary caries than composite materials, but the materials are equivalent when it comes to fractures of restorations. However, the studies included in the review article from the Cochrane Collaboration have a low grade of evidence (Rasines Alcaraz et al., 2014). A study by Opdam et al. (2007) shows a slightly better ten-year survival rate for composites (82.2%) than amalgam (79.2%). The study also shows that secondary caries (34%), fractures (13%) and endodontic treatment (12%) are common reasons for failure. Another study by Bernardo et al. (2007) shows that amalgam has a better seven-year survival rate (94.4%) than composites (85.5%). The failure rate was almost 3 times higher for composites and the most common reason for failure for both materials was secondary caries.

Dental composites could be classified based on their filler sizes and combination of different particles. They could also be classified based on their viscosity. The composites consist of two main phases: one organic matrix and one, mainly inorganic, filler particles. The non-polymerized organic matrix mainly consists of different types of monomers. Common monomers used in composites are Bis-GMA (Bisphenol A-glycidyl methacrylate), TEGDMA (Triethyleneglycol dimethacrylate) and UDMA (Urethane di-methacrylate). The Bis-GMA is a stiff and heavy molecule, which makes the composite highly viscous. TEGDMA is a smaller and more flexible molecule with a lower molecular weight, which makes it less viscous than Bis-GMA and more likely to undergo greater polymerization shrinkage. UDMA has a lower viscosity than Bis-GMA and it can be used alone but it is often combined with other monomers in today's composites to improve various performances (Lindberg, 2005**;**

Anusavice et al., 2013).

Another method to reduce shrinkage is by adding inorganic glass filler particles. By using different sized and shaped filler particles, maximal filler loading can be achieved. The amount of filler, size and shape affect the consistency of the composite. Small particles as nanofiller, gives a higher gloss when the composites are polished and results in better esthetics (Ilie et al., 2011; Anusavice et al., 2013).

In recent years the filler particle size has become smaller and most of today's composites contain a small amount of nanoparticles. Most of dental composites are hybrids, and depending on their filler size and filler load, they can be divided into micro-hybrid or nano-hybrid composites. Hybrid-composites per definition consist of filler particles from two or more filler size ranges. The particles can be in the size range of 10 nm to 10 µm. Microfilled composites have filler particles ranging from 10 nm to 50 µm. Nano-composites consist of particles or clusters with a size ranging from 1 nm to 1.4 µm (Lindberg, 2005; Anusavice et al., 2013). According to the European Commission's definition of a nanomaterial, at least 50% of particles must be in the size range 1 to 100 nm (European Commission, 2014).

Silane is a coupling agent, which bonds the filler particles to the matrix. Besides the matrix and the filler particles, there are other components in the composite. Color pigments give composites different suitable shades to match the tooth, activator-initiator systems initiate the polymerization process from a soft to a hard and durable filling. Polymerization inhibitors give us more time to form the composite before it starts to solidify and increase the storage time (Anusavice et al., 2013).

A curing light is used to start the curing process. When the light is applied, the monomers polymerize and form a rigid structure called a polymer network. During the polymerization a conversion of the double bounding into single bounding occurs between the carbon molecules. This conversion leads to shorten distance between the molecules resulting in polymerization shrinkage. After the polymerization the composite converts into a solid structure. The polymerization shrinkage can lead to stress, gaps, discoloring, secondary caries, cracks and increased sensitivity in restored tooth (Tiba et al., 2005; Han et al., 2012; Anusavice et al., 2013).

To decrease the polymerization shrinkage, manufacturers try to optimize the proportion of monomers and filler particles in their composites. By using more filler and less monomer they can decrease the polymerization shrinkage (Han et al., 2010). They also develop new types of monomers to replace or to be incorporated with today's monomers, such as high molecular weight and epoxy-based resins (Peutzfeldt, 2006). Filler particles are not just used to reduce the polymerization shrinkage but also to improve mechanical properties and wear resistance in composites. Composites with spherical shaped filler particles do not withstand wear as good as composites with irregular shaped fillers (Ilie et al., 2011; Rastelli et al., 2012).

Most manufacturers declare the amount of polymerization shrinkage of their composites. However, different methods used for measuring the polymerization shrinkage can result in different values. Two different systems, AcuVol and Drop Shape Analysis System model DSA10 Mk2 (DSAS), have been found to give equivalent results for two out of three tested composites (Tiba et al., 2005). The AcuVol system was also found to have comparable results with the ADA/NIST mercury dilatometer (Sharp et al., 2003).

A previous study has shown a correlation between filler loading in experimental composites and polymerization shrinkage. The higher the filler load is, the lower the polymerization shrinkage will be (Han et al., 2012). A correlation between filler load and polymerization shrinkage has been registered when six experimental and three commercial dental composites were studied. An AcuVol instrument was used to register the volumetric shrinkage. The experimental composites had the same compositions but different filler loading ranging from 50 to 80 weight- %. The three commercial composites had filler contents ranging from 55 to 80 weight- %. A strong statistically significant correlation was found between the volumetric shrinkage and filler content of the studied commercial and experimental composites (Han et al., 2010). But there are studies that do not show a correlation between the filler load and the polymerization shrinkage when an AcuVol device was used to measure the shrinkage (Tiba et al., 2005; Lien et al., 2010). It has been shown that even the same amount of filler can lead to different shrinkage results (Lien et al., 2010). Another study that used a mercury dilatometer to measure the shrinkage, showed that composites with a high amount of filler do not always have the lowest polymerization shrinkage (Kleverlaan et al., 2005). Few studies have been done to study the impact of "best-before date" on dental composites. There are also few studies done about the effect of different curing times on the polymerization shrinkage of dental composites.

The aims of the study were to investigate if a) the filler load, b) the curing time and c) tested after "best-before-date" will affect the polymerization shrinkage of commercial dental composites using a video-imaging device, AcuVol, to register the volumetric shrinkage. The hypotheses were that high filler loads will result in low polymerization shrinkage, and different curing times and tested after "best-before-date" will not significantly affect the polymerization shrinkage.

MATERIALS AND METHODS

The polymerization shrinkage of ten commercial composites was studied. The name and type of composite, manufacturer, filler load, filler size, shade, expiration date, lot number and polymerization shrinkage given by the manufacturer are seen in Table 1. Three different curing times were used; the manufacturer's recommended curing time (20 or 40 sec), half of the recommended curing time (10 or 20 sec) and one and a half of the recommended curing time (30 or 60 sec).

15 specimens were made of each composite, five for each curing time. A total of 150 specimens were tested. A random number generator (www.slump.nu) was used to establish an order to conduct the tests.

A lab protocol was set to ensure that the same procedure was used during the whole experiment.
Before each test, a light-measuring device (Bluphase meter, Ivoclar Vivadent, Schaan, Liechtenstein) was used to control the light-intensity of the light-curing unit (Astralis 7, Ivoclar Vivadent, Schaan, Liechtenstein). The light-curing unit was used to cure the composites using HIP mode with light intensity 700-900 mW/cm^2.

The AcuVol manufactured by BISCO Inc. (Schaumburg, IL, USA) was used to register the volumetric shrinkage of the composites. The AcuVol was calibrated before each experiment by running a 2 min test without any specimen on the pedestal.

A composite slurry was placed on the polytetrafluoroethylene pedestal in front of a camera inside of the AcuVol, Figure 1. The AcuVol has two modes to measure shrinkage, single-view volumetric reconstruction (SVVR) where the pedestal is fixed in position, and multiple-view

volumetric reconstruction (MVVR) where the pedestal rotates. MVVR was used for the recording of the volumetric polymerization shrinkage. The composite was manually formed using composite instrument into a semi-sphere shape with a size of approximately 2 mm in diameter. A baseline analysis of the specimen was conducted. Elapsed time between starting to manually form the composite until light curing was max. 1 min. The tip of the light-unit was positioned about 2 mm above the top of the composite specimen and cured. The polymerization shrinkage was measured for 10 min after the curing. All the data from every experiment was saved in Microsoft Excel. The 10-min-shrinkage value in vol. % was registered. The mean values with standard deviations (SD) were calculated for every composite and curing time. The results were presented in Figure 2 and Appendix 1.

Literature search

The database PubMed was used to search for scientific articles by using key words "dental composites", "volumetric shrinkage", "polymerization shrinkage", "filler" and "AcuVol". MeSH terms like "composite resins" were searched on Swedish MeSH. The key words and the MeSH terms were put together in different combinations to search for scientific articles. The literature search included studies not older than 10 years. Examples of searches using MeSH terms and key words on PubMed:

- "Composite resins" AND "AcuVol" resulted in 9 articles.
- "Dental composites" AND "polymerization shrinkage" AND "filler" resulted in 41 articles from the last 10 years.
- "Dental resin" AND "monomers" AND "new composites" resulted in 25 articles from the last ten years.

Ethical reflection

The Ethics Forum at the Department of Odontology at Umeå University finds that appropriate ethical considerations have been integrated into this degree project. All scientific articles studied are peer reviewed before publication. In studies based on laboratory tests ethical considerations may appear unimportant. However, it is important to use materials and methods that are relevant in relation to previous studies in order to be able to compare the results. In vitro studies, in extension, aim to process the material to provide an optimal clinical function, to reduce the risk of discomfort or in worst case harming the patient or dentist.

RESULTS

Curing time

The mean volumetric polymerization shrinkage values of the composites ranged between 1.8% and 5.0% when the recommended curing times, 20 or 40 sec, were used. The mean shrinkage values of the composites ranged between 1.8% and 4.3%, and 1.9% and 5.3% with curing times, 10/20 sec, and, 30/60 sec, respectively, Figure 2. Nine out of ten dental composites had lower or similar polymerization shrinkage values when curing times 10/20 sec were used when compared to the recommended curing time. Five out of ten dental composites had lower or similar polymerization shrinkage values when curing times 30/60 sec were used when compared to the recommended curing time.

Filler load

The composite with the highest filler load, Kalore, had the lowest mean shrinkage, and the composite with the lowest filler load, SDR, had the highest mean shrinkage when cured according to the recommendations. The universal composite 4U has the second highest filler content and the second highest mean volumetric shrinkage of all the composites when cured according to the manufacture's recommendation, Figure 2. Relations between filler loads and mean volumetric shrinkage of the nano-hybrid composites were observed. The nano-hybrid composites had the highest filler load and a large range of filler sizes. The lowest shrinkage in this group was registered of the composite Venus Diamond. A relation between filler loads and volumetric shrinkages of the nano-composites were also observed. The micro-hybrid composites, Kalore and Filtek Silorane, had the lowest mean shrinkage of the studied composites. In opposite to composites ELS and SDR that had high mean shrinkage and low filler load, Figure 2.

DISCUSSION

The results of the study showed that the video-imaging device, AcuVol, could be used to register the polymerization shrinkage of the dental composites. The hypotheses were partly rejected. The filler load is related to the polymerization shrinkage when the composites are arranged by type of composite i.e. nano-hybrid, nano-composite and micro-hybrid but not when related to all types of dental composites. No conclusion could be made when it comes to the impact of the best-before date and effect of different curing times on the shrinkage. The numbers of specimens tested need to be increased to get sufficient data for statistical analyses.

The micro-hybrid composite, Kalore, uses monomers with high molecular weight to decrease the polymerization shrinkage. Kalore has a type of monomer, DX-511, which is heavier than Bis-GMA and UDMA. Besides DX-511, Kalore has also diurethane methacrylate and dimethacrylate co-monomers (Kopperud et al., 2011; Ilie et al., 2011; Durner et al., 2012). The micro-hybrid, Filtek Silorane, has a different type of monomer with another chemical reaction than the other composites in our study. Oxirane rings have been used instead of chain-monomers usually used in composites. Polymerization occurs by a cationic reaction instead of methacrylate, where the radicals react and build a cross-link network. Polymerization leads to an opening the oxirane ring, which partially compensates the polymerization shrinkage (Zimmerli et al., 2010; Ilie et al., 2011). The use of these new types of monomers could explain the low polymerization shrinkage recorded in our study, 1.8 % for Kalore and 2.1 % for Filtek Silorane, Fig 2. The shrinkage value given by the manufacturer for Kalore is similar to the recorded value, 1.5-2.0 %, but the manufacturers given value for Filtek Silorane, 0.7-1 %, is about half of our recorded value. The shrinkage value for Filtek Silorane has been recorded as low as 1.4 vol.% (Boaro et al., 2010).

Polymerization shrinkage of 2.1 vol.% for the micro-hybrid ELS has been reported which is nearly half of the shrinkage value, 4.1 vol.%, registered in our study, and much higher than the nominal value, 1.3-2.5 % (Boaro et al., 2010). It is important to mention that a mercury dilatometer was used to measure the polymerization shrinkage and the composites were cured for 30 sec instead of the manufacturer's recommended curing time (Boaro et al., 2010). The micro-hybrid SDR have approximately doubled the shrinkage value in our study, 5.0%, compared to the value 3.5% given by the manufacturer.

All micro-hybrid composites have passed their expiration dates. Kalore is the only composite in our study, which has the same polymerization shrinkage value as the shrinkage given by the manufacturer even though the composite has passed its best-before date. Similar shrinkage results have been shown in previous studies (Tantbirojn et al., 2011; Naoum et al., 2012).

The nano-composites Filtek Supreme XTE and Tetric EvoCeram Bulk Fill both have the nominal value 2.0 %. The recorded value for both Filtek and Tetric is higher than the nominal value but it is closer for Filtek than for Tetric.

The nano-hybrid Venus Diamond contains a urethane monomer, TCD-urethane, a new type of

monomer that is heavier and bigger than TEGDMA. The TCD-urethane has low viscosity; consequently no other diluents are needed. The manufacturers given value for Venus Diamond was 1.6 %, which was much lower than we recorded, 3.21 vol.%. The shrinkage value for Venus Diamond has been found to be as low as 1.8 vol.% (Boaro et al., 2010). The nano-hybrid composite Ceram X mono had a higher recorded shrinkage value 3.9 % than the given value 2.3 %. Both Venus Diamond and Ceram X mono had passed their expiration date.

The shrinkage values in our study are higher in general compared to the values given by the manufacturer and results from other previous studies (Tantbirojn et al., 2011; Naoum et al., 2012; Boaro et al., 2013; Garcia et al., 2013; Karaman et al., 2014). The higher values of the polymerization shrinkage might be related to the composite's expiration date. Studies have shown that the properties, e.g. degree of conversion, micro hardness, opacity and micro roughness of expired composites may be altered with time (Garcia et al., 2010; Garcia et al., 2013).

It should also be taken into consideration that, the manufacturers that registered the nominal values, could have used different methods than the method used in our study. SVVR (single-view volumetric reconstruction) is stationary mode and MVVR (multiple-view volumetric reconstruction) is a rotating mode to measure the polymerization shrinkage in the AcuVol machine. MVVR is used in this study instead of SVVR, in order to reduce the source of errors of the hand shaped specimen. Multiple images of the specimen are taken when using MVVR. However previous studies using the AcuVol have not shown any significant differences between the two modes (Sharp et al., 2003; Han et al., 2010). The usage of another equipment for measuring the shrinkage could lead to different results. Although, comparable results have been found when comparing an AcuVol device and a mercury dilatometer (Sharp et al., 2003).

In this study, the composite specimens were placed, formed and cured within 1 min in order to minimize curing by the surrounding lights. This method is based on clinical procedures. In previous studies the composite specimens were allowed to rest for 5 and 10 min before light curing (Tiba et al., 2005; Lien et al., 2010; Han et al., 2012). The micro-hybrid Silorane was found to have higher polymerization shrinkage, 2.1 vol.% in our study, compared to approximately 1.4 vol.% when the composite were rested for 3 min before curing and measured 5 min after light curing (Lien et al., 2010). The laboratory protocol used seems to

influence the results of the polymerization shrinkage measurement.

In our study, three out of ten composites increased the polymerization shrinkage when the curing time was increased from half of the recommended curing time to one and a half recommended curing time. The increase was small and no conclusion can be made when it comes to the impact of increased curing time on the polymerization shrinkage.

In a study the curing time for four different composites were investigated by using two different light curing units, one LED and one halogen unit (Uhl et al., 2005). The study showed a linear correlation between volumetric shrinkage and curing time, the shrinkage increased with increased curing time. There were significant differences in shrinkage for one out of four studied composites when comparing the two light units.

The insufficient information about the sizes and shapes of the filler particles given by the manufacturers makes it difficult to draw any conclusion about the effect of the filler particles on the polymerization shrinkage. Some manufacturers give the size of the smallest and the biggest particles with a big range in between and some just give the average filler size. Composites with spherical shaped filler particles have been found not to withstand wear as good as composites with irregular shaped fillers (Ilie et al., 2011). However, spherical shaped filler particles have been found to make it easier to increase the filler load (Rastelli et al., 2012).

Not only the filler load affects the polymerization shrinkage, there are also other factors such as filler size, filler shape, composition of monomer, coupling agents and photo initiators that affects the shrinkage and thus, the stress of the composites (Tiba et al., 2005; Kleverlaan et al., 2005; Lien et al., 2010). Stress can result in debonding, marginal stains, microleakage, secondary caries and post-operative sensitivity (Tiba et al., 2005; Han et al., 2012; Anusavice et al., 2013).

The video-imaging device could be used to register the polymerization shrinkage of dental composites. However, the laboratory protocol used seems to be of great importance for the results of the polymerization shrinkage and also the type of composite tested. Thus, polymerization shrinkage processes and resultant stresses adjacent to dental composite fillings continue to challenge the clinicians. The need for reducing the polymerization shrinkage of composite materials, and the emergence of lower shrinkage stress are obvious.

REFERENCES

Anusavice KJ, Shen C, Rawl HR (2013). Phillips' Science of dental materials, 12th rev. ed. St. Louis: Elsevier, pp. 276-96.

Bernardo M, Luis H, Martin MD, Leroux BG, Rue T, Leitão J, DeRouen TA (2007). Survival and reasons for failure of amalgam versus composite posterior restorations placed in a randomized clinical trial. J Am Dent Assoc 138:775-83.

Boaro LC, Goncalves F, Guimaraes TC, Ferracane JL, Pfeifer CS, Braga RR (2013). Sorption, solubility, shrinkage and mechanical properties of "low-shrinkage" commercial resin composites. Dent Mater 29:398-404.

Boaro LC, Goncalves F, Guimaraes TC, Ferracane JL, Versluis A, Braga RR (2010). Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites. Dent Mater 26:1144-50.

Durner J, Obermaier J, Draenert M, Ilie N (2012). Correlation of the degree of conversion with the amount of elutable substances in nano-hybrid dental composites. Dent Mater 28:1146-53.

European Commission (2014). Definition of a nanomaterial. [Online] [cited 2014 Dec 09]. Available from: http://ec.europa.eu/environment/chemicals/nanotech/faq/definition_en.htm

Garcia D, Yaman P, Dennison J, Neiva G (2013). Polymerization shrinkage and depth of cure of bulk fill flowable composite resins. Oper Dent. [Epub ahead of print Dec 4, 2013]

Garcia Lda F, Mundim FM, Pires-de-Souza Fde C, Puppin Rontani RM, Consani S (2013). Effect of artificial accelerated aging on the optical properties and monomeric conversion of composites used after expiration date. Gen Dent 61:1-5.

Garcia Lda F, Roselino Lde M, Pires-de-Souza Fde C, Consani S (2010). Evaluation of the conversion degree, microhardness, and surface roughness of composite resins used after their expiration date. Gen Dent 58:262-7.

Han B, Dong YM, Wang XY, Tian FC, Gao XJ (2010). Effect of filler content of composite resins on polymerization shrinkage measured by a video imaging apparatus (Acuvol). Beijing Da Xue Xue Bao 18:582-5. [Abstract in English].

Han B, Dong Y, Gao X, Wang X, Tian F (2012). Effect of filler content on the micro tensile bond strength of composite resin and dentin in Class I cavities. Quintessence Int 43:16-22.

Ilie N, Hickel R (2011). Resin composite restorative materials. Aust Dent J;56 Suppl 1:59-66.

Ilie N, Rencz A, Hickel R (2013). Investigations towards nano-hybrid resin-based composites. Clin Oral Investig 17:185-93.

Karaman E, Ozgunaltay G (2014). Polymerization shrinkage of different types of composite resins and microleakage with and without liner in class II cavities. Oper Dent 39:325-31.

Kleverlaan CJ, Feilzer AJ (2005). Polymerization shrinkage and contraction stress of dental resin composites. Dent Mater 21:1150-7.

Kopperud HM, Finger WJ, Hørsted-Bindslev P (2011). Moderna tandfärgade fyllningsmaterial. Tandläkartidningen 103:88-94.

Leprincea JG, Palin WM, Hadisc MA, Devaux J, Leloupa G (2013). Progress in dimethacrylate-based dental composite technology and curing efficiency. Dent Mater 29:139-56.

Lien W, Vandewalles KS (2010). Physical properties of a new silorane-based restorative system. Dent Mater 26:337-44.

Lindberg A (2005). Resin composites, sandwich restorations and curing techniques (dissertation). Umeå, Sverige: Umeå universitet.

Mutter J (2011). Is dental amalgam safe for humans? The opinion of the scientific committee of the European Commission. J Occup Med Toxicol 13:2.

Naoum SJ, Ellakwa A, Morgan L, White K, Martin FE, Lee IB (2012). Polymerization profile analysis of resin composite dental restorative materials in real time. J Dent 40:64-70.

Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA. A retrospective clinical study on longevity of posterior composite and amalgam restorations. Dent Mater 23:2-8.

Peutzfeldt A (2006). Dentala kompositmaterial. Socialstyrelsen 2006-123-17.

Rasines Alcaraz MG, Veitx-Keenan A, Sahrmann P, Schmidlin PR, Davis D, Iheozor-Ejiofor Z (2014). Direct composite resin fillings versus amalgam fillings for permanent or adult posterior teeth. Cochrane Database Syst Rev. [URL accessed at: (http://onlinelibrary.wiley.com/doi/10.1002/14651858.CD005620.pub2/full#CD005620-bbs2-0052) on (September 15, 2014)].

Rastelli AN, Jacomassi DP, Faloni AP, Queiroz TP, Rojas SS, Bernardi MI, Bagnato VS, Hernandes AC (2012). The filler content of the dental composite resins and their influence on different properties. Microsc Res Tech 75:758-65.

Sensi LG, Strassler HE, Webley W (2007). Direct Composite Resins. Inside Dentistry 3:76.

Sharp LJ, Choi IB, Lee TE, Sy A, Suh BI (2003). Volumetric shrinkage of composites using video-imaging. J Dent 31:97-103.

Tantbirojn D, Pfeifer CS, Braga RR, Versluis A (2011). Do low-shrink composites reduce polymerization shrinkage effects? J Dent Res 90:596-601.

Tiba A, Charlton DG, Vandewalle KS, Ragain JC Jr (2005). Comparison of two video-imaging instruments for measuring volumetric shrinkage of dental resin composites. J Dent 33:757-63.

Uhl A, Mills RW, Rzanny AE, Jandt KD (2005). Time dependence of composite shrinkage using halogen and LED light curing. Dent Mater 21:278-86.

Zimmerli B, Strub M, Jeger F, Stadler O, Lussi A (2010). Composite materials: composition, properties and clinical applications. Schweiz Monatsschr Zahnmed 120:972-86

Table 1. Composite name, manufacturer, type of composite, filler content, filler size, shade, expiration date and lot number for the tested dental composites and the polymerization shrinkage given by the manufacturer, i.e. the nominal polymerization shrinkage.

| Composite	Manu-facturer	Type	Filler, vol-%	Filler size, μm	Shade	Exp. Date/ Lot. No.	Nominal polymerization shrinkage vol-%
4U	AB Nordenta, Enköping, Sweden	Universal	65	0.05-1.5	A3	2016-07/ LOT530 5947	N/A
Venus Diamond	Heraeus Kulzer, Hanau, Germany	Nano-hybrid	64	0.005-20	A3	2013-09/ 10035	1.6
Tetric Ceram	Ivoclar Vivadent, Schaan, Liechtenstein	Nano-hybrid	60	0.04-1	A3.5	2008-06/ GP0034	N/A
CeramX mono	Dentsply, York, PA, USA	Nano-hybrid	57	0.0023-1.5	M2	2014-06/ LOT120 7000307	2.3
Filtek Supreme XTE	3M ESPE, St. Paul, MN, USA	Nano composite	63.3	0.6-10	A3B	2015-09/ N465520	1.97
Tetric EvoCeram Bulk Fill	Ivoclar Vivadent, Schaan, Liechtenstein	Nano composite	53-54	0.550 (mean)	IVA	2015-10/ P63317	1.96
Kalore	GC Corporation, Tokyo, Japan	Micro-hybrid	69	0.016-17	M3	2012-03/ LOT090 3301	1.5-2
Filtek Silorane	3M ESPE, St. Paul, MN, USA	Micro-hybrid	55	0.47 (mean)	A3	2011-04/ 9FA	0.66-1
ELS (extra low Shrinkage)	Saremco Dental, Rhein valley, Switzerland	Micro-hybrid	50	0.07-2.6	A3	2010-12/ LOT12.2 010-15	1.3-2.5
SDR (flow)	Dentsply, York, PA, USA	Micro-hybrid	44	4.2 (mean)	Uni-versal	2012-12/ LOT110 104	3.5
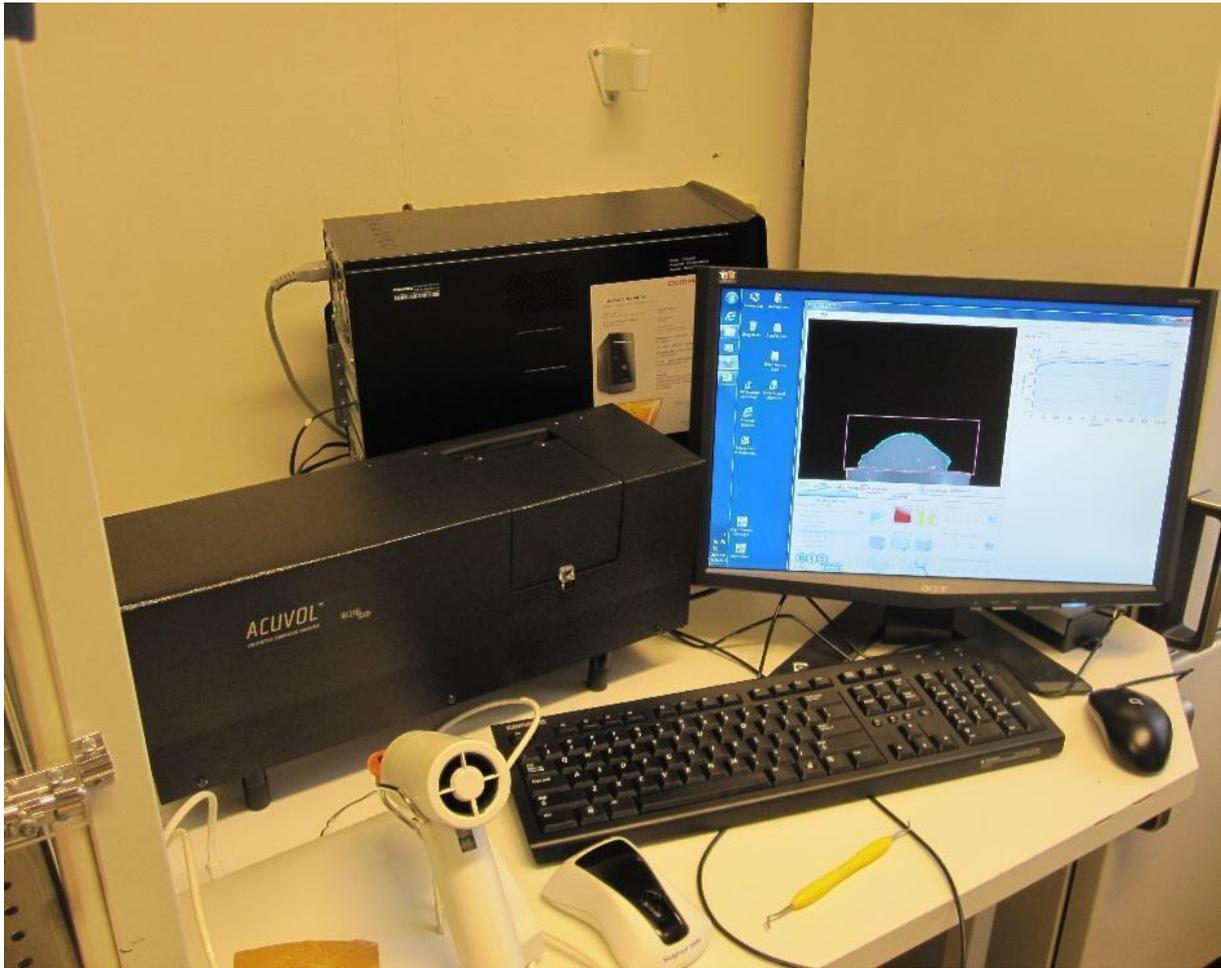
Figure 1. The AcuVol instrument for registration of polymerization shrinkage to the left, and computer screen, to the right, showing a composite specimen placed on the polytetrafluoroethylene pedestal inside of the instrument.
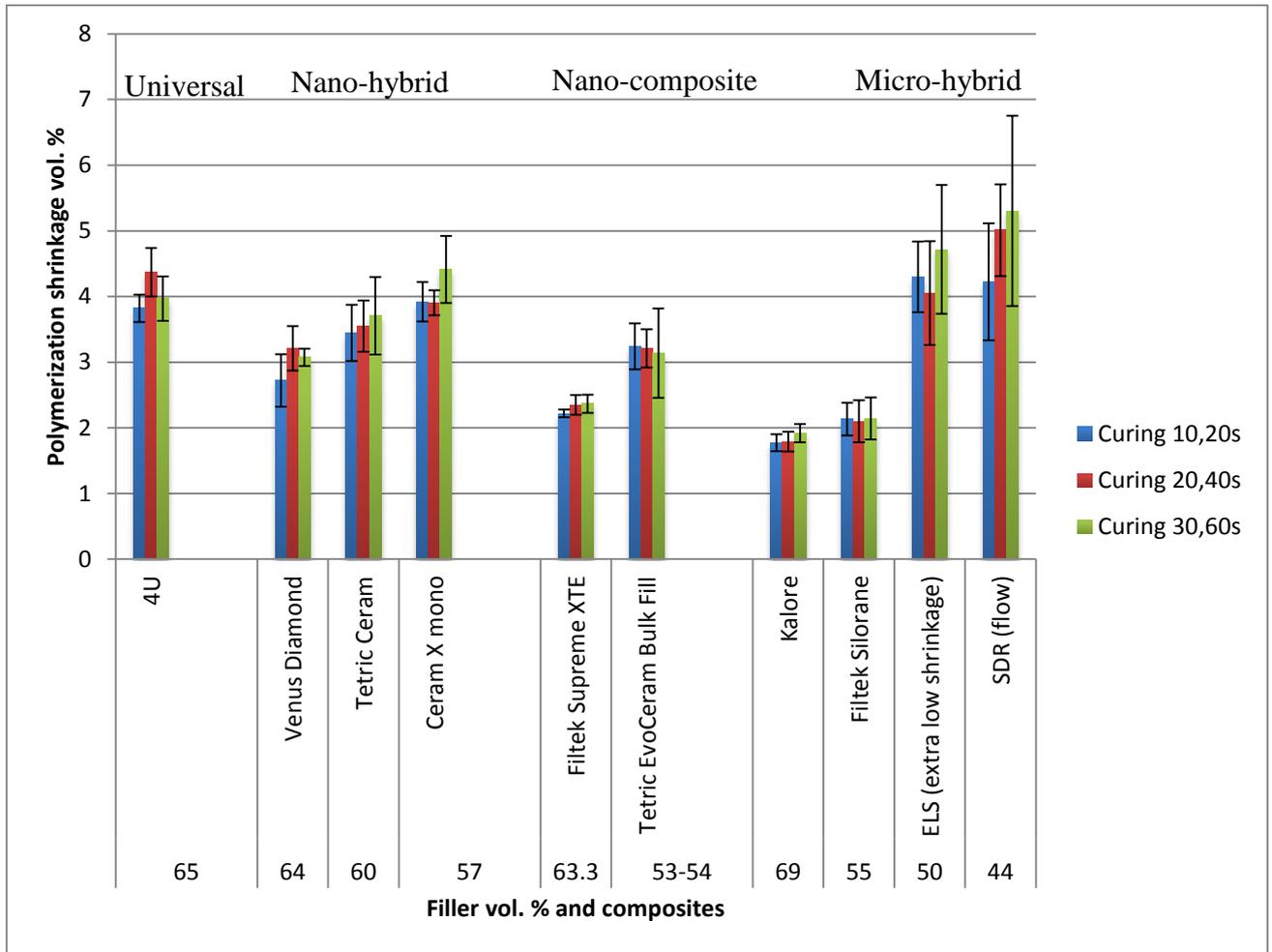
Figure 2. Volumetric polymerization shrinkage for composites (vol. %) with standard deviation (SD) indicated with black bar. Blue columns represents results for half of the recommended curing time. Red columns represent results for the recommended curing time. Green columns represent results for one and a half of the recommended curing time.

APPENDIX 1.

Composite name, type of composite and mean volumetric polymerization shrinkage with standard deviation (SD) when half of the recommended curing time (10/20 sec), recommended curing time (20/40 sec) and one and a half of the recommended curing time (30/60 sec) were used.

Composite, type	Polymerization-shrinkage, vol. -% Mean ± SD Curing 10/20 sec	Polymerization-shrinkage, vol. -% Mean ± SD Curing 20/40 sec	Polymerization-shrinkage, vol. -% Mean ± SD Curing 30/60 sec
4U Universal	3.82 ± 0.21	4.37 ± 0.37	3.97 ± 0.34
Venus Diamond Nano-hybrid	2.72 ± 0.40	3.21 ± 0.34	3.07± 0.13
Tetric Ceram Nano-hybrid	3.45 ± 0.43	3.55 ± 0.39	3.71 ± 0.59
CeramX mono Nano-hybrid	3.92 ± 0.30	3.91 ± 0.19	4.41 ± 0.51
Filtek Supreme XTE Nano-composite	2.22 ± 0.06	2.35 ± 0.15	2.37 ± 0.14
Tetric EvoCeram Bulk Fill Nano-composite	3.24 ± 0.35	3.21 ± 0.29	3.14 ± 0.68
Kalore Micro-hybrid	1.77 ± 0.13	1.79 ± 0.15	1.92 ± 0.14
Filtek Silorane Micro-hybrid	2.13 ± 0.25	2.10 ± 0.32	2.14 ± 0.32
ELS Micro-hybrid	4.30 ± 0.54	4.05 ± 0.79	4.72 ± 0.98
SDR Micro-hybrid	4.22 ± 0.89	5.01 ± 0.70	5.30 ± 1.45

APPENDIX 2.

Links for composite information:

- http://multimedia.3m.com/mws/mediawebserver?mwsId=66666UgxGCuNyXTtnxTX LxM6EVtQEcuZgVs6EVs6E666666--&fn=supr_xte_tpp_anz.pdf
- http://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSufSevTsZxtUnY_el8 2UevUqevTSevTSevTSeSSSSSS--&fn=Filtek_Silorane_TPP_EBU.pdf
- http://www.gceurope.com/pid/141/manual/en_Manual.pdf
- http://issuu.com/nordenta/docs/nordenta_produktmagasin_nr_4_2013/2
- http://www.sciencedirect.com/science/article/pii/S0109564113000109
- http://www.dentsply.co.uk/Uploads/Scientific_Compendium.pdf
- www.ivoclarvivadent.se/zooluwebsite/media/document/11227/Tetric+EvoCeram+Bul k+Fill
- https://www.google.se/url?sa=t&rct=j&q=&esrc=s&source=web&cd=7&ved=0CEoQ FjAG&url=https%3A%2F%2Fwww.ivoclarvivadent.com%2Fzoolu-website%2Fmedia%2Fdocument%2F949%2FTetric%2BCeram%2BFamily&ei=k7sA U6bCFoW8ygPzoYKYDA&usg=AFQjCNGXYOes7ZG_LjFKC46-JdqQ9DCqbQ&sig2=IHqOrUmIT55LvGxf55wcow&bvm=bv.61535280,d.bGQ&cad =rja
- http://www.heraeusvenus.com/media/downloads/bn_nl/VenusDiamond_Scientific_Co mpendium_201111_Benelux.pdf
- http://www.dentsplymea.com/products/restorative/composites/sdr