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Degradation of dental resin composites during intra-oral wear

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CHAPTER

1

General Introduction

General Introduction

Dental resin composites

Dental resin composites have become an integral part of modern dentistry (Jandt et al. 2009). Nowadays, dental resin composites are used worldwide to restore missing tooth structures, to modify tooth color and anatomical contour, to enhance aesthetics and function (Söderholm 1981, Oilo 1992, Ferracane 1994, Murdoch-Kinch and Mc Lean 2003, Schmalz and Arenholt-Bindslev 2009, Sakaguchi and Power 2012, Mustafa and Matinlinna 2014). The lifetime of composite restorations in the oral environment is difficult to predict. On the long-term, resin composites change in shape, dimensions and color during intra-oral wear (Freund and Munksgaard 1990, Göpferich 1996, Ferracane 2011, Opdam et al. 2012, Demarco et al. 2012, Delaviz et al. 2014, Van Dijken and Lindberg 2015, Van de Sande et al. 2015). A short lifetime of a composite restoration has been associated with restoration failure due to material degradation and secondary caries in the margin between tooth enamel or dentin and a composite restoration (Pallesen and Van Dijken 2015, Beck et al. 2015). Since the first composite was developed in the 1960s, continued improvements in material properties have resulted in the advanced modern materials with excellent wear resistance, durability, and aesthetics that mimic natural teeth (Ferracane 2011). Table 1 summarizes the improvements of physical and mechanical properties of dental resin composites since the introduction of BisGMA in 1960.

Table 1 Summary of the major steps in the development of dental resin composites (Ferracane 2011, Mustafa and Matinlinna 2014).

Year	Developmental steps in resin composites
1960	Introduction of organic polymer matrix of BisGMA
1970	Reduction of the diameter of filler particles from macrofiller to microfiller
1980	Introduction of hybrid composites with two types of fillers (fine particles of 2 to 4 µm and microfine particles of 0.04 to 0.2 µm. In 1985, the first indirect CAD/CAM resin composite was fabricated, which can be repaired and maintained more easily than ceramics.
1990	Introduction of flowable and packable composites. - Flowable composites have a low elasticity, and are recommended for use in cervical abfraction areas and can be applied by a syringe. - Packable composites have a very high viscosity and need to be compressed using a hard-flat surface instrument. They contain dimethacrylate resin monomers with filler loadings up to 66%-70% by volume. Filler particles with porous or irregular shape which are incorporated in the modified resin monomer to make them packable.
2000	Introduction of nanofiller composite materials.
2008	Use of new methacrylate monomers to inhibit volumetric shrinkage and polymerization stress.
2010	Self-adhesive flowable composite become available in the market.
2012-2014	The latest advancement in resin composite is the development of nanocluster composites (nanosized silica and zirconia particles). Recently there are two distinct types of dental resin composites that contain nanoparticles: - Nanofillers, nanosized particles ranging from 1-100 nm incorporated in the matrix - Nanohybrids, not a true nanofilled composite because it consists of blended nanoparticles and microparticles (0.4 to 5 µm)

Dental resin composites are composed of four major components: an organic polymer matrix that is usually methacrylate based, inorganic filler particles (commonly obtained from quartz, glass or sol-gel derived ceramic), coupling agents such as silanes, and an initiator-accelerator polymerization system. A commonly used monomer is 2,2-bis [4(2-hydroxy-3-methacryloxypropoxy)-phenyl] propane, also known as bisphenol A glycidyl methacrylate (BisGMA) (Sakaguchi and Power 2012, Mustafa and Matinlinna 2014). These monomers are rather viscous, which makes it difficult to incorporate filler particles. Due to the relatively high viscosity, low molecular-weight diluent monomers such as triethylene glycol dimethacrylate (TEGDMA), or Bis-EMA, are blended into the viscous monomer to achieve better workable consistency and handling in the clinic. These monomers are added by the manufacturer not only to reduce the viscosity but also to increase polymerization. Inorganic filler particles are a major part of resin composites by volume and weight. Conventionally, dental resin composites are classified by the size and type of the fillers: macrofiller, microfiller, nanofiller, and the hybrid, mixtures of fillers with different sizes (Schmalz and Arenholt-Bindslev 2009, Sakaguchi and Power 2012). Fillers are meant to reinforce the resin matrix and therefore must have a size distribution that fits into the matrix space. Type and characteristics of different dental resins composite categories are summarized in Table 2.

Table 2 Categories and characteristics of dental resin composites based on the types and sizes of the filler particles (Sakaguchi and Power 2012, Mustafa and Matinlinna 2014)

Type of Filler	**Particle size**	**Characteristic and properties**	**Recommended restoration**
Macrofiller	0.6 – 3.0 µm	Low wear resistance, rather opaque	Not usable for aesthetic restorations
Microfiller	± 0.04 µm	High polish quality and esthetics	Class 1, Class 2, Class 3
Nanofiller	1-100 nm	High polish quality, high strength, high elasticity	Class 1, Class 2, Class 3, Class 4, Class 5, Class 6 (MOD areas)

Bonding between the organic resin matrix and inorganic filler particles during polymerization is important for a successful composite restoration. Silane coupling agents, as 3-methacryloxypropyltrimethoxysilane (MPS), 3-acryloxypropyltrimethoxysilane (MPTS), 3-isocyanatoprophyltriethoxysilane (3-MPS) are used as a bridge between the organic resin matrix and inorganic fillers as schematically illustrated in Fig. 1. Silane coupling agents contain a silicon atom in the center of two functional organo and hydrolysable groups (Fig. 1). The coupling agents have a critical role to enhance the mechanical properties of the resin composite and to minimize its wear during intra-oral use (Mustafa and Matinlinna 2014).

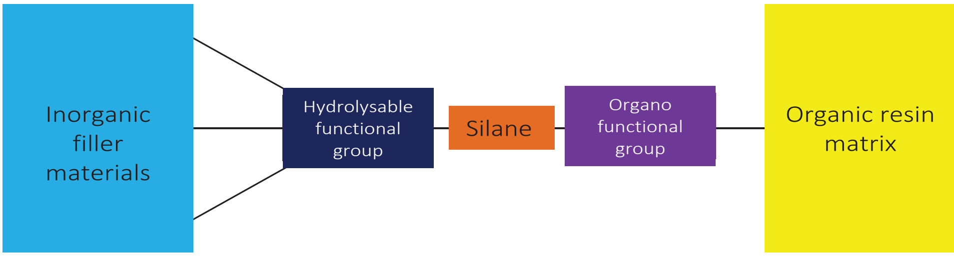

Figure 1 The organo functional group will bind with the organic resin matrix, while the hydrolysable functional group will attach to an inorganic filler material.

The formation of a cross-linked network during polymerization is achieved via free radical chain polymerization of the corresponding methacrylate polymer. The reaction is initiated by light or a chemical reaction to produce free radicals, which in turn attack the carbon double bonds, causing polymerization. The polymerized resin is highly cross-linked because of the presence of difunctional carbon double bonds. The degree of polymerization depends on the polymerization method, the temperature, light intensity and exposure time and whether the resin composite is for direct or indirect use. Indirect resin composite restorations are pre-shaped and post-cured at increased temperatures and light intensities outside the oral cavity, whereas direct composites are applied and cured in the oral cavity. Characteristics, properties, advantages and disadvantages of direct and indirect resin composites are listed in Table 3, together with their clinical indications.

Table 3 Advantages, disadvantages and clinical indications of indirect and direct resin composites.

Resin composites	Advantages	Disadvantages	Clinical indications
Direct resin composite	Easy to polish, easy to handle, low cost, multipurpose restorations.	Lower degree of curing, higher polymerization shrinkage than indirect resin composites.	Small cavities for limited occlusal area.
Indirect resin composite	Less porosity, less polymerization shrinkage, higher degree of curing, lower wear, better anatomy and contact with tooth structure than direct composites.	Laboratory cost are high, need special equipment.	Multiple cavities, crowns and bridges.

Effects of the oral environment on resin composites

The aggressive complexity of the oral environment can degrade resin composites, which can give rise to changes in physico-chemical properties, sometimes observable as color changes (Freund and Munksgaard 1990, Larsen and Munksgaard 1991, Steinberg and Eyal 2002, Eick et al. 2004, Ikeda et al. 2007, Beyth et al. 2008, Delaviz et al. 2014). Effects of the oral environment on resin composites are summarized in Fig. 2 and include chemical factors, mechanical factors and physical factors, with time as an overruling factor for all (Winkler et al. 1991, Oilo 1992, Ferracane 1994, Mair et al. 1996, Santerre et al. 2001, Fúcio et al. 2008, Bayne 2012).

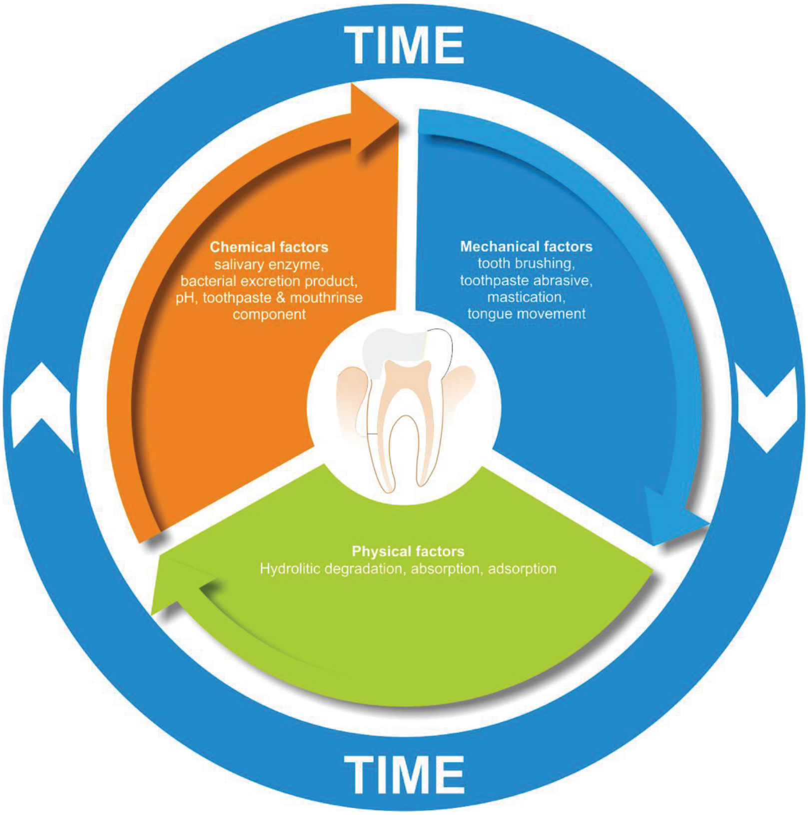

Figure 2 Three essential factors that contribute to the degradation of dental resin composites.

Although presented as separate factors, chemical, mechanical and physical factors work in concert during intra-oral wear. However, little is still understood about the way these factors work together. Different *in vitro* models have been developed to evaluate the effect of the oral environment on the degradation of dental resin composites. However, *in vitro* aging models for composites study only single factors and therewith lack the synergy of factors operative in the oral cavity. Moreover, still little is known how the complex interplay of different factors during wear and necessary oral hygiene such as tooth brushing affect the properties of dental resin composites. In order to achieve further improvement of dental composites, such a better understanding is direly needed.

Aims of this thesis

The general aim of this study is to compare the effects of intra-oral wear and brushing on the surface properties of direct and indirect resin composites. Specific aims are:

- to investigate the cumulative effect of exposure to the human oral cavity on optical color changes and how this relates to bulk filler content and surface filler particle exposure (Chapter 2);
- to investigate the *in vivo* effects of intra-oral wear and tooth brushing on the microbial composition of oral biofilm formed on the surfaces of composite materials with a different number of ester-linkages in order to correlate biofilm composition with composite degradation (Chapter 3);
- to compare the obtained results of different methods that are used to investigate the early degradation of dental resin composites (Chapter 4).

Accordingly, some comments and general recommendations will be made and proposed:

1) that relate to the developmental pathway of the degradation of dental resin composites;
2) that can aid in future degradation studies;
3) regarding clinical considerations as to the choice of a resin composite, and educating a patient on how to achieve longer lasting performance (Chapter 5).

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