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Factors influencing marginal cavity adaptation of nanofiller containing resin composite restorations

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ABSTRACT

Objectives. The aim of this study was to investigate the effects of polymerization contraction, shrinkage stress and Young's modulus of nanofiller containing resin composites on early marginal adaptation of restorations in cavities.

Methods. Six nanofiller containing and two reference resin composites were studied. Marginal gap widths of restorations in cylindrical 4.2 mm wide and 1.5 mm deep dentin cavities, non-bonded or bonded with a self-etch adhesive, and in Teflon cavities of same dimensions were determined 15 min after irradiation ($n = 8$). Polymerization shrinkage strains were measured using the bonded-disk ($n = 8$) and a strain gage method ($n = 8$). For determination of contraction stress the composites ($n = 10$) were bonded to and cured in Araldit molds using a photoelastic method. Flexural moduli of the restoratives were studied according to ISO specification 4049 ($n = 5$). Statistical analysis was performed with one- and two-way ANOVA, Kruskal–Wallis ANOVA test and post hoc tests ($p < 0.05$).

Results. Only two nanofiller composites (Kalore, GC, Japan) and Venus Diamond (Heraeus Kulzer, Germany) showed consistently gap-free margins in bonded dentin cavities. The mean gap widths in non-bonded and in Teflon cavities were 6.1–12.8 and 14.1–25.5 μm, and linearly correlated ($r^2 < 0.85$). Significant linear relationships were observed between strain, stress and marginal gap widths in non-bonded and Teflon cavities ($p < 0.01$). Flexural moduli (15 min) were between 1.66 and 8.63 GPa.

Significance. Marginal cavity adaptation of restorations in bonded dentin cavities reflects complex interactions between adhesive bonding on the one hand, and polymerization contraction strain, stress and elastic modulus, on the other.

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1. Introduction

During recent years a steadily increasing number of resin composites containing nanofiller particles have been introduced to the dental marketplace. The term “nano” seems to be very fashionable and is extensively used by manufacturers without readily perceivable justification. These products are often characterized as low-shrinkage restorative resins, thus insinuating improved adaptation to bonded cavity walls and in consequence better long-term clinical performance. This claim is however not substantiated by the few published clinical reports comparing nanofiller containing composites with conventional hybrid-type composites [1–5]. Both types of resin composites performed satisfactorily after a few years in service, although secondary caries was still the main reason for restoration failure. Therefore, polymerization shrinkage remains still a major challenge to the longevity of resin composite restorations.

As with conventional composites the monomers included in nanofiller containing resins are dimethacrylates. Hence, upon activation the intermolecular spaces between monomers are reduced by conversion of C=C bonds to covalent C–C bonds. Such polymerization shrinkage leads to stress as soon as the gel-phase is reached, where the polymer gradually loses viscous flow and becomes an elastic solid. With increasing post-gel polymerization contraction the stiffness of the polymer and the contraction stress increase, at a high stress rate and rapid gain in rigidity during the early stage of polymerization [6–8]. Adverse clinical consequences of the shrinkage stress are tooth/cavity deformation and cuspal movement [9], failure at the composite-cavity interface [10], post-operative sensitivity [11], microleakage [12–14], and in the long-term caries [3].

Several authors evaluated the interactions of polymerization contraction, stress and rigidity using a cavity model for determination of the gap dimensions along the cavity margin and/or the cavity wall and the resin-based restorative [15–21]. Such a model is useful to demonstrate the overall effect of resin polymerization shrinkage; however the effects of individual parameters related to the curing process such as contraction, stress and rigidity cannot be separated.

Several methods have been suggested to investigate curing shrinkage kinetics of resin composites. Watts and Cash [22] have described a “bonded-disk” method for registration of curing contraction, calculating volumetric contraction from the linear displacement of a thin glass disk placed on a brass ring with the resin composite sample located centrally. Alternatively, the linear curing shrinkage of resin composites is investigated with so-called linometers. Typically, the composite is placed between two opposing rods, attached to a load cell and the movable traverse of a testing machine [23–25]. Other report describes measurements of linear dimensional changes of curing resin composites using light microscopy [26]. Recent more sophisticated methods for evaluation of the amount of polymerization contraction are digital holographic interferometry [27], X-ray microcomputed tomography [28], a procedure that enables measurement of resin volume shrinkage on clinically relevant geometries, and digital image correlation [29]. Strain gages proved to be simple yet sensitive measuring tools for determination of post-gel polymerization contraction of composites [30–34].

Polymerization contraction creates stresses in the restorative material, at the interface to the surrounding tooth, and in the tooth substrate. The amount of contraction stress created depends on various factors, *i.e.* the shrinkage magnitude, the flow of the resin composite, the elastic modulus of the setting restorative, the bonding to the surrounding cavity walls, the cavity size and geometry (C-factor), and the application and processing techniques [35,36]. Shrinkage stress can be partly relieved by resin composite flow relaxation depending on composition of the restorative, in particular on type and amount of filler particles included [37,38]. Both, kind and content of filler, and composition of the resin matrix are determinants of the amount of shrinkage and stress, and of the resulting polymer stiffness that rapidly increases when the paste is converted from viscous compound to elastic solid. Therefore, contraction stress kinetics have been evaluated intensively, using different evaluation methods, such as finite element analysis [39,40], photoelasticity [21,41–43], strain gages attached to the composite [44,45] and different types of tensilometers [13,46–48].

With most of the testing methods mentioned the values obtained are relative figures that do not permit conclusions about the absolute magnitudes of strain and stress occurring in the cavity. In spite of this limitation these methods are suitable and convenient to investigate systematically parameters that influence on strain and/or stress of composites under different conditions.

Aim of this study was to investigate at an early stage after light activation effects of polymerization contraction, shrinkage stress and stiffness (Young’s modulus) of nanofiller containing resin composites on marginal adaptation of non-bonded and bonded composite restorations in cylindrical dentin cavities as well as in Teflon model cavities of same dimensions. The research hypothesis to be tested was that application of resin restoratives with low polymerization contraction, low contraction stress, and low stiffness would result in superior marginal cavity adaptation of composite restorations.

2. Materials and methods

The six nanofiller containing resin composites and two reference materials, a hybrid-type (FIL) and a microfilled composite (DUR), used in this study are listed in Table 1, including their main compositions, as extracted from publicly available manufacturer information. For cavity bonding the recently introduced single-step self-etch adhesive iBond SE (ISE; Heraeus Kulzer, Hanau, Germany) was used according to manufacturer instructions and combined with all composites tested. Throughout the investigation the LED light-curing unit Translux PowerBlue (Heraeus Kulzer, Hanau, Germany) was used. The light intensity was regularly checked with a radiometer (Demetron/Kerr, Danbury, CT, USA) to secure an output of >650 mW/cm^2.