



Nanoparticle release from dental composites



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ABSTRACT

Dental composites typically contain high amounts (up to 60 vol.%) of nanosized filler particles. There is a current concern that dental personnel (and patients) may inhale nanosized dust particles (<100 nm) during abrasive procedures to shape, finish or remove restorations but, so far, whether airborne nanoparticles are released has never been investigated. In this study, composite dust was analyzed in real work conditions. Exposure measurements of dust in a dental clinic revealed high peak concentrations of nanoparticles in the breathing zone of both dentist and patient, especially during aesthetic treatments or treatments of worn teeth with composite build-ups. Further laboratory assessment confirmed that all tested composites released very high concentrations of airborne particles in the nanorange ($>10^6 \text{ cm}^{-3}$). The median diameter of airborne composite dust varied between 38 and 70 nm. Electron microscopic and energy dispersive X-ray analysis confirmed that the airborne particles originated from the composite, and revealed that the dust particles consisted of filler particles or resin or both. Though composite dust exhibited no significant oxidative reactivity, more toxicological research is needed. To conclude, on manipulation with the bur, dental composites release high concentrations of nanoparticles that may enter deeply into the lungs.

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1. Introduction

Modern dental composites (“tooth-colored filling material”) for tooth restoration are made of a polymer filled with inorganic filler particles. In order to prevent excessive shrinkage, dental composites are highly filled with filler content, usually between 50 and 70 vol.%. A plethora of different types and sizes of filler particles can be found in contemporary dental composites. In the past, composites used to contain quartz fillers [1,2], but as quartz is radio-lucent, composites today usually contain radio-opaque glass filler particles containing elements with high atomic masses, such as barium, strontium, zirconium or ytterbium. These amorphous glass particles are usually larger than 0.4–1 μm but, to optimize filler packing, nanosized filler particles (<100 nm; e.g., pyrogenic silica) are added to fill the spaces between these large particles. The latest innovations in filler technology have made it possible to add even larger amounts of nanosized particles without overly increasing the viscosity of the unpolymerized composite, and one manufacturer even succeeded in fabricating a composite containing only nanosized particles (Filtek Supreme XTE, 3M ESPE) [3]. Only the

latest generation of composites are called nanohybrid and nanocomposites, but actually, all dental composites on the market today contain considerable amounts of nanosized filler particles [4].

Dental composites are nowadays routinely used to restore decayed and traumatized teeth, and they will be increasingly used now that the World Health Organization has started promulgating phasing down the use of amalgam [5]. Moreover, unlike amalgam, composites can be glued to the tooth surface, which gives way to many more indications for the use of composites. Composites are, for example, frequently used for cosmetic treatments, such as closing unaesthetic diastemas between teeth, veneering discolored teeth and correcting the position and shape of teeth [6]. Moreover, thanks to the good mechanical properties of composites and the latest improvements in adhesive technology, composites are also increasingly used to rehabilitate severely worn dentition [7]. Composites are then used to replace the tooth tissue lost to erosion or abrasion, which represents a less expensive and less invasive alternative to treatment with full-mouth, fixed ceramic restorations.

Normal use of composites encompasses the application of a non-polymerized composite paste, followed by polymerization by blue light, and finishing and shaping by bur or polishing disks in situ. Some researchers have expressed concern that there may

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be a health risk connected to the use of nanoparticles in composites [8,9]. Previous research revealed that dental personnel may inhale aerosolized composite dust while shaping and polishing new composite restorations, and/or on removal of old composite restorations [10–12], and Schmalz and Arenholt Bindslev have already recommended avoiding inhalation of composite dust [13]. Concerns over nanoparticles are related to alleged adverse health effects, given their high mobility, their deep penetration into the lungs and their large and active surface area [14–16].

In a previous study, personal sampling of the air in a dental office revealed that on polishing of front restorations, respirable dust (<5 µm) is released [12]. Typically, short episodes with high concentrations of fine dust could be identified using an optical particle counter. However, this type of instrument relies on light scattering by particles, which scales with the particle size to the sixth power and is therefore only useable to detect larger particles (>500 nm for the particular instrument used in the previous study). Moreover, the particles were quantified by means of mass concentrations, which only reflect nanosized particles to a minor extent, considering their low mass [12].

The objective of the present study was to investigate more thoroughly the release of airborne nanoparticles from composites. In contrast to the previous study [12], measuring devices suited to assessing airborne nanoparticles were used. This study involved both measurement of dentists' personal exposure as well as laboratory investigations to characterize the particles released from dental composites during grinding.

2. Materials and methods

2.1. Personal sampling of nanosized particulate matter in dental office

A miniature diffusion size classifier [17,18] (miniDiSC, University of Applied Sciences North-Western Switzerland, FHNW, Windisch, Switzerland) was used to analyze the release of nanoparticles in real time in a university dental office (Restorative Dental Clinic). This personalized aerosol monitor measures the number concentration, alveolar lung deposited surface area concentration and mean particle size in the size range 10–300 nm and for concentrations ranging from 10^3 to 10^6 cm⁻³. The miniDiSC sampled through an electrically conductive, flexible tube ~50 cm long. The tube inlet was attached to the collar of the dentist, while the instrument itself rested in the pocket of the dentist. The flexible tube attached to the miniDiSC prohibited the use of the impactor that is delivered with the instrument to remove larger particles. Measurements were performed during extensive restorative/aesthetic treatments with the so-called nanocomposite Filtek Supreme XTE (3M ESPE), such as veneering and total crown build-up of front teeth. Final contouring and finishing of the composite restorations was standardly performed with a diamond bur (roughness 46–107 µm). Water cooling and high-flow suctioning using the intra-oral vacuum suctioning device was only occasionally used, according to the standard procedures in the clinic. Sof-Lex polishing disks (coarse, medium, fine and ultrafine grit, 3M ESPE, St. Paul, MN, USA), rubber points (Eve, Ernst Vetter, Pforzheim, Germany) and polishing paste (Prisma Gloss, Denstply Detrey, Konstanz, Germany) were used for polishing the restorations. A second personal aerosol monitor device placed in the same dental cabinet on a bench ~5 m away from the patient recorded background concentrations, which served as the control.

2.2. Laboratory characterization of nanoparticles

Five commercial composites, including so-called “nano(hybrid)” composites and a traditional “hybrid” composite were included in this study, enabling more general conclusions to be

drawn. Their compositions and classifications are given in Table 1. For each composite, five composite samples of identical size of 17.4 × 5.4 × 1.6 mm were prepared in a metal mold. Prior to polymerization, the composite was covered with a glass plate and light-cured on each side for 40 s with a light-curing unit (L.E. Demetron, Kerr, Orange, CA, USA) with an output >1000 mW cm⁻². Each block weighed ~0.2–0.3 g, which corresponded to the size of a mesial-occlusal-distal restoration (MOD) in a molar [19].

2.2.1. Laboratory measurement of size and concentration of airborne nanoparticles released from grinding composites

Entire blocks of composite ($n = 5$) were ground in an enclosed chamber using a dental bur, and released particle number size distributions were measured by means of electrical mobility analysis. A sampling point near the grinding action was placed inside the chamber, and was connected through a flow split to both (1) a scanning mobility particle sizer (SMPS; model 3936 with long differential mobility analyzer (DMA) 3081 and water UCPC model 3776; TSI, Shoreview, MN, USA) for measuring submicron number size distributions [20,21] and (2) an electrostatic precipitator (ESP) (Nanometer Aerosol Sampler NAS, TSI model 3089) for sampling for further electron microscopic characterization [22]. The experimental set-up is shown in Fig. 1. When the ESP was not sampling, air was still drawn through the filter to maintain identical flow conditions. The SMPS measured in the size range 15–661 nm with a size resolution of 64 channels per size decade, and each measurement took 120 s.

The experiment was carried out in an experimental chamber with low background contamination (<500 cm⁻³) made of Plexiglass (270 × 270 × 420 mm) with two openings at the sides sealed with disposable gloves, enabling manipulation of the specimens and the bur. The composite blocks were held with forceps during grinding with a rough diamond bur (842314014 Komet, Lemgo, Germany, grain size 100 µm) in a Kavo Intracompact handpiece (200,000 rpm) connected to an electric micromotor (EWL K9, Kavo, Biberach, Germany). The motor was placed outside the chamber so that unavoidable particle emissions from the motor did not mix with the sample aerosol.

After each test, the box was air-flushed to reduce the background particle concentration to 500 cm⁻³ or below. The weight of the block was recorded before and after, and the number concentrations were corrected for the weight.

2.2.2. Electron microscopic characterization

In the ESP, airborne dust was sampled electrostatically on copper grids for transmission electron microscopy (TEM; JEOL, JEM-1200 EX II, Tokyo, Japan) and silicon dioxide substrates for scanning electron microscopy (SEM). A cyclone was used to remove particles larger than 450 nm, and a charger was used to enhance the sampling efficiency of the ESP [23]. The chemical identity of the sampled particles was additionally investigated by SEM (JSM-7500F, JEOL Ltd., Japan) and electron dispersive X-ray (EDX; Apollo XL detector with 30 mm² detector, Ametek, EDAX Inc., USA).

2.2.3. Size measurement of suspended particles

To measure the size distribution of sedimented composite dust in double distilled H₂O, a volume of 5 ml containing 1.25 mg ml⁻¹ of each dust was briefly vortexed and then ultrasonicated for 10 s (3 mm probe, VibraCell, Sonics & Materials, Danbury, CT, USA). The nano- and micro-fraction was made accessible to optical tracking analysis by sedimenting larger particles by centrifugation (2000g, 10 min). Mass fraction of the supernatant was determined gravimetrically and ranged from 2.6% to 4.2%. Particle size distribution in the supernatant was investigated with a NanoSight LM10 instrument (Wiltshire, UK), equipped with a green laser, a cooled CCD camera (Andor-DL-658 M-OEM, Belfast, UK), and analysis software

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