REVIEW

Characterization of Aerosols and Fine Particles Produced in Dentistry and Their Health Risk Assessments

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Synopsis
Human lung receives many inhaled particles in daily life. In dentistry, rotary cutting instruments (e.g. diamond points and carbide burs) driven by water-cooled high-speed air-turbine and micro-motor headpieces produced aerosols, splatter and cut debris, all of which have the potentials to be breathed by dental professions and patients. The small aerosols and particles less than 0.5 µm might enter deep inside the terminal bronchioles and alveoli of the lungs, at which the macrophage plays a scavenging role. If the particles are difficult to digest (e.g. crystalline silica), oxidative stress is imposed, causing the diseases of the lung and near-by organs (e.g. silicosis and mesothelioma). Microorganisms-contaminated aerosols cause the infectious diseases such as Mycobacterium tuberculosis, influenza viruses, hepatitis C virus and HIV. To prevent lung damage and infectious disease caused by aerosols and fine particles in dentistry, several countermeasures are recommended such as personal protection barriers as masks, gloves and safety eye glasses; the use of high volume evacuators; and the use of the air-room-cleaning system with high-efficiency particulate filters.

Key words: dentistry, aerosol, fine particles, microorganisms, inhalation

1. Introduction
In daily life, human lung filter out over a billion particles from the inhaled air every day. Most of them are dust, such as fumes from gasoline and diesel engines. The lung behaves as a serial filter with larger particles filtered out at higher efficiencies in the respiratory tract and then cleared by the mucociliary escalator within a day (Fig. 1) [1]. Smaller particles, however, reach the terminal bronchioles and alveoli of the lungs, in which no mucociliary clearance takes place. Although most inhaled particles are harmless, some might provoke acute and chronic respiratory diseases. Currently, of particular concern in daily life are particles with an aerodynamic diameter of less than 2.5 µm (PM2.5), because they can be deposited in the terminal bronchioles and nonciliated alveolar regions of the lung [2]. Clearance of foreign materials in these regions is conducted mainly by alveolar macrophages (Fig. 1) and occurs over a period of days to months after exposure [1].
In dentistry, dentists remove carious teeth of dental patients with diamond points (i.e., diamond particles Ni-electroplated on stainless steel bur) driven by water-cooled high-speed air-turbine or micro-motor (engine) headpieces; and restore remained teeth with various restorations and prostheses (e.g., inlays, crown and bridges) made of metals, ceramics, polymers and composites. In oral surgery, rotary cutting instruments (e.g., tungsten carbide burs) remove teeth and bones [3]. In orthodontic treatments, rotary cutting instruments also remove appliances (e.g., metal brackets bonded to teeth) [2]. During such cutting procedures, many aerosols, splattering (including patients’ saliva and blood) and fine particles (debris) with potential health risks are generated; sprayed in the atmosphere near a dental chair; and might be inhaled by dentists, oral hygienists and patients, even using a near-by dental vacuum equipment [4]. The use of an extra-oral high evacuator system is highly recommended, but its usage in Japan is still limited. In Fig. 2, a typical dental chair unit is shown with standard accessories, highlighting the air-turbine handpiece, near-by vacuum and extra-oral high evacuator [5].
In dental laboratory, dental technicians receive dental stone models duplicated from patients’ mouths; and manufacture restorations and prostheses by several means such as casting of metal via lost-wax method for crown, heat-curing of acrylic monomers for denture and vacuum-firing of porcelains for esthetic covering while using laboratory materials such as refractory investments containing crystalline SiO₂, rotary abrasives (e.g. points made of SiC particles bonded in porcelain) and a near-by vacuum. The air in the dental laboratory is, however, usually fairly polluted with floating powders, because a near-by vacuum and room ventilation are not fully effective to remove the entire dust from the air [6].

In this review article, we characterize aerosols, splatters and debris produced in dental professions, consider their danger and refer to the countermeasures.

2. Aerosols, splatters and fine particles sprayed in a dental office

All procedures performed with the use of dental unit handpieces (employing air, water and cutting abrasives) cause the formation of aerosol and splatter which are commonly contaminated with bacteria, virus, fungi, also often with saliva and blood [4]. In Table 1, the sizes of bacteria, fungi and virus are posted. Aerosols are liquid and solid particles, 50 μm less in diameter suspended in air. These aerosols will remain suspended in the air for as much as 30 min after the dental procedure, and can easily reach the respiratory system. Splatter is usually described as a mixture of air, water and solid substance. Water droplets in splatter are from 50 μm to several millimeters in diameter and are visible to the naked eye. The heavier splatter will fall rapidly to the floor. Air-water aerosol and splatter produced during dental treatments emerges from a patient’s mouth and mixes with the surrounding air, and might be breathed by both dental professions and patients. Water in the air-borne droplets can evaporate, leaving small particles (droplet nuclei) that may carry respiratory microorganisms [4].

The analysis and understanding of the compositions of the aerosols and splatters sprayed in a dental office are, thus, quite important to protect the health of both dental professions and patients. Although the composition of aerosols varies with each patient and operative sites, there existed several related reports. Madden et al. [7] confirmed that during the tooth cutting procedure using the air-turbine handpiece, 99% of the aerosol cloud contained particles of 5 μm or less. Harrel and Molinari [4] reported that the composition of aerosols might contain components of saliva, nasopharyngeal secretions, plaque, blood, tooth components and any material used in the dental procedures, and that the smaller particles of an aerosol (0.5 to 10 μm in diameter) have the potential to penetrate and lodge in the smaller passages of the lungs and are thought to carry the greatest potential for transmitting infection. Sotiriou et al. [8] reported that the usual dental procedures produced relatively much smaller (< 0.5 μm) (remaining) particles than larger particles (> 0.5 μm). Day et al. [2] reported that during enamel cleanup after the removal of fixed appliance, the debris produced with slow-speed and high-speed handpieces was small enough (2 to 30 μm) to reach the terminal alveoli of the lungs, and the identified debris elements were calcium, phosphorous, silica, aluminum, and iron. Calcium and phosphorous

<table>
<thead>
<tr>
<th>Living substance</th>
<th>Typical size (μm)</th>
</tr>
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<tbody>
<tr>
<td>Human cell (macrophage)</td>
<td>20</td>
</tr>
<tr>
<td>Bacteria</td>
<td>0.2 to 2</td>
</tr>
<tr>
<td>Fungi</td>
<td>2 to 10</td>
</tr>
<tr>
<td>Virus</td>
<td>0.02 to 0.2</td>
</tr>
</tbody>
</table>

Note: Virus has the dimension of nano-materials.

Fig. 3 Cut debris of titanium with carbide bur driven by a high-speed air-turbine headpiece [9].
might derive from tooth fragments, while silica, aluminum and iron might be originated from cutting instruments and polishing abrasives. In Fig. 3, cut debris of titanium with carbide bur driven by a high-speed air-turbine headpiece was shown [9]. Relatively long and large ribbon-shaped cut debris was found with several tiny fragments of the sizes less than 1 μm. Szymanska [10] found that an ultrasonic scaler produced more aerosols than the high-speed handpiece. Ishihama et al. [3] reported that during oral surgery, significant amounts of blood-contaminated materials were sprayed out as aerosols.

3. Microorganisms-contaminated blood and saliva in aerosols
The mouth harbors bacteria and virus from the nose, throat and respiratory tract. These may contain various pathogenic bacteria and viruses that are present in the saliva and oral fluids. Dental procedures that aerosolize saliva might cause airborne contamination with organisms from these sources. According to the report of Harrel and Molinari [4], the most serious potential threat present in aerosols is Mycobacterium tuberculosis. The saliva and nasopharyngeal secretions in aerosols also may contain other pathogenic organisms, such as common cold, influenza viruses, herpes viruses, SARS virus, and pathogenic streptococci and staphylococci (including MRSA). The blood-borne infection in aerosols might contain hepatitis B virus, hepatitis C virus and HIV. It should be assumed that all patients might have an infectious disease that has the potential to be spread by dental aerosols. Szymanska et al. [11] reported that dental units favor the presence of biofilm and microbial contamination of the dental unit waterlines water. Microorganisms from contaminated DUWL (dental unit water line) are transmitted with aerosol and splatter, generated by working unit handpieces. They mentioned genus/species of bacteria and fungi identified in the dental unit waterlines, such as Gram-negative bacteria (e.g. Brevundimonas vesicularis and Moraxella spp.); Gram-positive bacteria (e.g. Micrococcus leteus and Streptococcus spp.); and Fungi (e.g. Candida albicans and Aspergillus amstelodami). On the other hand, patients’ oral cavity microflora might contain Gram-positive bacteria (e.g. Streptococcus mutans and Staphylococcus aureus) and Gram-negative bacteria (e.g. Porphyromonas gingivalis) [12].

4. Alveolar macrophage reactions against fine particles
In Fig. 4, three damages of alveolar macrophages due to fine particles are depicted [1]. Macrophage cannot digest long fiber, and is slowly damaged by oxidative stress (Fig. 4 (a)). If macrophage cannot dissolve small particles that are chemically inert such as crystalline silica, it will generate excessive free radicals (superoxide), harming own tissues (Fig. 4 (b)). When macrophage phagocytizes too many particles, the cellular mobility is diminished (Fig. 4 (c)) so that the exclusion of the particles becomes more difficult. If fine particles are biological (e.g. cedar pollen with the size of about 30 to 40 μm), macrophage exhibits specific antigens against fragments of the intruding bio-

**Fig. 4** Three damages of alveolar macrophages due to fine particles: (a) Damage when phagocytizing long fiber, (b) that when phagocytizing chemically inert particles, and (c) that when over-phagocytizing particles.
logical particles, activating immune reactions mediated by lymphocytes (T cells and B cells) [13]. Sometimes, the immune reaction becomes very intense, exerting its effect on the whole body (e.g. hay fever).

As for the dissolution power of the macrophage in the lung, ionic-bond dominant dental stone (CaSO₄·2H₂O) can be digested easily, but covalent-bond dominant crystalline silica (SiO₂) was much difficult to disintegrate [1]. It appears that materials difficult to dissolve by macrophage might contain stainless steel, gold alloys, titanium, Co-Cr alloys, porcelain and Zirconia while those easier to disintegrate by macrophage might include tooth, bone, apatite, wax, silicon rubber and acrylic resin.

5. Damage and disease in lung and near-by organs caused by fine particles in dentistry

Crystalline silica has lung and near-by organ health risks. The inhalation and deposition of dust containing silica can lead to silicosis, a slowly progressive fibrosis disease of the lungs. When fine particles of silica dust are deposited in the lungs, macrophages that ingest the dust particles will secrete inflammatory cytokines such as tumor necrosis factors. In turn, these stimulate fibroblasts to proliferate and produce collagen around the silica particle, resulting in fibrosis and the formation of the nodular lesions.

Simple nodular silicosis occurs after many years of exposure to relatively low levels of dust inhalation. Furthermore, the surface of silicon dust can generate silicon-based radicals that lead to the production of hydroxyl and oxygen radicals as well as hydrogen peroxide, which can inflict damage to the surrounding cells [1]. This disease has been reported in dental laboratory technicians [6].

Macrophages phagocytize fine particles, and try to dissolve in intracellular phagosomes by generating free radicals and low pH. Fig. 5 indicates that sub-micron titanium particles were phagocytized by a cultured human macrophage [14]. These titanium particles were confined in several phagosomes, and appeared to be down-sized. This process caused the macrophage to secrete abundant inflammatory cytokines (e.g. TNFα, IL-1β and IL-6) via (superoxide-induced) redox pathway [15], which might lead to inflammation of the surrounding tissues and osteolysis.

If particles in the lung were metals containing copper and iron (e.g. dental silver alloy with gold, palladium and copper), free copper and iron ions might be released, and catalyze the (DNA damaging) OH⁻ formation reaction from H₂O₂, known as Fenton reaction [16]. This lung damage due to metallic fine particles in dental professions has not been well examined, yet.

![Fig. 5](image_url) TEM-photomicrograph of a human macrophage phagocytizing sub-micron titanium particles [4]. Note: The macrophage was cultured for 1 day in titanium particles suspended culture medium. Titanium particles inside the macrophage appeared black.
Asbestos liner was previously used in a dental laboratory when casting metals, and several dental technicians were reported to die due to inhaled asbestos [17]. Once invisible long-fibrous asbestos (about 3.0-20.0 µm in length and can be as thin as 0.01 µm.) is inhaled, it can lodge itself within the body’s organs causing cells to mutate and become cancerous (mesothelioma) over 20 to 30 years. Though the exact way asbestos causes mesothelioma is currently being researched, medical professionals have four different theories [18]: Asbestos causes irritation and inflammation of mesothelial cells, which results in irreversible scarring, cellular damage, and eventually cancer. Asbestos fibers enter cells and disrupt the function of cellular structures that are essential for normal cell division, causing cellular changes that lead to cancer. Asbestos causes the production of free radicals. These molecules damage DNA, and cause cells to mutate and become cancerous. The presence of asbestos causes cells to produce oncproteins. These molecules cause mesothelial cells to ignore normal cellular division restraints, and this can lead to the development of cancer. Lung cancer is also caused by inhaled asbestos with mechanisms similar to those of mesothelioma. The asbestos danger is now not regarded as a today’s dental professional concern because the usage of asbestos in dentistry is strictly prohibited by a law [19], but is still a persistent problem for older dental technicians who have previously used casting ring liners made of asbestos.

6. Countermeasures
The following steps are recommended in a dental office to minimize the risk triggered by dental aerosols; (i) personal protection barriers as masks, gloves and safety eye glasses, (ii) the use of a rubber dam, (iii) the use of an antiseptic pre-procedural oral rinse (e.g. 0.01% chlorhexidine solution), (iv) the use of an high volume evacuators (both near-by vacuum and extra oral high-volume evacuator system), and (v) the use of the air-room-cleaning system (like an air-conditioner) with high-efficiency particulate filters. In Japan, one company (Aeroservice Co.) [20] provides an air-cleaning system (Aerosystem 35) that can filter out fine particles of the sizes down to 0.01 µm. This air-cleaning system is regarded as a prerequisite for super-clean implant and oral surgeries to prevent infection by some dentists. Needless to say, (vi) DUWL (dental unit water line) should always be disinfected by routine professional maintenance.

Although air room ventilation is helpful [21], the use of an entire room air-cleaning system is also recommended in a dental laboratory in future. If dental technicians have used asbestos liners in the past, they must ask physicians to check their lung health conditions, and receive appropriate medical treatments if necessary.

Acknowledgements
This study was supported in part by (1) Grant-in-Aid (B) 21390526 by Japan Society for the Promotion of Science and (2) Grant-in-Aid for the Open Research Project from 2007 to 2011 from Ministry of Education, Culture, Sports, Science and Technology, Japan.

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