Abstract

Introduction: Fine aerosolised droplets and splatter generated during dental procedures influences the composition of the indoor air quality of dental care facilities and poses a potential threat to the workers’ health. Therefore there is a need to assess the risks from exposure to bioaerosols and splatter and identify measures of reducing possible hazards.

Methodology: A review of the literature related to occupational exposure and health hazards in dentistry was conducted. The search primarily focused on endotoxin exposure from contaminated dental unit waterlines.

Results: This review highlights the various occupational hazards experienced by dental personnel. However, focus is directed on exposure to biological agents as a result of fine aerosol and splatter generated from dental procedures. More emphasis is on endotoxin exposure from contaminated dental unit waterlines and the negative impact it may have on dental workers. The review also aims to inform the reader of proposed endotoxin levels in both air and water and how and by whom it should be measured.

Conclusion: Understanding the main sources of endotoxin in dental practice and its influence on indoor air and potential threat to dental workers is pertinent to infection control strategies.
Introduction

It appears as if bacterial contamination only became a problem after the 1960s and has become a growing concern for clinical dentistry. Although infection control has assumed great importance, the waterlines of dental units remain a potential weakness in the control of infection, as they can easily become contaminated with both patient-derived and municipal water impurities. Reports of waterline contamination by potential pathogens like gram negative bacteria and their by-products (e.g. endotoxin) raises awareness of the seriousness of the contamination. The generation of aerosols from dental unit waterlines (DUWLs) is a potential source of exposure to microorganisms and endotoxin to both the health care provider and the patient. Despite the advances made in modern dentistry, biological hazards still put considerable strain on infection control procedures. As the existence of gram negative bacteria in the dental environment dominates, investigations into its role as an occupational hazard should be prioritised.

Methodology

A literature review was done which targeted peer-reviewed publications related to the topic occupational exposure and health hazards in dentistry. Several publications reviewed referred to conference proceedings and statutes, which were subsequently obtained and included in the manuscript. The review process involved three phases. The initial phase of the review process included searches with specific search phrases using the internet (PubMed, Google, Google Scholar) and major occupational health journals. A series of combination terms were used to refine the search outputs. These included "dental & bacterial & aerosols", "dental & endotoxin & health & effects", "dental & endotoxin & aerosols", "dental & occupational & hazards", "dental & occupational & risks & endotoxin", "dental & risk & endotoxin", "dental & aerosols", "dentistry & occupational & hazards", "dentistry & occupational & risks", and "dental & exposure & reduction". The second phase of the review process involved scanning the abstracts from the first phase for relevant key words or a combination thereof. Key words included: occupational...
exposure, occupational disease, occupational health, dentist, dental, dentistry, assistants, dental students, bioaerosols, biological, occupational hazard, endotoxin, dental unit waterlines or DUWLs. The third phase of the review process involved a more rigorous assessment of the identified abstracts based on the following inclusion criteria: 1) relevant to occupational health (i.e. risk to dental workers and not patients, unless otherwise stipulated), 2) exposure to bacteria and their by-products (i.e. gram negative bacteria and endotoxins) and 3) health effects to endotoxin.

**Results**

The initial literature search resulted in 1463 publications that were evaluated for possible inclusion in the study. On the basis of the selection criteria 60 publications were included in this review and 1403 were excluded. Although many of the excluded publications covered topics on occupational hazards in dentistry, the majority were focused on bloodborne pathogens and the risk to patient and patient recovery. In addition several of the publications related to endotoxin and dentistry are concerned with infection of open wounds during treatment. The aim of the current review was on endotoxin exposure primarily from dental unit waterlines and the risk to the dental workers which narrowed the search considerably.

**Sources of bioaerosols**

**Dental units**

Dental units are the focal point of dental clinics. The units are equipped with a network of thin, plastic tubes known as DUWLs. The tubing can contain approximately six meters of narrow bore flexible polyurethane or polyvinyl chloride (PVC) tubing. Although DUWLs are usually supplied by well-maintained municipal water, they become heavily contaminated over time as microorganisms adhere to the luminal surface of the waterlines, coalescing into a film containing multiple microbiological species called a biofilm. Previous research has shown extensive growth of biofilm in DUWLs using scanning electron microscopy. Although microorganisms consistent with oral flora are recovered from biofilm communities, the majority of microbes are gram negative water bacteria or endotoxin-containing microvesicles, protozoa cysts and mineral deposits. These impurities are usually found in small numbers in municipal water systems and may also enter the dental unit during repair and maintenance.

Scientific evidence has documented that the water used as a coolant and irrigant during dental procedures can be heavily contaminated with microorganisms to potentially dangerous levels and can reach colony forming units (cfus) of one million per ml. To decrease the medical risk of DUWL contamination a possibility is to reduce the bacterial contamination of water to a lower limit suggested by the American Dental Association to less than 200 cfu/ml. In a cross-sectional multicentre DUWL survey of 265 dentists in
general practice, the temporal onset of asthma may be associated with occupational exposure to contaminated DUWL. Dentists who were exposed in their dental surgery to total aerobic counts at 37°C at a concentration ≥ 200cfu/ml were more likely to report symptoms of asthma "since starting dentistry".\textsuperscript{15} Large multi-chair dental clinics such as those associated with schools of dentistry, military installations and public health clinics are confronted with unique problems with regard to control of contaminated DUWLs. Some dental units may remain unused for frequent quiescent periods, thereby allowing undisturbed biofilm to increase in mass due to the lack of shearing force from laminar water flow.\textsuperscript{8, 14} Unacceptable levels can also result from periods of water stagnation due to the rhythm of work during the day and during the night. Investigations demonstrated that biofilms can form within 8 hours after connecting a new dental unit to mains water supply developing into a rich climax community of micro colonies embedded in a protective extracellular matrix. With time, individual microorganisms, as well as pieces of the biofilm, can dislodge contributing to the microbial load in the water as it exits the waterlines.\textsuperscript{16} Szymanska describes the numerous studies done by other researchers demonstrating the widespread and unacceptably high levels of contamination in surgeries a short period after new dental units were installed.\textsuperscript{14}

**Dental procedures**

Many dental procedures produce fine aerosol and splatter composed of various combinations of water; organic particles (tissue and tooth dust) and organic fluids (blood and saliva). These may be inhaled by the attending dental staff, as it splashes off the surface of the patient's mouth. Aerosol production is an inescapable effect of the rapidly vibrating tips of dental handpieces. Fitted transducer elements create vibrations from 25000 Hertz to 40000 Hertz which are then transmitted as mechanical energy to the tips.\textsuperscript{17} To prevent heat production from the high energy levels, water is supplied to the handpieces serving as a coolant as well as to lavage the working area in order to increase the health care provider's vision. The aerosolised water comprises particles of varying size ranging from 0.001 µm to 100 µm including both aerosol and splatter. While most of the water in the spray is removed by high-volume aspiration, particles greater than 100 µm in diameter disperse and deposit quickly on the surface of objects due to gravitational forces. Splatter particles, moving along trajectories, can reach the dental personnel as the range of splatter is from 15 to 120 cm.\textsuperscript{2} Splatter of aerosol onto mucous membranes or intact skin was the second (26.9%) most frequent type of occupational exposure reported in a recent South African study.\textsuperscript{18}

**Other**

The potential routes for the spread of infection in a dental office apart from dental units and procedures are direct contact with body fluids (e.g. saliva and respiratory fluids) of an infected patient or other sources in the dental clinic such as air-conditioning systems.\textsuperscript{19} Body fluids are unlikely to be contaminated with endotoxin unless mixed with
contaminated dental water during procedures. However, poorly maintained ventilation and air-conditioning systems can be a potential source of fungal and other microbial organisms. The air-conditioning system could therefore act as a vehicle for the transmission of such microorganisms in the dental clinic.\textsuperscript{20, 21}

**Constituents of bioaerosols produced in dentistry**

Many reports in the literature demonstrate increased numbers of airborne bacteria during various aerosol-producing dental procedures. The airborne bacterial load resulting from high speed turbines may reach up to 300cfu/m\(^3\), and a 250\% increase over background counts can be reached during a 50-minute dental procedure. Thirty minutes of ultrasonic scaler use can increase background bacterial counts by approximately 5000cfu/m\(^3\) and has been reported to be the greatest producer of contaminated aerosol and splatter.\textsuperscript{17, 22, 23}

Infectious agents such as viruses (e.g. hepatitis B virus, hepatitis C virus), bacteria and fungi are spread by aerosols from contaminated dental units.\textsuperscript{3, 10} Gram negative rods producing allergens and endotoxin are important risk factors among the potentially allergenic and toxic microorganisms.\textsuperscript{7} Environmental endotoxin is heterogeneous containing variable amounts of lipopolysaccharide (LPS), phospholipid and membrane protein. LPS are stable water soluble molecules composed of lipid and polysaccharide. The lipid moiety of LPS is termed ‘lipid A’ and is responsible for the toxic properties of LPS.\textsuperscript{24} In addition the chemical structure of the polysaccharide and, to a small degree, the lipid A, portions of LPS vary between serotypes and species of gram negative bacteria, and within a single type of bacteria when grown under different conditions.\textsuperscript{11} Endotoxins are easily released in large quantities in the form of discoid particles (microvesicles) 30-50 nm in diameter with a characteristic triple-tracked membrane.\textsuperscript{11} They are components of particulate matter less than 10 \(\mu\)m in aerodynamic diameter fraction (PM\(^{10}\)).\textsuperscript{25, 26} Differentiating between particle size is important as not all particles pose a health risk. Particles less than 50 \(\mu\)m are small enough to stay airborne for an extended period before they settle on environmental surfaces or enter the respiratory tract. The smaller particles of an aerosol (0.5 to 10 \(\mu\)m 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 infections.\textsuperscript{19}

**Health effects of endotoxin**

Inhalation of endotoxins cause an inflammatory response in the respiratory tract and toxic pneumonitis by non-specific activation of alveolar macrophages and the subsequent release of cytokines and other mediators.\textsuperscript{27} Exposure to airborne endotoxins can also cause acute fever and lung function alterations accompanied by respiratory complaints such as chest tightness, cough, shortness of breath and wheezing, and is a known trigger
for asthma. Other clinical reactions include irritation, skin rashes, fever and rhinoconjunctivitis.\textsuperscript{28} The symptoms observed depend upon the dosage, route of entry, molecular structure, and other poorly defined susceptibility factors. Specific effects of endotoxin include its activity as an immunologic adjuvant both for IgE antibodies to bystander antigens when administered through the respiratory route and also as an adjuvant for delayed hypersensitivity to chemical hapten on the skin. Therefore, endotoxin acts synergistically with allergen resulting in a magnification of specific allergen induced mediator release.\textsuperscript{28, 29}

**Occupational exposure risk in dental personnel**

Occupational health complaints are not unusual to dentistry\textsuperscript{10, 18} and exposures were found to be unacceptably high in a South African study.\textsuperscript{18} However, the latter study did not differentiate between the various occupational health complaints or diseases. Dentists are exposed to a number of occupational hazards which include biological (e.g. bacteria, viruses), chemical (e.g. acrylates, metals), physical (e.g. noise, radiation), psycho-social (e.g. shift work and stress) and ergonomics (work station design). These hazards cause the appearance of various ailments, specific to the profession, which develop and intensify with years. These diseases and disease complexes range from stress related issues, musculoskeletal disorders, asthma and allergies.\textsuperscript{30, 31} Due to a lack of in-depth epidemiological research, to date there is still little evidence of significant health problems associated with the use of contaminated DUWLs.\textsuperscript{8, 9} Only three epidemiologic studies suggesting occupational exposure to contaminated DUWLs have been reported.\textsuperscript{32} In 1974, Clark recovered the same species of gram negative bacteria (Pseudomonas species) from dental units and the nasal flora of 14 of 30 dentists he evaluated. While no clinical symptoms were reported, seeding of the respiratory tract with gram negative bacteria has been identified as an antecedent event in the development of gram negative pneumonia in hospitalized patients.\textsuperscript{32} Studies have demonstrated that dental health care workers show evidence of increased exposure to legionella bacteria as evidenced by elevated antibody titres when compared with demographically similar control populations. Although these studies suggest a possible increased risk of experiencing illness among dental health care workers, no clinical cases of legionellosis were reported in these studies.\textsuperscript{33, 34}

Reports in the literature have also indicated that the clinical dental team experience an increased prevalence of respiratory infections compared to the general population or other health care professionals.\textsuperscript{15, 35-38} However, the lack of definitive evidence may also reflect the difficulty of establishing epidemiological links between infections with extended incubation times and antecedent dental procedures.\textsuperscript{39, 40} Although not occupational, Mathew and colleagues found a significant decrease in lung function in 15% of 57 children aged 6 to 18 years who underwent dental treatment. There are scanty reports of investigations of endotoxin in DUWLs and exposure to the dental team.\textsuperscript{15, 26, 41-43}
Endotoxin is the major predictor of the development and progression of occupational airways disease in a variety of occupational settings.\textsuperscript{15, 44, 45} However, the occupational risk of asthma caused by endotoxin among dental workers who are subjected to prolonged daily exposure to contaminated dental waterlines has not been conclusively demonstrated.\textsuperscript{15} There is therefore a need for epidemiological and clinical studies investigating the link between endotoxin exposure and health effects in dental personnel.

**Proposed exposure levels for endotoxin**

The quality of dental water is of considerable importance since the dental team and patients are regularly exposed to it and its aerosols. These aerosols are a source of indirect infection for dentists, and may constitute an occupational hazard in their work. Water that does not meet potable-water standards is inappropriate for use in dentistry. However, documented instances of related occupational illness have not been reported. Exposure to water containing high numbers of bacteria violates basic principles of clinical infection control. Despite the reported health effects associated with endotoxin, a permissible exposure limit has not been promulgated, partly because of weaknesses in epidemiologic evidence arising from problems with quantifying airborne concentrations.\textsuperscript{46} This is the result of discrepancies in the dose-response relationships between endotoxin exposure and health effects observed by different groups.\textsuperscript{47}

**Endotoxin levels in water:** At present, there appear to be no standards for endotoxin in drinking water or recreational waters. A consensus opinion on prevention measures is that the water used for dental procedures should be the same quality “as for drinking water” and sterile water should be used for surgical procedures.\textsuperscript{9} The United States Pharmacopeia, have set a limit for endotoxin in sterile water for irrigation at 0.25EU/ml.\textsuperscript{48} This limit could be used as a bench-mark for dental procedures requiring sterile water.

Another attempt to decrease the medical risk of DUWL contamination is to reduce the bacterial contamination of water to a lower limit suggested by the American Dental Association to less than 200 cfu/ml.\textsuperscript{27}

**Endotoxin levels in air:** The Dutch Expert Committee on Occupational Standards recommends a health-based occupational exposure limit for airborne endotoxin of 50 EU/m\textsuperscript{3} based on personal inhalable dust exposure measured as eight hour time weighted average.\textsuperscript{49}

**Approaches to endotoxin risk reduction**

Owing to the multiple ports of entry of microorganisms to the DUWL system, no single method or device but rather combinations of procedures and equipment should provide
water that is of a standard higher than that of drinking water. However, all systems require strict adherence to maintenance protocols to perform to their full potential. A number of measures are proposed which can assist in reducing the levels of contamination within the DUWLs and clinic environment.

**Flushing**: Dental units should be flushed for "several minutes" at the beginning of the working day to expel the overnight build up of microbial load and for 20 – 30 seconds between patients to remove material that may have been retracted during treatment. However, there have been reports which mention that flushing has little benefit due to the existence of biofilm within the DUWLs, which can exceed the pre-flush as pieces are dislodged during treatment. Therefore, to reduce exposure, flushing needs to be done in conjunction with other scientifically validated interventions (e.g. chemical treatment, filtration), unless proven otherwise.

**Chemical treatment**: A number of chemical compounds have been used to remove biofilm and eliminate planktonic bacterial counts with various degrees of success. Depending on the nature of the chemical treatment, it may be used intermittently (shock treatments) or continuously to treat the DUWLs. Electro-chemically activated water has been shown to effectively reduce bacterial counts and remove biofilm in dental waterlines and is thus a promising alternative.

**Filtration**: The use of a disposable filter on the DUWL to eliminate bacteria from entering the handpiece is one way of reducing endotoxin exposure. However, to be effective these filters must be changed daily and must be located on each water-bearing line as close as possible to the handpiece. The filters do not affect the flow rate of water to any significant degree.

**Independent reservoirs**: Independent reservoirs isolate the unit from municipal water and permit the use of water of known microbiological quality. The user can introduce cleaners and germicides to control or eliminate biofilm formation within the water delivery system. A number of major manufacturers offer independent reservoirs as standard equipment or as optional accessories.

**Suction devices**: The use of high-performance sucking devices during aerosol generation also assists in reducing exposure.

**Ventilation**: A ventilation and air-conditioning system in good working order is useful in reducing contamination of dental environments.

**Irradiation**: Ultraviolet (UV) treatment of water has been used to reduce endotoxins in water-cooling towers and water treatment plants. This method would appear to be an attractive non-polluting alternative for point of entry of mains water purification.
**Personal Protective Equipment (PPE):** PPE greatly lowers the risk of transmission. However, when masks do not fit snugly, contamination will bypass the filtering effect of the mask.\(^\text{17}\) In addition, the risk of contamination continues long after the dental procedure is over as true aerosols remain airborne for up to 30 minutes after the procedure. One study reported that 15-83% of 0.06-2.5 µm sized plasma aerosol particles could pass through the filter media of 9 makes of surgical masks used by dental professionals for protection from occupational infection.\(^\text{52}\) For this reason, the use of multilayered, cup-style facemasks instead of conventional, single-layered masks is recommended.\(^\text{53}\)

It should also be borne in mind that monitoring is a process that can help identify technique errors or noncompliance, and also provides positive reinforcement for the dental staff. Validation studies need to be conducted by the manufacturer which would then determine the frequency of monitoring in the clinical setting.\(^\text{3}\) Monitoring of endotoxins is performed by sampling inhalable aerosols or bulk water samples. The endotoxin levels are commonly assessed using the Limulus Amoebocyte Lysate assay which measures biologically available endotoxins and therefore gives measurements relevant to occupational exposure assessment.\(^\text{24}\) The measurements need to be done with an experienced team which consists of a microbiologist, occupational hygienist and dental technician. Any recommendation requiring actioning with respect to the measurements needs to be discussed with management to ensure that the control measures are reasonably practicable in the particular setting.

Since dental personnel and the increasing numbers of people with diminished resistance to overt and opportunistic pathogens are seeking dental treatment and may be susceptible to infection as a result of exposure to contaminated dental unit water, every effort should be made to ensure that water within the waterlines are of an acceptable level. The ultimate decision to take measures to improve and maintain the quality of water used in dental practice lies with the employee / dentist. In terms of the Occupational Health and Safety Act No.85 of 1993, the employer needs to create a safe working environment as reasonably practicable.\(^\text{54}\)

**Conclusion**

There are four main sources of bioaerosols in dental practice, albeit DUWLs pose a major source of endotoxin.\(^\text{26, 43}\) All these need to be addressed to ensure the occupational health of these employees are not compromised. Endotoxin levels rise during certain dental procedures, quiescent periods experienced during weekends, study breaks and vacation, increased temperatures, lack of disinfection procedures, water quality, small bores of DUWLs and low flow rate.\(^\text{9, 53, 55-57}\) To ensure that endotoxin levels do not rise above the recommended level of 50 EU/m\(^3\), regular maintenance of dental units, temperature control and improved ventilation within clinics need to be addressed.
Recommendation

Addressing endotoxin levels include both engineering controls and administrative controls. From an engineering perspective the dental manufacturer bears the primary responsibility for ensuring that dental units are designed to reduce the problem of DUWL contamination. However, in terms of the Occupational Health and Safety Act the responsibility lies with the dentist in choosing to purchase new dental units that are capable of delivering water of an acceptable standard or in retrofitting existing equipment. In addition, the performance of the units to their full potential is also subject to strict adherence to maintenance protocols. Despite the technological advances to date, engineering controls still need to be coupled with administrative controls for optimum reduction of risk of transmission (e.g. multilayered, cup-style facemasks). Periodical screening of personnel for exposure to endotoxins and subsequent health effects will ensure that early intervention takes place when problems are identified and long-term health effects are minimised. This is, however easier said than done due to several uncertainties in the link between endotoxin and health effects.

Areas of future research

Despite a strong correlation between endotoxin exposure and disease in certain occupational settings, uncertainties arise in the dental facilities due to the ubiquitous nature of endotoxins. Where endotoxin is found so are large numbers of other agents which may have allergic and toxic properties. Therefore, further research clarifying the role of endotoxin exposure and health effects particularly work-related asthma (WRA) in dental personnel is required, since WRA is a heterogeneous disease triggered by a multitude of exposures.

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