

THE DENTAL UNIT WATERLINE CONTROVERSY:

DEFUSING THE MYTHS, DEFINING THE SOLUTIONS

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ABSTRACT

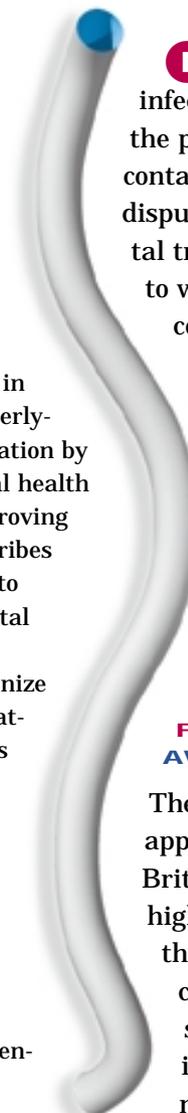
Background and Overview.

This article reviews the literature on the subject of dental unit waterline contamination. It has been expanded from the text of a lecture given at the Scientific Frontiers in Dentistry program sponsored by the National Institute for Dental and Craniofacial Research in Bethesda, Md., in July 1999. The author examines the underlying biological causes of waterline colonization by microorganisms, the evidence of potential health consequences and possible means of improving the quality of dental water. He also describes examples of devices currently marketed to improve and maintain the quality of dental treatment water.

Conclusions. Microorganisms colonize dental units and contaminate dental treatment water. While documented instances of related illness are few, water that does not meet potable-water standards is inappropriate for use in dentistry.

Clinical Implications.

Exposure to water containing high numbers of bacteria violates basic principles of clinical infection control. Dentists should consider available options for improving the quality of water used in dental treatment.



In recent years, few issues in the field of dental infection control have been more controversial than the phenomenon of dental unit waterline, or DUWL, contamination. While few dentists now seem willing to dispute the existence of microbial contamination in dental treatment water, many dentists remain unsure as to what to do about it. A number of factors probably contribute to their confusion, including the absence of well-documented links to health problems in dental health care workers and patients and a lack of consensus among the experts about the best approaches to solving the problem.

This article will address this topic by trying to answer the following most frequently asked questions, or FAQs, about the nature of DUWL contamination, its possible health effects and the technologies that exist to address it.

FAQ 1. HOW LONG HAS DENTISTRY BEEN AWARE OF THIS ISSUE?

The existence of contaminated water in dental units appears to have first been reported in 1963 in Great Britain by Dr. G.C. Blake,¹ after installation of new high-speed air-rotor handpieces. Since dental units of that era were not equipped with systems to provide coolant water, the handpieces were equipped with separate water reservoirs. What led Dr. Blake to investigate the quality of dental treatment water is not clear.

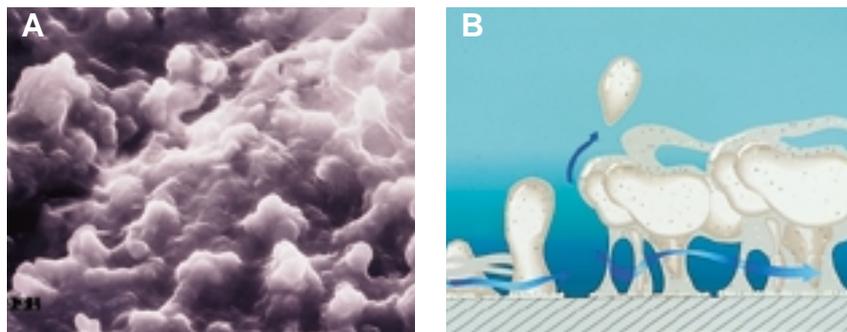


Figure 1. Biofilm architecture. A. Dental unit waterline magnified $\times 5,000$, showing the polysaccharide slime layer and typical biofilm surface architecture. (Photo courtesy of the USAF Dental Investigation Service.) B. An artist's conception, revealing the presence of complex features such as channels for convective flow within the biofilm. (Illustration used by permission of the Center for Biofilm Engineering, Montana State University, Bozeman.)

However, his finding—that large numbers of bacteria (some potentially pathogenic) were present in water and aerosols—has been confirmed by dozens of published articles during the last 37 years. He also was the first to test the effectiveness of chemical germicides as a possible solution to the problem.¹

Since Blake's landmark publication, dozens of articles have appeared in dental journals worldwide describing the existence of microbial contamination in dental water systems and investigating methods to control it. Most of the approaches currently in use (flushing, chemical treatment, filtration) were evaluated in some form before 1980.² There is presently little evidence that these articles have had a significant impact on the practice of dentistry.

Nevertheless, by the early 1990s, a profession sensitized to infection control issues because of the worldwide human immunodeficiency virus, or HIV, epidemic began to show more interest in the topic. Reports of waterline contamination by *Legionella* and other potential pathogens probably

increased overall awareness.³ Research also began to elucidate the role that biofilms played in the presence and persistence of the phenomenon.⁴ This awareness led the Centers for Disease Control and Prevention to first address the topic of water quality in its 1993 infection control guidelines.⁵ The American Dental Association Council on Scientific Affairs⁶ followed suit by convening an expert panel on DUWLs in 1995; the panel's work culminated in a formal statement published in JADA in 1996.

Gaining a basic understanding of the nature of microbial contamination of dental water is a crucial step in seeking a satisfactory resolution of this controversial issue. To accomplish that, we first must answer a few questions, starting with FAQ 2 below.

FAQ 2. WHAT IS A BIOFILM?

Biofilms are microbial communities that adhere to solid surfaces wherever there is sufficient moisture (including plant and animal tissues). Consisting primarily of bacteria, biofilms

often exhibit astonishingly complex communal architecture. Most biofilms are heterogeneous in species and morphology and are enveloped in a polysaccharide slime layer known as a glycocalyx. The glycocalyx protects the organisms within from desiccation, chemical insult and predation, as well as from attacks by plant and animal immune systems. The relationship between biofilm organisms is often symbiotic, with one species providing key cofactors required by another. Some species apparently communicate with others in the biofilm community using a variety of signaling compounds. Depending on environmental conditions, these chemical signals can initiate slime formation or order the breakup of the biofilm. Biofilms also provide an environment conducive to the proliferation of a wide variety of other microscopic life, including fungi, algae, protozoa and nematodes.⁷ Absent the algae and nematodes, this description of biofilms should sound familiar to dentists, as dental plaque is a classic biofilm.⁸ Figure 1 shows a scanning electron micrograph of a biofilm inside a DUWL and a schematic representation of typical aquatic biofilm architecture, including channels that allow convective flow within the community.

The formation of biofilms on water-bearing surfaces in dental units results in fouling of the water that passes through the unit with high levels of suspended bacteria. Most organisms recovered from dental water systems are gram-negative noncoliform water bacteria.^{4,9-11} Although most of the species recovered have limited

pathogenic potential in immunocompetent people, the Safe Drinking Water Act sets a standard for noncoliform bacteria in drinking and recreational water at 500 colony-forming units per milliliter, or CFU/mL.¹² (This is a standard measure for microbial contamination that represents a single colony grown on solid media. A CFU may consist of a single cell or many bacterial cells clumped together.) The American Public Health Association and American Water Works Association recommend the same standard for recreational waters such as swimming pools and spas.¹³ By comparison, DUWL contamination in untreated systems often exceeds 1,000 CFU/mL. Counts ranging between 10,000 and 100,000 CFU/mL may be commonplace.¹⁴

FAQ 3. IF DRINKING WATER IS SAFE, WHY IS DENTAL UNIT WATER SO BAD?

Despite high-profile incidents such as the *Cryptosporidium* outbreak that sickened thousands in Milwaukee in 1994,¹⁵ most drinking water in the United States meets established standards for biological contamination on a day-to-day basis. Many clinicians are puzzled as to how dental units can become so heavily contaminated when they are supplied by well-maintained municipal water systems. The answers lie in a convergence of biology, physics and geometry that can be summarized into three components: surface colonization, laminar flow and surface:volume ratio.

Surface colonization.

Many materials commonly used to deliver water to dental handpieces and air/water syringes provide excellent substrates for

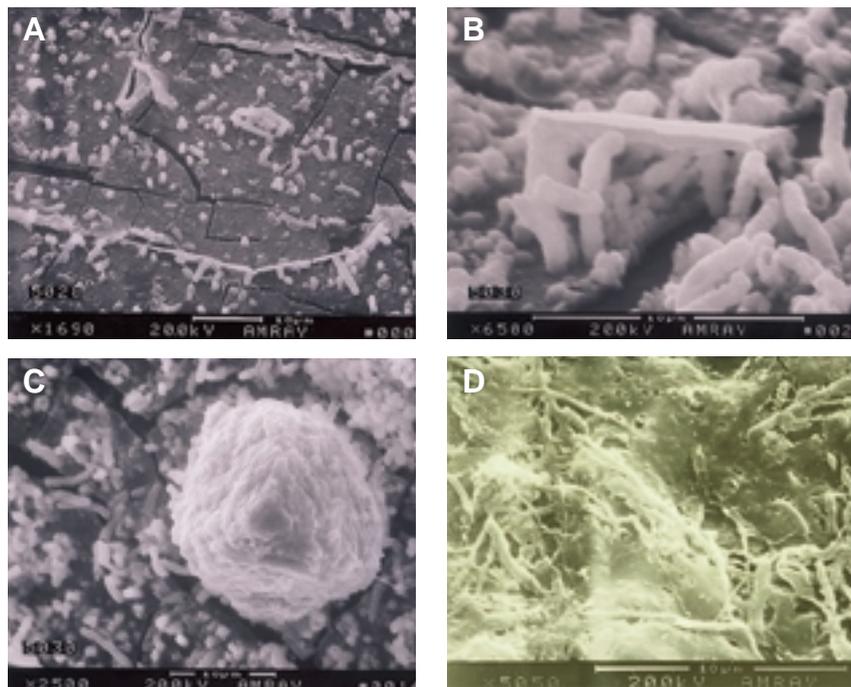


Figure 2. Biofilm colonization sequence on dental unit waterline surface. A. Carbonate deposits (which resemble ice floes). B. Initial attachment. C. Division of cells into microcolonies. D. Formation of biofilm.

the initial attachment of bacteria and the subsequent proliferation of biofilm. Moreover, most treated drinking water contains minerals—principally calcium carbonate—that are deposited on water-bearing surfaces. Organic molecules subsequently concentrate on these surfaces and promote adhesion of bacteria suspended in water supplied by the municipal water system.⁷ Figure 2 demonstrates a typical sequence of biofilm formation on calcium carbonate deposited on a polyurethane DUWL. Over time, individual cells attached to the surface multiply to form microcolonies that ultimately coalesce to form a continuous sheet of bacteria protected by the glycocalyx. Figure 3 shows a biofilm in a DUWL formed after only six weeks of exposure to tap water.

Laminar flow. Fluids moving through narrow-bore tubing

characteristically assume a hydrodynamic pattern known as laminar flow. Closer to the tubing surface, frictional forces slow the movement of fluids until flow at the surface is stabilized; this creates an environment conducive to the formation of biofilm.¹⁶ In laminar flow systems, biofilm can flourish with minimal risk of being dislodged. This is one of the principal reasons that flushing of waterlines can eliminate suspended (planktonic) microorganisms, but usually is not effective in removing biofilms.¹⁷ Figure 4 presents a highly simplified representation of a laminar flow pattern in a DUWL.

Surface:volume ratio.

Although understanding the biology (attachment and proliferation of biofilms) and physics (laminar flow) operating in dental water systems is crucial in answering this FAQ, it is geom-



Figure 3. Biofilm formation on dental unit waterline tubing after six weeks of exposure to tap water. (Photo courtesy of Richard Karpay, D.D.S.)

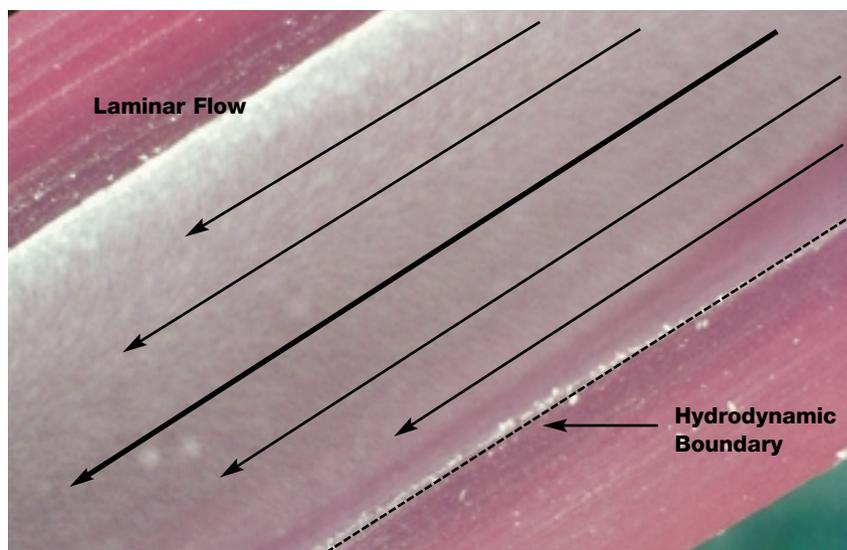


Figure 4. Laminar flow. Arrows represent the relative velocity of fluid through a dental unit waterline, which decreases as the fluid travels because of frictional forces along the tubing walls. The relatively stable region below the hydrodynamic boundary layer is conducive to biofilm proliferation.

etry that ultimately explains why dental unit water is more contaminated than water from an adjacent faucet. After all, biofilms also are present in the water mains and lines that link the faucet to the municipal water system, and the same hydrodynamic principles apply as well.

As the diameter of a cylinder—in this case, the waterline—decreases, an increasingly larger surface area becomes available for colonization. The total combined volume of waterline tubing in most dental units is somewhat less than 100 mL. To understand the effect of tubing diameter on surface area, I

will describe a hypothetical 100-mL volume of water as it flows from the city water main to the end of the handpiece hose. Figure 5 demonstrates what happens when 100 mL of water is confined in a section of 10-inch diameter water main. In this case, there are only four square inches of surface area available for biofilm formation (the size of a 2-in. × 2-in. gauze sponge). As the water enters the dental office, it is channeled into a pipe roughly one-half in. in diameter. The same 100-mL volume of fluid is now in contact with a surface area equivalent to the faces of six credit cards (roughly 42 square in.). On entering the $\frac{1}{16}$ -in.-diameter tubing that courses through a modern dental unit, the bacteria suspended in our water sample now find more than 400 square in. of surface available for colonization (equivalent to one and one-half pages of a daily newspaper). The juxtaposition of large quantities of organic material with very small quantities of water also accounts for the almost total consumption of residual chlorine observed in colonized dental water systems.^{18,19} The net result of all of these phenomena is treatment water that frequently is contaminated with high levels of microorganisms.

FAQ 4. WHAT ORGANISMS ARE PRESENT AND WHERE DO THEY COME FROM?

Now that we have some idea how and why there are so many organisms in dental treatment water, it is reasonable to ask, "What are they, and where do they come from?" Many early researchers assumed that most of the organisms they found in dental water were retracted

from the oral cavity. On the basis of this assumption, they often used culture media and incubation methods designed to recover human flora.^{2,20} This did not always give an accurate picture of the true nature of the microbial communities residing in dental units. While organisms consistent with oral flora are recovered, the majority of microbes living in the biofilm communities are gram-negative water bacteria of the same varieties that survive in small numbers in municipal water systems.²⁰

Older dental units that were designed to retract water (to prevent water dripping from handpieces and air/water syringes) can, in fact, retract oral flora.²¹ Since these organisms usually are well-adapted to the warm, nutrient-rich oral environment, they typically do not compete well with the water flora that predominate in waterline biofilms. Some experts, however, conjecture that heating dental water to ensure patient comfort actually may increase the prevalence of bacteria "pre-adapted" to life in a warm-blooded host, including *Legionella* bacteria (W.W. Bond, M.S., former deputy chief, Hospital Environment Laboratory Branch, Hospital Infections Program, National Center for Infectious Diseases, Centers for Disease Control and Prevention, oral communication, April 30, 2000).

As biofilms mature, they provide a hospitable environment for fungi, protozoa and other organisms that survive in drinking water systems.⁷ While most of these organisms have minimal pathogenic potential in immunocompetent hosts, some protozoa serve as hosts for pro-



Figure 5. Surface:volume ratio. The surface area available for colonization for a fixed volume varies with a waterline's interior diameter. The surfaces pictured represent the internal surface area provided for 100 milliliters of fluid by each of the lines pictured. A. A newspaper. B. Credit cards and a piece of 2-in. × 2-in. gauze.

liferation of parasitic bacteria, including *Legionella*.^{22,23}

Although independent reservoirs can be effective in improving DUWL quality, lax handwashing discipline and careless handling of bottles and feeder tubes can result in contamination of the water systems with enteric or skin organisms. The same thing can happen when dental water systems are repaired. A case of coliform contamination in dental units has been reported.²⁴

Worrisome organisms.

Although most of the organisms recovered from dental units are water bacteria with little demonstrated potential to cause disease in immunocompetent hosts, potential pathogens do find their way into dental water systems. *Pseudomonas aeruginosa* has been reported as being present in dental units⁹ (although many organisms reported as "*Pseudomonas* species" in older articles might actually be bacteria that have since been assigned to other genera). This gram-negative rod is associated with a wide range

of opportunistic infections and is a cause of pneumonia in hospitalized patients. *Pseudomonas* and related species in the genus *Burkholderia* also are associated with pneumonia in patients with cystic fibrosis, or CF. A study conducted in Denmark, however, found that the risk for patients with CF who were undergoing dental treatment with contaminated units was equal to the yearly "natural background" incidence (1 percent to 2 percent) of acquisition of *P. aeruginosa* in that clinic.²⁵

Legionella pneumophila and related species also have been isolated in dental treatment water. These weakly staining bacteria thrive as intracellular parasites of protozoa (principally amoebae). They are the causative agents for legionnaires' disease and a related condition known as Pontiac fever. Outbreaks and sporadic cases of legionnaires' disease occur in both hospital and community environments and may account for as many as 10,000 to 15,000 cases of pneumonia each year in the United States,

with an estimated mortality rate of 5 percent to 15 percent. Risk factors that increase susceptibility to this disease include smoking, pre-existing respiratory disease and age.²⁶

Aquatic nontuberculous *Mycobacterium* species associated with pulmonary disease and opportunistic wound infections also have been recovered in dental unit water.²⁷ All of this brings us to the next FAQ.

FAQ 5. ARE YOU CERTAIN ALL DENTAL UNITS (INCLUDING MINE) ARE CONTAMINATED?

This question has the shortest answer of all: unless procedures specifically designed to prevent, eliminate, trap or kill biofilms are performed, there is little reason to believe that any dental unit can avoid being colonized by bacteria.

If the bacteria are there, the next logical question—because we know that some of the bacteria have been shown to produce disease—should be FAQ 6.

FAQ 6. IS THERE ANY PROVEN HEALTH RISK?

Epidemiologic studies. The first part of the evidence basis for answering this question lies with three epidemiologic studies. In 1974, Clark²⁸ 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.²⁹ Studies have demonstrated that dental health care workers

show evidence of increased exposure to *Legionella* bacteria as evidenced by elevated antibody titers 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 either study.^{30,31}

Clinical case reports.

Martin³² published a case report describing *P. aeruginosa* wound infections in two immunocompromised patients. The organ-

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ism isolated from the infected sites was matched by pyocin typing to bacteria recovered from the dental unit. In both instances, the patients were treated and recovered.³² In an article describing the prevalence of *Legionella* contamination in dental unit water, Atlas and Williams²² mentioned the case of a 65-year-old dentist who died after developing legionnaires' pneumonia.

Although several species of *Legionella* bacteria were isolated in high numbers from a dental water source in his office, as well as in low levels from sources in his home, the authors were unable to establish a conclusive dental association.²² As previously mentioned, a small-scale study in Denmark failed to identify exposure to contaminated water as a risk factor for increased incidence of respiratory infection in patients with CF who were undergoing dental treatment.²⁵

Legal cases. A 1990 civil suit against a dental unit manufacturer was reported anecdotally by Dr. Robert Runnels (R. Runnels, D.D.S., written communication, October 1999). The plaintiff claimed that bacterial endocarditis and the need for subsequent prosthetic heart valve surgery resulted from dental treatment with contaminated water. The same strain of gram-negative water bacteria (*Moraxella*) was isolated from the patient and the dental unit. The plaintiff intended to argue that the organism entered the unit as a result of retraction of oral flora that occurred because the dental unit was not equipped with an antiretraction valve. Although Dr. Runnels was asked to provide an expert opinion in the case, he was not required to sign a nondisclosure statement and therefore was free to discuss the case. Subsequently, the case was settled out of court for an undisclosed sum (R. Runnels, D.D.S., written communication, October 1999).

Dr. Edward Zinman, a dentist and lawyer, disclosed a second legal case during a two-part "CBS Morning News" seg-

ment on DUWLs that was broadcast on Oct. 11 and 12, 1999.³³ The plaintiff, who suffered a brain abscess after undergoing dental treatment, claimed that her illness resulted from exposure to contaminated dental treatment water and won an out-of-court settlement against her dentist. The plaintiff also was interviewed by ABC News, in a nationally broadcast segment on "20/20" that aired originally on Feb. 18, 2000.³⁴

Unfortunately, the clinical particulars of these cases are unknown since no scientific investigation has been published to date.

Environmental investigations. Endotoxins are lipopolysaccharides in the cell wall of gram-negative bacteria that can produce a wide range of physiological responses, including localized inflammation, fever and even toxic shock.³⁵ Since many of the organisms recovered in dental treatment water are gram-negative bacteria, some researchers have speculated about the presence of bacterial endotoxins in dental treatment water. Recently, Puttaiah and Cederberg³⁶ reported that contaminated dental treatment water indeed may contain levels of endotoxin as high as 500 endotoxin units/mL, or EU/mL, with an average of about 80 EU/mL. In comparison, the United States Pharmacopeia, or USP, sets a limit for endotoxin in sterile water for irrigation at only 0.25 EU/mL.³⁷ At present, there appear to be no standards for endotoxin in drinking or recreational waters.

Unanswered health questions. While the clinical effects of endotoxin in treatment water

are unknown, Mathew and colleagues³⁸ found a significant decrease in lung function in 15 percent of 57 children aged 6 years through 18 years who underwent dental treatment. Although the authors did not suggest an association with respirable contaminants from dental handpiece coolant spray, bacterial endotoxin is a recognized trigger for asthma.^{35,39} Further investigation may help clarify whether such an association exists.

Most investigations of dental water have focused on bacterial contamination. As previously noted, however, fungi and protozoa also are present and may have health consequences. For example, *Cladosporium* is an aquatic fungus recovered from DUWLs^{4,10,40} that has been associated with hypersensitivity pneumonitis.⁴¹ In addition to their ability to serve as a host for replication of bacteria, some of the protozoa identified as inhabitants of water systems also are potentially pathogenic.⁴²⁻⁴⁴

There also has been speculation on the issue of disinfectant byproducts such as trihalomethanes resulting from chemical treatment of biofilm-colonized dental unit water systems.¹⁹ This problem may be most acute when chemical agents are introduced continuously into systems that still harbor residual biofilm matrix.

Whatever the true nature of health effects associated with microbially contaminated dental treatment water, there is little evidence of a major public health problem—at least not in terms of the "dead bodies" that some people seek as proof. Nevertheless, the evidence suggests reason for concern. As a result, the issue has

come to the attention of regulatory agencies and advisory bodies at both state and federal levels.

FAQ 7. WHAT RECOMMENDATIONS OR REGULATIONS ADDRESS THE QUALITY OF DENTAL TREATMENT WATER?

Recommendations. The Centers for Disease Control and Prevention Recommended Infection Control Practices for Dentistry, 1993, urged dentists to install and maintain anti-retraction valves to prevent oral fluids from being drawn into DUWLs. They also recommended flushing waterlines daily for several minutes and for 20 to 30 seconds between patients to discharge oral fluids that may have entered the lines during treatment. Furthermore, they stated that only sterile solutions should be used for procedures that involve the cutting of bone.⁵

The 1996 American Dental Association⁶ statement on DUWLs challenged the dental manufacturing industry to develop methods to control biofilms in dental unit water systems. The statement established a goal for dental water to contain no more than 200 CFU/mL of heterotrophic bacteria in unfiltered output.⁶ The Organization for Safety and Asepsis Procedures⁴⁵ issued a statement in 1996 supporting both the CDC and ADA guidelines, but containing more explicit guidance on waterline monitoring and the use of sterile irrigants in surgery.

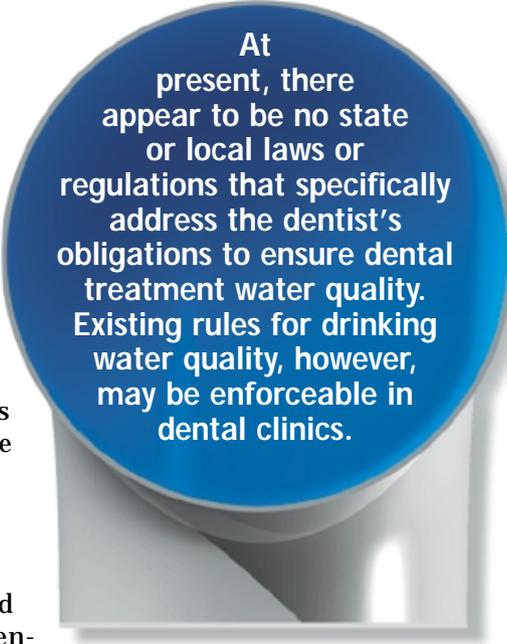
The ADA waterline panel reconvened in early 1999 to review the progress made in pursuit of the 1996 goal. The panelists concluded that industry had responded with a wide range of potential solu-

tions and that the goal of improved dental treatment water is achievable.⁴⁶ The ADA Seal of Acceptance program now includes products intended to maintain dental water quality.

Regulations. At present, there appear to be no state or local laws or regulations that specifically address the dentist's obligations to ensure dental treatment water quality. Existing rules for drinking water quality, however, may be enforceable in dental clinics, especially those pertaining to coliforms or *Legionella* contamination.¹² (The Safe Drinking Water Act sets limits for heterotrophic water bacteria, as well as these specific organisms, in drinking water.¹²) While the topic was not specifically addressed by an Occupational Safety and Health Administration rule, the agency's compliance officers recently were advised of the potential for occupational exposure to bacteria from contaminated DUWLs.⁴⁷ Manufacturers of dental units and products intended to improve the quality of dental treatment water are obligated to comply with a number of federal laws and regulations enforced by the U.S. Food and Drug Administration, or FDA, and the U.S. Environmental Protection Agency, or EPA. These requirements will be discussed later in this article (see page 1437).

In 1997, the California State Board of Dental Examiners held hearings on the subject of dental water contamination. The board has

established a requirement for the use of sterile irrigating solutions for invasive procedures and accepted an ad hoc DUWL committee report recommending no additional action before 2000.⁴⁸ In February 1999, a bill was introduced into the California State Assembly (Assembly Bill 498) that would have established the ADA goal of 200 CFU/mL as an enforceable standard after January 1, 2001.⁴⁹ Failure to provide



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water meeting this standard would have constituted unprofessional conduct under the state Business and Professions Code. Although the 1999 assembly did not pass the bill, a revised version was introduced for 2000 that would direct state health authorities to investigate the potential health consequences of the presence of pathogenic bacteria in water in a variety of public settings, including dental offices.⁵⁰

FAQ 8. WHY SHOULD WE DO ANYTHING ABOUT WATERLINE CONTAMINATION?

For those not yet persuaded to action by the evidence provided, I offer the following rationale: clinical infection control procedures concentrate on breaking the chain of infection that consists of potential pathogens in sufficient numbers, a susceptible host and a portal of entry. The susceptibility of the host (patient or health care worker) and the pathogenicity of the organisms are the links over which we have the least control. For this reason, most efforts to break the chain concentrate on reducing the numbers of organisms in the clinical environment. Indeed, most dental practices expend considerable effort and expense to accomplish this goal as an everyday matter through surface disinfection, instrument sterilization, hand-washing and use of antimicrobial mouthrinses.

As with recommendations to improve the quality of dental treatment water, few of the aforementioned procedures are based on strong epidemiologic evidence. Nevertheless, reducing the numbers of microbes in water from dental units is absolutely consistent with long-accepted infection control principles. Does it make sense to sterilize a dental handpiece, store it in an impervious package designed to ensure its sterility, and then use it to introduce into the oral cavity water that fails to meet accepted microbiological standards for drinking or recreational water?

The reader also may wish to consider the issue in light of the doctrine of informed consent. As

do all health care professionals, dentists have an ethical obligation to provide patients and employees alike with a safe clinical environment. Patients must be informed of potential risks associated with treatment and provide their consent. Similarly, employees may need to be informed of potential hazards as defined under statutes directing the "right to know." While the incidence of infections associated with contaminated dental treatment water appears to be low, would most patients consent to treatment with water contaminated with thousands or even millions of bacteria?

If the reader accepts that the answer to each of these questions is "no," the next question that must be answered is FAQ 9.

FAQ 9. WHAT MEANS ARE NOW AVAILABLE TO IMPROVE AND MAINTAIN THE QUALITY OF WATER USED ON DENTAL TREATMENT?

Current approaches. Researchers beginning with Blake¹ in 1963 have investigated treatment options intended to maintain the quality of dental treatment water. The largest number of studies of waterline treatment published over the last 37 years have investigated various chemical agents intended to inactivate microorganisms, induce detachment of biofilms or both. The second largest group of studies examined the flushing of waterlines; the use of filters has received the least attention in the peer-reviewed literature.²

On the basis of this research and other work in the related fields of microbiology and engineering, a number of products

have been developed. Most strategies to improve the quality of water provided by conventional dental units employ the use of chemical treatment either alone or in combination with other technologies, including microfiltration. Another alternative is to entirely bypass the conventional dental water delivery system and use either autoclavable or disposable pathways.

Waterline flushing. The efficacy of mechanical flushing alone to control microbial contamination in dental unit water is not well-supported by the scientific literature.^{10,11,17,51,52} Although flushing can temporarily reduce the number of organisms suspended in DUWLs, there is no predictable effect on adherent biofilm. Bacterial aggregates breaking free from the biofilm have been shown to recontaminate dental unit water during the course of subsequent clinical treatment.¹⁷ Flushing for several seconds between patients, however, may remove materials that may have entered the water system during patient treatment.

Independent reservoirs. Independent reservoir systems are available as original equipment or as after-market accessories for most dental units. By isolating the dental unit from the municipal water supply, the clinician can control the quality of water introduced into the system. But without treatment with chemical agents to inactivate or detach biofilm or installation of point-of-use filters, independent reservoirs are of little value in improving the quality of treatment water. Independent reservoirs are relatively inexpensive to install compared with other devices.

Some dental manufacturers now ship independent reservoirs as standard equipment, and after-market units can be installed for as little as \$100 per unit. Recurring costs will depend on the source water and treatment agents selected for use.

Chemical treatment. An ideal agent for control of biofilm would be bactericidal but not toxic or irritating to humans. It would detach biofilm and discourage subsequent reformation, while protecting the dental unit's internal components from corrosion or degradation. If delivered continuously in treatment water, it would have no effect on enamel or dentin bonding agents. And, of course, to be truly ideal, it would be inexpensive and easy to use. Although such an agent does not appear to exist, there are products that possess some of these desired characteristics.

Intermittent chemical release. Chemicals may be introduced into water systems either intermittently or continuously. Most intermittent treatment regimens use potentially biocidal concentrations of germicide that also may remove biofilm. Borrowing terminology from the swimming pool industry—which must also deal with biofilm—some experts refer to this approach as "shock treatment." The usual practice is to deliver the agent for a specified contact time and frequency using an independent water reservoir that isolates the unit from the municipal water supply. This also permits the use of water of known microbiological quality for subsequent therapeutic procedures. A major advantage of intermittent chemical use is that the active agent is purged

from the system before patient treatment. Disadvantages include the potential for surviving biofilm organisms to rebound between treatments; potential staff exposure to chemicals; and the potential for adverse impact on metal, rubber and synthetic dental unit components.

Continuous chemical treatment. Continuous treatment uses either lower concentrations of potentially biocidal agents or less toxic (biostatic) substances in the water used for patient treatment (just as municipal water systems rely on residual chlorine to maintain the safety of drinking water). Continuous treatment regimens also may employ initial shock treatment to inactivate or eliminate biofilms. Although continuous treatment offers less potential for recolonization of waterlines, it still may damage equipment. Since the agent is always present and may be aerosolized, the effects of chronic exposure on the health care worker must be considered. Enamel and dentin bond strength of dental adhesive materials also may be affected.^{53,54}

Chlorine compounds have been studied more extensively than any other class of chemical agents intended to control or eliminate biofilm in dental unit water systems. Although most investigators have used sodium hypochlorite (usually in the form of diluted household bleach in varying concentrations),^{11,19,55-59} chloramine T⁴⁰ and elemental chlorine³ also have been evaluated. Sodium hypochlorite is a potent germicide with broad-spectrum antimicrobial action that is used widely to treat both

potable and recreational waters and has shown promising results as a means to improve the quality of treatment water in numerous clinical trials. Several manufacturers of dental equipment—including A-dec, DCI International, DentalEZ and Proma—now authorize weekly treatment of water systems with household bleach diluted 1:10 to control biofilm accumulation and improve the quality of treatment water. However, no sodium hypochlo-



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rite-based solution has been submitted to the FDA for clearance or registered with the EPA specifically as a waterline biocide.

Although some investigators have voiced concern about the formation of potentially carcinogenic disinfectant byproducts, such as tri-halomethanes, as a result of chlorine's reacting with biofilm organic polymers, the use of intermittent protocols minimizes the exposure risk for patients and staff. However, the

use of chlorinated treatment water in the presence of residual biofilm may increase this risk. Although Karpay and colleagues¹⁹ detected tri-halomethanes when rechlorinated tap water with three parts per million, or ppm, free chlorine was used in independent reservoirs, none of their samples exceeded EPA limits.

While household bleach is inexpensive and readily available, the relative complexity of the treatment protocols may result in noncompliance by office staff and subsequent re-establishment of biofilm (a problem not unique to the use of bleach).⁵⁵ As an oxidizing agent, sodium hypochlorite can corrode metal components and damage rubber or synthetics. Nevertheless, these effects can be limited by following the manufacturer's recommendation.⁵⁶

Other agents that have been proposed or evaluated for improving dental water quality include chlorhexidine gluconate, hydrogen peroxide, iodophors and commercial mouthrinses. Recently, several proprietary agents have received FDA clearance for marketing as waterline cleaners. These include a glycerin-based bur lubricant (introduced continuously) that contains 0.12 percent chlorhexidine gluconate, 12 percent ethanol and flavoring agents (Bio 2000, Micrylium Laboratories), a hydrogen peroxide-based solution used intermittently (Sterilex Ultra, Sterilex Corp.), and a citric acid-based product (Bioclear, Waggoner Product Development Corp.). Dentacide (Frio Technologies) is an iodine-based solution sold as a periodic waterline cleaner and thereby

TABLE

A COMPARISON OF PROPRIETARY WATER TREATMENT CHEMICALS.			
PRODUCT NAME	MANUFACTURER	DESCRIPTION	MANUFACTURER'S CLAIMS
Bio 2000	Micrylium Laboratories	Glycerin-based bur lubricant (chlorhexidine gluconate 0.12 percent, alcohol 12 percent) used continuously and/or overnight	Kills <i>Pseudomonas aeruginosa</i>
Bioclear	Waggoner Product Development Corp.	Citric acid (0.224 percent) used continuously	Eliminates and prevents attachment of biofilms Is safe for most dental equipment components
Dentacide	Frio Technologies	Iodine-based cleaning solution used daily (overnight)	Eliminates and prevents attachment of biofilms Is safe for most dental equipment components
Sterilex Ultra	Sterilex Corp.	Alkaline peroxide-based, used weekly; is hydrolytic, oxidative and lipid- and water-soluble	Breaks up biofilms

is exempted from EPA or FDA requirements.

The table presents, as examples, four of the proprietary solutions available for improving and maintaining the quality of dental treatment water.

As a result of an agreement between the FDA and the EPA, waterline treatment agents that are not part of a device (such as bleach protocols used with FDA-cleared dental units) now must be registered by the EPA. Agents that are continuously present in dental water systems are considered therapeutic agents and also must be cleared by the FDA. At present, neither the FDA nor the EPA will permit the marketers of chemical waterline agents to make claims either for germicidal efficacy or biofilm removal in dental unit water systems. Therefore, all FDA-cleared products in this category must be labeled as cleaners rather than germicides. Before they will be able

to make germicidal claims, makers of chemical agents also must register their products with the EPA as required by the Federal Insecticide, Fungicide and Rodenticide Act. To provide standard evaluation methods for this application, the ADA and the American National Standards Institute, or ANSI, have joined forces through the Accredited Standards Committee MD 156 and have initiated a work project to develop a national specification for DUWL antimicrobial agents.

Although it may be tempting to experiment with various chemicals and to invent new treatment protocols, the potential for unintended consequences is real. The concept that "if a little bit of something is good, a lot more would be better" can result in damage to equipment and harm to patients or staff. The prudent clinician always will seek advice from the equipment

manufacturer or supplier before using any chemical agent or device.

Automated treatment devices. Devices to introduce chemical agents into the water system automatically also are available. This approach potentially could reduce the effect of compliance variables on clinical success. Devices such as the Odyssey I (Tuttnauer USA) generate an ozone and silver germicide via electrolytic action on incoming water. Periodic treatment regimens also can be automated using devices such as the Clean Source 1 (Aqua-rius Technologies) or the Porta Purge (Micrylium Laboratories). DentaPure iodinated resin cartridges (MLRB International) continuously release 2 to 6 ppm free iodine into treatment water to control biofilm; their use life ranges from one week to one year. These cartridges may be used either with municipal water

connections or in independent water reservoirs.

The source water dilemma. Irrespective of the method used to control or eliminate biofilm in the water system, the quality of unfiltered output can be no better than that of the water entering the system. Some independent water systems are equipped with a bypass switch that allows the clinician to switch back and forth from independent reservoirs to municipal water. Other offices refill reservoirs with water from the tap. Although tap water may meet drinking water standards, it usually contains some viable bacteria and organic molecules that accumulate on waterline surfaces and can quickly initiate new biofilm formation. Using water of known microbiological quality is the best way to eliminate uncertainty and ensure consistent delivery of high-quality treatment water.

An excellent source of water for use in dental water systems is bottled sterile water for irrigation, as it not only is free of viable microorganisms but also has very low levels of minerals and organic compounds that can encourage re-establishment of biofilm. No conventional dental unit, however, can deliver sterile irrigating solutions unless the water pathway is sterile as well.

If an autoclave with a fluid sterilization cycle is available, the office can prepare sterile water for use in independent reservoirs. Heating water to boiling also can produce water free from viable vegetative bacteria. However, minerals and organic compounds still will be present in sterile or boiled tap water.

Continuous ultraviolet germicidal irradiation, or UVGI, of incoming tap water may reduce the numbers of viable microbes in incoming water. The Odyssey I (Tuttnauer USA) and the Water Purifier System (DCI International) both employ UVGI for this purpose. However, bulbs must be replaced at specific intervals, since they lose germicidal efficacy over time.

While distillers and deionizers can reduce mineral or organic content, they are less reliable in eliminating bacterial contamination. Distiller hoses and holding tanks must be cleaned on a regular basis to ensure water of acceptable quality. The membranes and resin columns used to deionize water actually may become colonized with biofilm themselves.⁶⁰ Alternatively, the source water may be treated with chemicals or replaced altogether with alternative solutions.

Filtration. While relatively few studies in peer-reviewed journals have evaluated the efficacy of filtration in dental units,^{57,61,62} micropore membrane filters are used to remove microorganisms from water and solutions in a wide range of medical and industrial applications. Filtration is even used to sterilize heat-labile sterile pharmaceutical solutions.⁶³ In the dental clinic setting, however, the carefully controlled conditions and sterility assurance programs found in pharmaceutical plants and research laboratories are impractical. If the units are connected to municipal water supplies, the water also may contain impurities—including minerals, organic compounds and endotoxin—that

are not always removed by filters. Therefore, even when water produced by filtration in the dental clinic is bacteria-free, it should not be used in place of sterile water in surgical procedures.

Nevertheless, studies conducted to date suggest that filters can produce water that meets or exceeds the 200 CFU/mL goal established by the ADA for nonsurgical procedures when used according to the manufacturer's recommendations. Two independent evaluations of microfiltered water used in dentistry found that 80 percent of output water samples were bacteria-free, and none of the remaining specimens exceeded 200 CFU/mL of heterotrophic plate count bacteria.^{63,64} Murdoch-Kinch and colleagues⁵⁷ found that use of 0.22- μ m filters resulted in fewer numbers of organisms observed on scanning electron microscopy in postfiltration tubing sections than in prefiltration sections. Mayo and Brown⁶² found no detectable organisms in water samples taken immediately downstream from 0.2- μ m proprietary filters; however, when they increased the distance at which the filter was placed from the air water syringe, levels of bacteria in effluent water increased—probably owing to the formation of biofilm in the postfiltration waterlines.

Among the potential advantages of filters are the reduction or elimination of reliance on chemicals, the potential for damage to dental units and possible staff exposure to chemical residues. Installation usually can be performed at minimal cost; it requires only the placement of a filter housing on each water-bearing line as close as

possible to the handpiece or water syringe. In addition, units may remain connected to the municipal water supply.

While filters have been shown to be effective in removing suspended bacteria from dental treatment water, they will have no effect on the biofilm that continues to flourish in the prefiltration segments of waterlines unless concomitant treatment to remove them is performed. Persistence of biofilm in the dental unit water system carries the attendant risk of biofouling, clogging and elution of endotoxin in treatment water. Some experts have speculated that ultramicrobacteria—extremely small but viable bacterial cells that develop under conditions of nutrient deprivation¹⁶—may pass through membrane filters more easily than typical vegetative bacterial cells. Testing by the manufacturer that validates the use-life of filters using worst-case test organisms can help prevent such problems in the clinical setting. As with all therapeutic interventions, conscientious compliance with the manufacturer's instructions will help ensure optimal performance.

At least three companies are currently marketing filter systems. SciTech Corp. provides two products, including Clearline One-Day (a disposable 0.22- μ m filter changed daily) and Clearline Plus (a 0.22- μ m disposable filter with a built-in antiretraction valve and a one-week use-life). SciTech recommends periodic cleaning the postfilter waterline to prevent biofilm accumulation. Pall Corp. markets the Aquasafe Dental Water Filtration

System, which consists of a single reusable filter housing with two different 0.2- μ m filter elements. The standard filter removes bacteria and has a one-day use-life. The high-performance filter element also removes endotoxin and has an optimal performance duration of one patient. The DentaPure point-of-use filter from MLRB International Inc. employs an iodinated resin in combination with a 0.22- μ m point-of-use filter. The release of small



Since conventional dental units cannot be sterilized, they cannot reliably provide sterile water for use in surgical procedures—even when they are treated with chemical agents or filtration.

amounts (5 ppm) of iodine purportedly retards the growth of biofilm formation in the postfiltration tubing segment.

Sterile water delivery systems. Since conventional dental units cannot be sterilized, they cannot reliably provide sterile water for use in surgical procedures—even when they are treated with chemical agents or filtration. Sterile water delivery systems bypass or replace the dental unit water system to provide sterile irrigants for powered

surgical instruments. Examples of sterile water delivery systems include a variety of oral surgery and implant handpiece systems. Other devices bypass the dental unit water delivery systems in various ways. The Sterile Water Pump (Biotrol) uses an electric peristaltic pump and a specially modified International Standards Organization, or ISO, connector to deliver water from a standard intravenous bag and IV tubing to air-driven handpieces. The AXCS Sterile Irrigation System (DentalEZ) system also uses bagged solutions but relies on a pressurized cuff to drive the solutions. An air-powered pinch-valve assembly attached to a second ISO connector controls the flow of fluids through a standard IV set connected to the handpiece by an adapter. The AquaSept device (Lares Dental) uses an autoclavable reservoir and handpiece tubing assembly to replace each water-carrying line. The reservoirs can be filled with clean or sterile solutions depending on the application. The SteriWater system (Veltek Associates) provides an entire miniaturized dental unit assembly including a control block, handpiece lines and a fluid reservoir that can be sterilized between patients in a tabletop autoclave.

FAQ 10. SHOULD I TEST MY WATER?

Although clinicians may be curious as to whether specific organisms with greater pathogenic potential are present in dental units, routine testing for specific organisms such as *Legionella* or *Pseudomonas* rarely is indicated because current treatment methods target the entire biofilm, rather than



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specific organisms. A negative test for a difficult-to-culture pathogen such as *Legionella* at a given time may give false assurance of the safety of dental treatment water. Unless a different treatment regimen will be used when spe-

cific organisms are recovered, there is no need for such testing except when directed by local health authorities as part of an investigation of a suspected waterborne illness. The documented isolation of pathogenic organisms from dental water systems also may have medicolegal implications for dental practice. For these and other reasons, current CDC guidelines do not recommend routine microbiological culturing of environmental and medical device surfaces.⁶⁶

Monitoring. Some researchers have suggested that compliance may play an important role in the success of clinical efforts to maintain the quality of dental treatment water.^{19,55} Monitoring is a process distinct from environmental sampling that can help identify technique errors or noncompliance; it also can provide positive reinforcement for the dental staff. Clinical monitoring is a quality assurance process, however, not a validation of process efficacy. The manufacturer must perform adequate tests to ensure the safety and efficacy of products before they are marketed. These studies also

should determine the need for, and frequency of, monitoring in the clinical setting. In general, test methods used to enumerate noncoliform bacteria in drinking water should be adequate to ensure compliance with water management procedures.

DECIDING WHAT TO DO

In the final analysis, the decision to take measures to improve and maintain the quality of water used in dental practice lies with the dentist. Prudent clinicians who choose to take this issue seriously should consider the following recommendations.

- Review the scientific literature to keep current on new developments and be prepared to answer questions from patients and staff.
- Use only sterile fluids for surgical procedures.
- Contact the equipment manufacturer or dealer to obtain current recommendations for improving and maintaining water quality.
- When purchasing new equipment, select products that can reliably and economically maintain good water quality.

SUMMARY

DUWL cleanliness is not a public health crisis. Nevertheless, water that is unfit to drink as defined by nationally recognized standards is unsuitable for therapeutic use in dentistry. Continued inaction on the part of the dental profession can serve only to undermine public confidence in our commitment to quality dental care. ■

The opinions expressed in this article are those of the author and do not reflect the official policy of the U.S. Department of Defense or other departments of the U.S. government.

Dr. Mills is a coinventor of the AXCS Sterile Irrigation System, which has been licensed by the U.S. Air Force to DentalEZ Inc. He is eligible to receive a percentage of royalties collected by the Air Force. He holds no other proprietary interest in any commercial products or services.

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