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Penetration of Airborne Microorganisms Through a Surgical Mask and a Dust/Mist Respirator

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This study investigated bacterial penetration of different bacterial shapes, aerodynamic sizes, and flow rates through a surgical mask and a dust/mist respirator. The bacterial penetrations were compared with those of spherical corn oil particles of the same aerodynamic diameter tested under the same conditions. The tests were performed at different levels of aerosol penetration. Bacteria, ranging from spherical to rod-shaped with a high aspect (length to width) ratio, were selected as test agents. Among these, *Pseudomonas fluorescens* physically simulates *Mycobacterium tuberculosis* by shape and size. The concentrations of bacteria upstream and downstream of the test devices were measured with an aerodynamic size spectrometer. This instrument was found to measure the total viable and nonviable bacterial concentration effectively and dynamically over the entire bacterial size range down to 0.5 μm in aerodynamic size. The results indicate that the spherical corn oil particles and the spherical *Streptococcus salivarius* bacteria have the same penetration in the size range from 0.9 to 1.7 μm. It has been found that rod-shaped bacteria penetrate less. The penetration difference between the spherical and rod-shaped bacteria depends on the aspect ratio of the bacteria. For an aspect ratio of 4, the penetration of rod-shaped bacteria is about half that of spherical ones. Thus, it is projected that a respirator with 90% efficiency against spherical microorganisms or test particles (10% penetration) will be 95% efficient against rod-shaped microorganisms of the same aerodynamic equivalent diameter with an aspect ratio of 3 to 4, such as *Mycobacterium tuberculosis* (5% penetration).

Keywords: aerodynamic size spectrometer, bacterial penetration, *Mycobacterium tuberculosis*, respirator, efficiency, microorganism

Surgical masks were designed originally to protect patients against infectious agents produced by health care workers who were sneezing, coughing, or speaking.[1,2] The mean size of the droplets expelled in these ways is about 4 μm or larger.[3] A surgical mask provides a barrier that prevents large droplets from escaping into the wearer's immediate air environment. Surgical masks, be they flat or cone-shaped, efficiently retain large droplets, but they allow much or most of the airborne material of 1 μm or smaller to penetrate through the filter material.[4–6]

Today health care workers and hospital administrators are concerned about the presence of airborne antibiotic-resistant strains of the tuberculosis bacterium[7] and the release of bacteria through the use of new medical technology, such as the carbon dioxide laser that may aerosolize viable tissues and cells.[8–11] Thus, there is a need to protect health care workers from infectious agents in the air surrounding them. As the size of these airborne infectious agents may be as small as 1 μm or less, health care respirators worn for protection against airborne bacteria present in the environment are more efficient than surgical masks. The

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1993 Draft Guidelines by the Centers for Disease Control and Prevention (CDC)[7] require "the ability to filter particles 1 micron in size in the unloaded state with a filter efficiency of >95%, given flow rates of up to 50 liters per minute." They also state that "available evidence suggests that infectious droplet nuclei are in the 1–5 micron size range, therefore respirators used in health-care settings should be able to filter the smallest particles in this range efficiently." The 1994 notice of proposed rulemaking by the National Institute for Occupational Safety and Health (NIOSH) proposes that new particulate filters meet or exceed the performance recommendation contained in the 1993 CDC document.[12]

Industrial respirators are generally tested with inert, spherical, or near-spherical test particles. Testing with spherical particles represents the "worst case," i.e., the highest possible penetration.[13–20] Airborne microorganisms are generally complex in shape, and may, therefore, penetrate less than spherical particles of the same aerodynamic size. Through this study an understanding is sought of the differences in penetration between nonspherical bacteria and spherical test particles.

Bacteria have been employed in testing surgical masks used against bacteria-containing droplets expelled by the wearer.[3,21,22] In the bacteria filtration efficiency (BFE) test, *Staphylococcus aureus* (about 0.8 μm in geometric diameter) is nebulized from water and is contained in water droplets of about 2.3 μm.[21] In the Greene and Vesley method, a challenge bioaerosol with a mean size of 4 μm or larger is generated from a person's mouth directly while the person says the words "sing and chew."[3,22] Both methods use the six-stage Andersen viable cascade impactor (Graseby Andersen, Inc., Atlanta, Ga.) to collect bacteria on blood agar plates on both sides of the mask being tested. Thus, both methods give an evaluation of mask penetration by viable bacteria carried by supermicrometer-sized water droplets, which simulate the expelled saliva from health care workers; but these methods are not suitable for the evaluation of the penetration of unattached nonclumped bacteria through respiratory protection devices. When bacteria are aerosolized through the use of new medical technology, any liquid that may have become airborne with the bacteria may evaporate quickly, and the smallest bacterium that may be drawn to the respirator filter is that of a single-cell (nonclumped) bacterium.

In a recent study *Mycobacterium chelonae* has been used as a surrogate for testing the penetration of *Mycobacterium tuberculosis* through respiratory protection devices.[23] It was found that *Mycobacterium chelonae* penetrated somewhat less than spherical PSL (polystyrene latex) particles of 0.8 μm diameter. However, the aerosol sizing equipment used in this study may not have been capable of prompting definitive statements about the penetration differences. In another study *Bacillus subtilis* subsp. *niger* was used as the surrogate aerosol for *Mycobacterium tuberculosis*.[24] The aerosol sizing instrument used in this study was also of limited use for size-differentiating between spherical test particles and rod-shaped bacteria. Therefore, one objective of the present study was the development of a method for dynamically measuring the filter penetration of airborne microorganisms.

The major focus of this study, utilizing the new measurement method, was to show how the aerosol penetration of a surgical mask with low filtration efficiency and a dust/mist respirator with higher filtration efficiency depends on the size and shape of the test organism, and how the total bacterial penetration (which includes dead, injured, and viable bacteria) differs from the one obtained with traditionally used spherical test particles. *Pseudomonas fluorescens*, a bacterium that is physically similar in size and shape to *Mycobacterium tuberculosis*, and three other bacteria with varying sizes and shapes were aerosolized as challenge agents in this study. Face-seal leakage, an important performance parameter, is not addressed in this study.

EXPERIMENTAL MATERIALS AND METHODS

A surgical mask and a dust/mist respirator made by the same company (3M Co., St. Paul, Minn.) were selected for this study: the No. 1838 Filtron high-performance surgical mask, which is flat and has relatively high aerosol penetration, and the NIOSH-approved No. 1814 dust/mist respirator, which is cone-shaped and has relatively low aerosol penetration. The purpose of selecting test devices with these two different penetration levels was to verify that the conclusions derived from the tests are applicable to a wide range of filter penetration levels. Both devices are made of three components: the cover web, the filter medium, and the shell. The cover web and shell provide very limited filtration for large particles. The filter medium is the main part of these devices, responsible for filtering the microorganisms. The filter efficiency of respiratory protection devices and surgical masks depends on the filter material and the thickness of the filter layer.

Since the major focus of this study was to determine how the filter penetration of rod-shaped microorganisms differs from that of spherical microorganisms and spherical test particles, bacteria of different aspect (length to width) ratio were selected for study: *Streptococcus salivarius* ATCC 13419 (American Type Culture Collection Inc., Rockville, Md.)[25] with a single-cell spherical form; *Bacillus megatherium* ATCC 14581 with an aspect ratio of 2.6;[26] *Pseudomonas fluorescens* ATCC 13525 with an aspect ratio of 3.0;[28] and *Bacillus alcalophilus* ATCC 21522 with an aspect ratio of 4.4.[26] The cells were prepared and aerosolized as described below. The inert spherical test particles were aerosolized from corn oil.

For the airborne microbial penetration test, *Pseudomonas fluorescens* ATCC 13525 was selected to physically simulate rod-shaped *Mycobacterium tuberculosis* (whose length is 1 to 4 μm and width is 0.3 to 0.6) because this bacterium is nonpathogenic and similar to *Mycobacterium tuberculosis* in shape and size.[27–30] *Mycobacterium tuberculosis* H37Ra and *Mycobacterium bovis* BCG vaccine could have been chosen, but the interest of this study is in physical size and shape and not metabolic nor genetic similarities. Although there are other nonpathogenic bacteria with size and shape similar to the *Mycobacterium tuberculosis* bacterium, such as *Bacillus* and *Escherichia*,[26,31] they have more flagella than the *Pseudomonas fluorescens* bacterium. The *Pseudomonas fluorescens* bacterium has only two flagella at its two ends, while the *Mycobacterium tuberculosis* bacterium has none. Therefore, *Pseudomonas fluorescens* is a better physical substitute for *Mycobacterium tuberculosis* than the others.[29] The importance of flagella in filter penetration has, so far, not been tested. The physical sizes and shapes of the four test bacteria and of *Mycobacterium tuberculosis* are listed in Table I.

As seen in Table I, the two references for *Pseudomonas fluorescens* give different size ranges, but about the same aspect ratios. Therefore, the size of this test bacterium was examined by scanning electron microscopy (SEM) (Hitachi S-570, Hitachi Co., Tokyo, Japan) following 18 hours of incubation and three washings as described below. The bacterial sample was dried and coated with gold/palladium in a sputter coater (Desk II, Denton Vacuum Co., Cherry Hill, N.J.) prior to taking the SEM micrograph. The process of taking SEM micrographs may shrink the size of the microorganisms by as much as 30%.[32] The actual size of a living

TABLE I. Physical Size of Bacteria Tested

Bacterium	Shape	Diameter (μm)	Length (μm)	Average Aspect Ratio[A]	Reference
Streptococcus salivarius ATCC 13419	sphere[B]	0.8–1.0	N/A	1.0	Hardie[25]
Bacillus megatherium ATCC 14581	rod	1.2–1.5	2–5	2.6	Claus and Berkeley[26]
Pseudomonas fluorescens ATCC 13525	rod	0.3–0.5 0.7–0.8	1.0–1.5 1.5–3.0	3.1 3.0	Breed et al.[27] Palleroni[28]
Bacillus alcalophilus ATCC 21522	rod	0.7–0.9	3–4	4.4	Claus and Berkeley[26]
Mycobacterium tuberculosis	rod	0.3–0.6	1–4	5.5	Wayne and Kubica[29]

[A] The average aspect ratio is calculated by dividing the average length by the average diameter of the bacterium.
[B] Some single cocci are formed during aerosolization; but generally they appear in irregular chains.

microorganism may therefore be somewhat larger than the SEM-measured size.

Throughout the period of experimentation, the bacterial cells were maintained on Tryptic soy agar slants at 5°C (Difco Laboratories, Detroit, Mich.). To prepare them for use in the experiments as a challenge to the test devices, the cells were streaked on Tryptic soy agar plates and incubated at 25°C for 18 hours. Then, sterile deionized water was added to these plates, and the growth was removed with the aid of L-rods. This growth was washed either once, three times, or six times (depending on the experiment) with sterile deionized water using a centrifuge at 2860 × g (Marathon 6K, Fisher Scientific, Pittsburgh, Pa.). Prior to nebulization all three differently washed bacterial suspensions were kept at the same absorbance level of about 1.21 as measured by a spectrophotometer at a wavelength of 600 nm to produce similar suspension concentrations (Spectronic 21D, Milton Roy Co., Rochester, N.Y.). This cell suspension was placed in the nebulizer for use in the experiments.

The test setup is shown schematically in Figure 1. Two aerosol generators, one for microorganisms and the other for spherical aerosol particles, were arranged in parallel. As one of the generators was in use, the other was closed off from the test system. The generated aerosol was mixed with clean dilution air to attain the desired aerosol concentration. It was then passed through a 10-mCi ^{85}Kr electrical charge neutralizer (TSI Inc., St. Paul, Minn.) before entering the test chamber. The surgical mask and the dust/mist respirator were tested in this chamber by dynamically measuring their upstream and downstream aerosol concentrations with an aerodynamic size spectrometer (Aerosizer, Amherst Process Instruments Inc., Hadley, Mass.). The penetration was calculated by dividing the downstream concentration by the upstream concentration of the tested device.

A six-nozzle Collison nebulizer (BGI Inc., Waltham, Mass.) aerosolized the bacteria from the prepared suspension with about 7 psi clean compressed air. This resulted in an airborne bacterial concentration of about 30 cm^{-3} in the test chamber. Spherical corn oil droplets (Eastman Kodak Co., Rochester, N.Y.) of about 40 cm^{-3} were generated in the 0.1 to 10 μm size range with a size-fractionating aerosol generator. In this device the corn oil aerosol size distribution is tailored to reduce small particle coincidence in the size spectrometer, and to produce enough large particles for good statistical results.[33,34] Whenever particles are artificially generated, they may be highly charged. Usually, generated particles containing charges of one polarity exceed those of the opposite polarity. Positive and negative ions that are naturally present in the air reduce these charges with time to lower levels and to an approximate equality between the positive and negative charges.[35,36] This state, referred to as the Boltzmann equilibrium, is attained in the test setup by the indicated electrical charge neutralizer, which is a tube with an axially aligned ^{85}Kr radioactive source. Such a device is routinely used in laboratory experiments containing an aerosol generator.[20,36]

The aerosol entered the 1.2 m wide, 1.0 m deep, and 2.2 m high test chamber at the top and was exhausted at the bottom. Inside the chamber perforated metal sheets at the top and bottom ensured a uniform aerosol concentration in the vicinity of the test mannequin. The selected test device was sealed to the mannequin with silicone and petroleum jelly. Each device was tested at constant airflows of 16, 32, 50, and 80 L/min to simulate breathing rates ranging from conditions of rest to strenuous work. Aerosizer sampling from outside the test device was alternated with sampling from inside the device. The flow rates and sampling lines were the same both up- and downstream of the test device. The aerosol concentration remained constant within 5% during each period of testing.

The Aerosizer was chosen because it resolves smaller particle sizes than other aerodynamic particle size spectrometers.[37,38] Its performance limitations were evaluated by parallel measurements with a laser aerosol size spectrometer (LAS-X, Particle Measuring Systems, Inc., Boulder, Colo.). The LAS-X counts particles from 0.1 to 3 μm and was used in experiments to differentiate airborne bacteria from residue particles aerosolized into clean air (see below).[38] Since the LAS-X measurements depend on the refractive index of the tested microorganism, this instrument was calibrated for each tested microorganism with a Marple cascade impactor (model 266, Sierra Instruments Inc., Carmel Valley, Calif.). Thus, each optical equivalent diameter of the LAS-X was converted to its

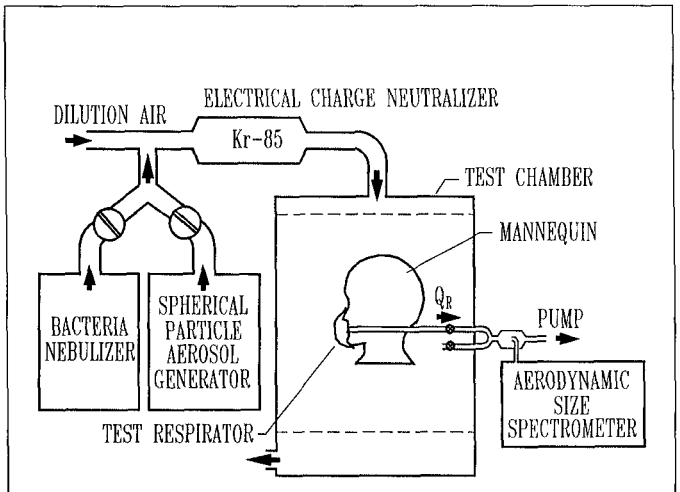

FIGURE 1. Dynamic test system for respirator studies on bacteria and reference corn oil particle penetration

aerodynamic equivalent diameter.[39] The impaction substrate of the impactor was coated with a thin layer of petroleum jelly to avoid particle bounce. To confirm the validity of the Aerosizer data, the LAS-X took data in parallel with the Aerosizer throughout the experiments.

Each measurement was performed four times on each of the test devices. The data for each test condition were averaged. The standard deviation is indicated in the figures wherever it was significant.

RESULTS AND DISCUSSION

The size distributions of *Pseudomonas fluorescens*, aerosolized after one, three, and six washings, are shown in Figure 2. The bacterial aerosol concentration, N, is plotted as a function of the aerodynamic equivalent diameter, d_{ae}, as measured by the Aerosizer. These data demonstrate that the number of washings does not significantly affect the aerodynamic size distribution of the bacteria. The bacterial size distribution after one washing is slightly wider, with a corresponding decrease in its peak value, and the peak is at a slightly larger size than measured after three or six washings. This difference may be due to residual surface material, such as growth medium or bacterial slime still coating the bacteria after only one washing. As seen in Figure 2, the peak size of the bacterial size distribution after three or six washings is about 0.8 μm with a geometric standard deviation σ_g=1.31. The residue particles, resulting from the evaporation of nebulized droplets not containing bacteria and composed of growth medium and slime, have been monitored with the LAS-X optical size spectrometer measuring down to 0.1 μm in particle diameter. After three washings the residue particles are less than 0.3 μm in diameter and are clearly separated from the larger bacterial mode.[38] Thus, the aerosol concentration measured by the Aerosizer in these experiments is the total bacterial concentration consisting of all viable and nonviable bacteria in the air.

The sizes of the *Pseudomonas fluorescens* bacteria used in the experiments were analyzed by SEM. They were found to be rod-shaped and about 1.5 to 2.0 μm long and 0.4 to 0.7 μm wide. This size range is between the higher and lower size ranges given by the two references quoted in Table I. The measured average aspect ratio of 3.2 is similar to the aspect ratio quoted in the two references. The reason for the size differences may be due to different bacterial preparation procedures, such as different incubation time and growth temperatures, different media, and measurement methods used.[40,41] The SEM measurements confirm that *Pseudomonas fluorescens* is physically similar in size and shape to *Mycobacterium tuberculosis*.[4,29] No flagella were found in the SEM micrographs of *Pseudomonas fluorescens*. They are therefore assumed to have been removed before. They were probably broken off by the high physical shear forces during aerosolization from the Collison nebulizer. This makes *Pseudomonas fluorescens* physically even more similar to the *Mycobacterium tuberculosis*. Thus, the physical penetration results of this study are considered valid for predicting the penetration of *Mycobacterium tuberculosis* through the test devices.

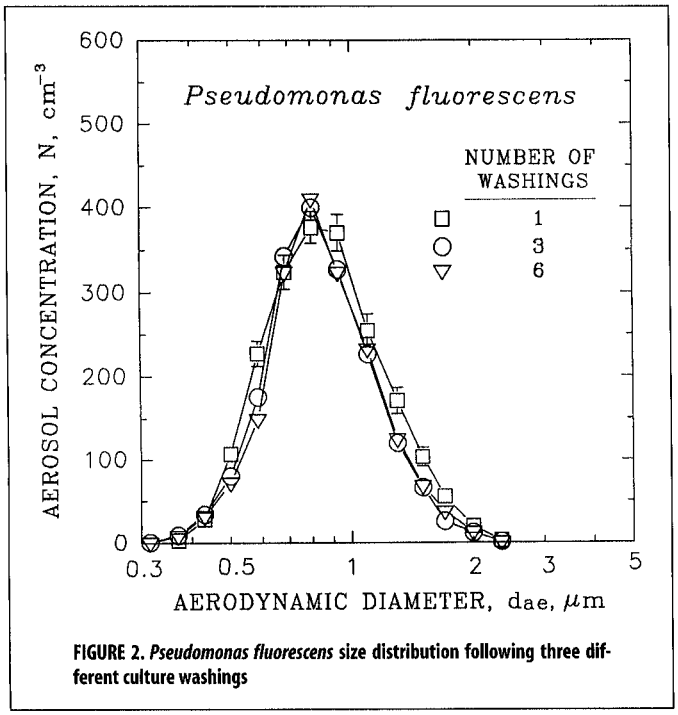

FIGURE 2. *Pseudomonas fluorescens* size distribution following three different culture washings

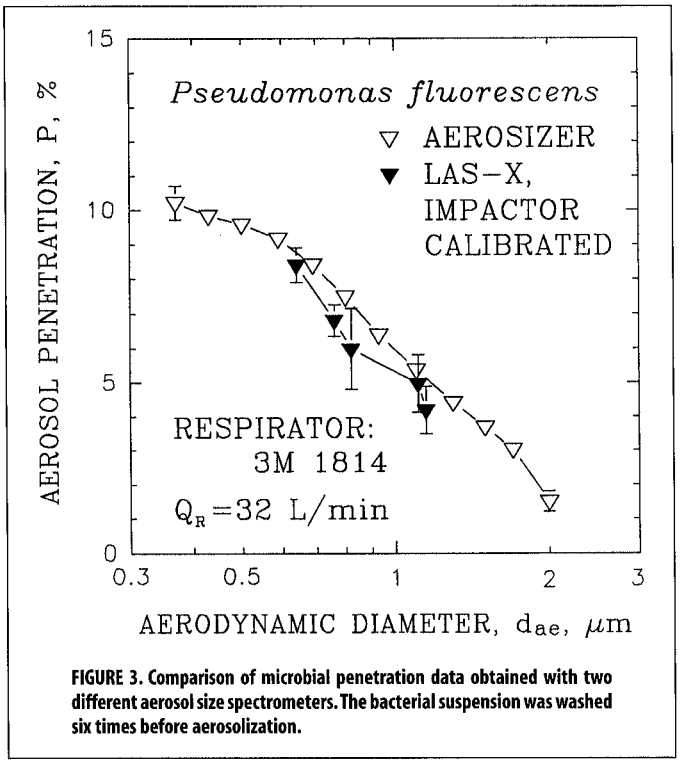

FIGURE 3. Comparison of microbial penetration data obtained with two different aerosol size spectrometers. The bacterial suspension was washed six times before aerosolization.

Figure 3 shows the penetration of six-time washed *Pseudomonas fluorescens* bacteria through the No. 1814 dust/mist respirator as a function of aerodynamic diameter, measured by two different means. The flow rate through the test devices, Q_R, was fixed at 32 L/min, and the aerosol penetration, P, is recorded as the ratio of the aerosol concentration downstream of the respirator to that upstream. The Aerosizer data are as recorded by the instrument. The bacterial sizes from the LAS-X optical size spectrometer were converted to aerodynamic diameters through calibration with the Marple impactor. As seen, both methods give the same penetration data within the standard deviation of four tests for each experimental condition. The small difference, if significant, may be caused by the shape of the bacteria.[37,42,43] Comparison tests at other conditions were similar.

Figure 4 shows how spherical corn oil droplets differ from the rod-shaped *Pseudomonas fluorescens* bacteria in their penetration through the No. 1838 surgical mask and the No. 1814 dust/mist respirator when these test devices are exposed to microbial aerosol flows of Q_R=32 L/min. As seen for both devices, the corn oil

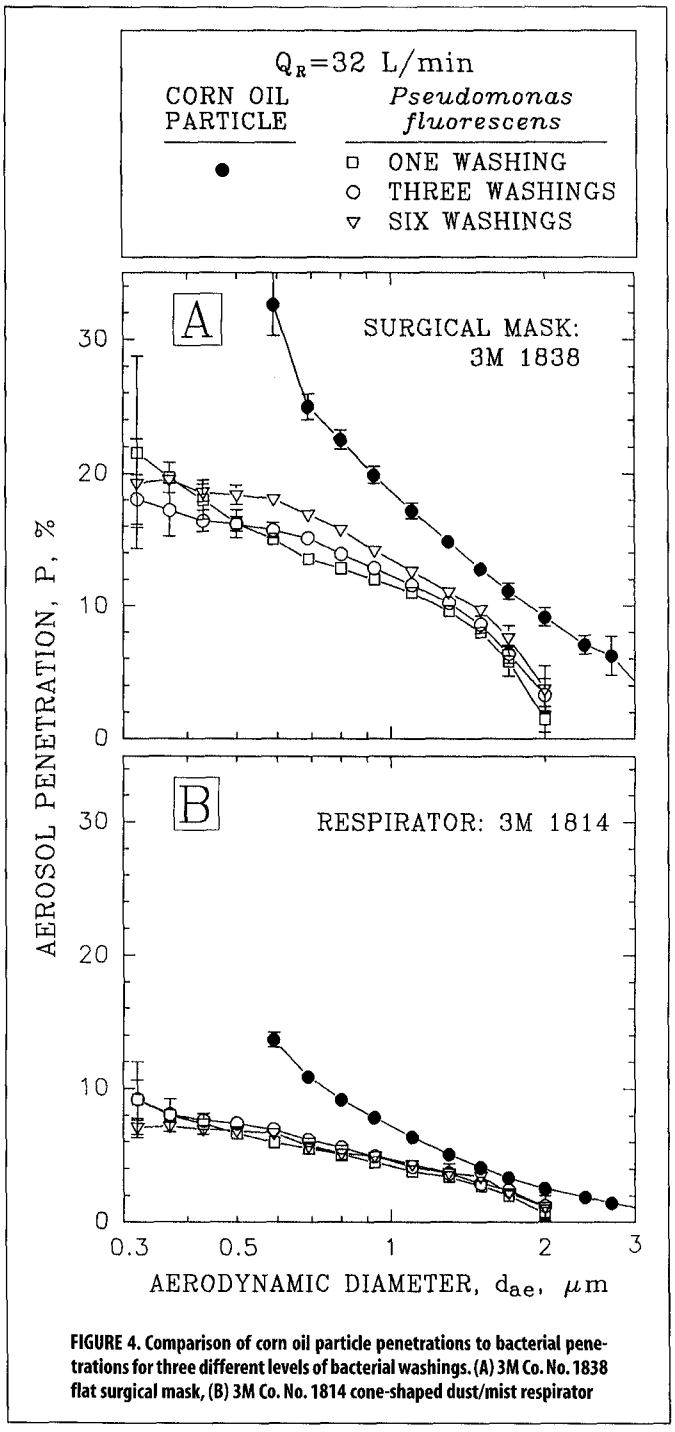

FIGURE 4. Comparison of corn oil particle penetrations to bacterial penetrations for three different levels of bacterial washings. (A) 3M Co. No. 1838 flat surgical mask, (B) 3M Co. No. 1814 cone-shaped dust/mist respirator

droplets penetrate about 35 to 40% more than the *Pseudomonas fluorescens* bacteria in the 0.6 to 1 μm aerodynamic size range and about 30% more in the 1 to 2 μm size range.

Figure 4 also shows the effect of bacterial preparation on penetration through both respiratory protection devices. As seen, there are only slight penetration differences for the indicated number of washings and the penetration results are repeatable within a standard deviation of less than 10%. Figure 4A shows that the penetration for one-time washed bacteria is somewhat lower over most of the measured size range. This may be due to residue material that is still attached to the surface of the bacteria after one washing. This residue coating may affect the shape and therefore the aerodynamic characteristics of the bacteria.

Figure 5 shows the effect of flow rate on penetration. The penetration of corn oil droplets is always higher than that of *Pseudomonas fluorescens* at all flow rates. A study with a different bacterium, *Mycobacterium chelonae*, has also shown less penetration with bacteria than with spherical test particles.[23]

To further understand the bacterial penetration, the ratio of the *Pseudomonas fluorescens* penetration to the corn oil particle penetration at the same flow rate is plotted in Figure 6 to indicate the difference between the penetrations. For aerodynamic sizes between 0.7 and 0.9 μm the penetration ratio ranges from about 45 to 60%, and decreases somewhat with increasing flow rate. For this size range the primary removal mechanisms appear to be mechanical interception and electrostatic attraction by the electrically charged fibers of the filter material.[20,44] Interception depends on the physical proximity of the aerosol particles to the filter material and is therefore particle size and shape dependent and independent of flow rate. Although the test aerosol is charge-neutralized before reaching the test device (see Figure 1), this does not mean that all test aerosols are without electrical charge. The aerosol cloud contains some positively and negatively charged particles. Nonspherical particles can hold more charges than spherical particles of the same volume.[45] This appears to be due to the greater surface area of the nonspherical particles relative to the spherical ones. Therefore, interception and electrostatic attraction cause greater removal (i.e., less penetration) for rod-shaped bacteria than for spherical particles of the same aerodynamic size. The somewhat greater removal of the 0.7 to 0.9 μm bacteria at the higher flow rate appears to be due to a small impaction component that increases with flow rate. With increasing particle size, the importance of impaction increases and that of electrostatic attraction decreases.[20,46,47] Therefore, the dependence of the penetration ratio on flow rate increases, and the difference between the two penetrations decreases at low flow rates, as seen in Figure 6.

Figure 7 shows the aerosol penetration data for corn oil particles and four bacteria that differ in average aspect ratio from 1 to about 4.4. The flow rate through the No. 1814 dust/mist respirator was kept constant at 50 L/min for all experiments. As seen, aerosol penetration decreases with increasing aspect ratio of the bacteria. In the testing of the filter penetration of inert elongated particles such as asbestos fibers, a decrease in particle penetration has also been observed as the length of the fibers of a given diameter increased.[48] In the aerodynamic particle size range of 1 to 1.7 μm, the penetration of *Streptococcus salivarius* cells is approximately the same as that of the spherical corn oil particles. *Streptococcus salivarius* cells are spherical with a diameter of 0.8 to 1.0 μm

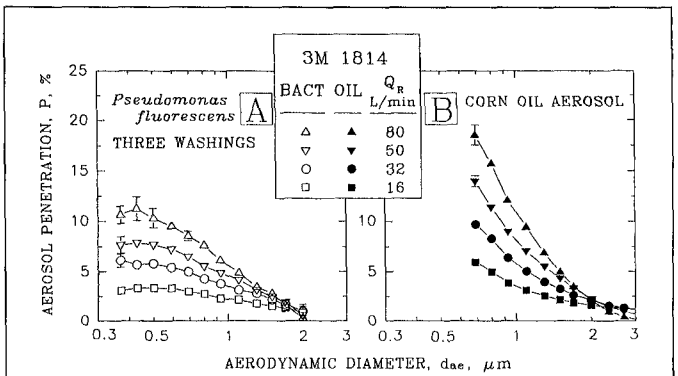

FIGURE 5. Effect of flow rate on aerosol penetration. (A) Rod-shaped *Pseudomonas fluorescens* test bacteria, (B) spherical corn oil test particles

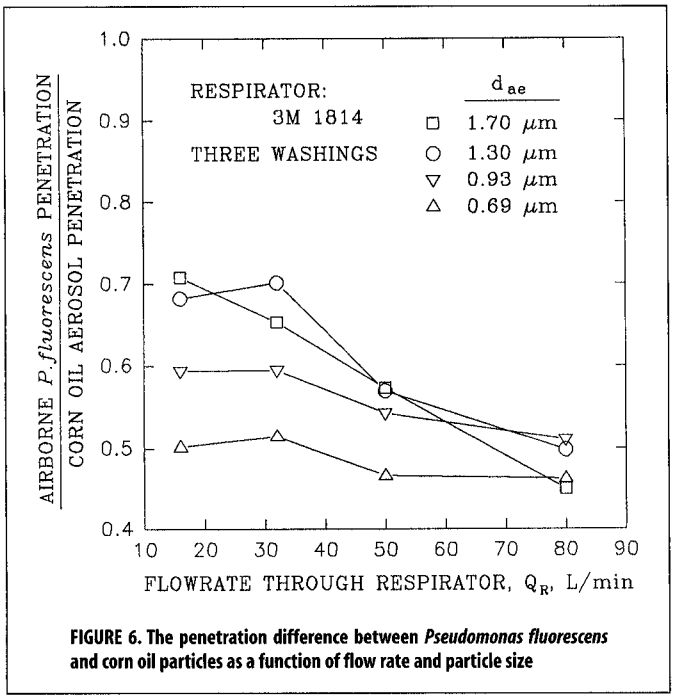

FIGURE 6. The penetration difference between *Pseudomonas fluorescens* and corn oil particles as a function of flow rate and particle size

(see Table I). The cells usually appear in chains, which may, however, break into single, double, and triple spheres during nebulization. Therefore, the penetration of *Streptococcus salivarius* bacteria for aerodynamic sizes above about 1.7 μm is less than for the corn oil particles, as the cells are likely to be agglomerated above this size. It is not clear at this time why the penetration for *Streptococcus salivarius* cells below 0.8 μm is less than that of the corn oil particles. The curves of Figure 7, however, clearly show that the filter penetration of bacteria is a strong function of their shape, and that spherical bacteria behave similar to spherical inert particles.

To further indicate the effect of bacterial shape on filter penetration, Figure 8 shows that the ratio of bacterial penetration to spherical test particle penetration at the same aerodynamic diameter is a function of the aspect ratio, i.e., shape of the bacteria. The data are shown for an aerodynamic diameter of 1 μm, as this size is required by the 1993 CDC guidelines[7] for testing respiratory protection devices. As seen, the bacterial penetration relative to spherical corn oil particles decreases from about 100% for spherical bacteria to less than 50% for the bacteria with an average aspect ratio exceeding 4, i.e., bacteria with an aspect ratio larger than 1 penetrate less than spherical bacteria or test particles of the same aerodynamic diameter. The larger the aspect ratio, the fewer bacteria penetrate. The straight line is an approximate fit to the data. The bacterial penetration of *Pseudomonas fluorescens*, which is similar in size and shape to *Mycobacterium tuberculosis*, is between 50 and 60% of that of spherical test particles. While not tested at such conditions, it is projected that a respiratory protection device with a filter efficiency of 95% for spherical particles (5% penetration) collects about 97.5% of rod-shaped bacteria with a high aspect ratio (half of 5%=2.5% penetration). Thus, a respiratory protection device that is 90% efficient against spherical test particles is likely to be about 95% efficient against rod-shaped microorganisms with a high aspect ratio, such as *Mycobacterium tuberculosis*.

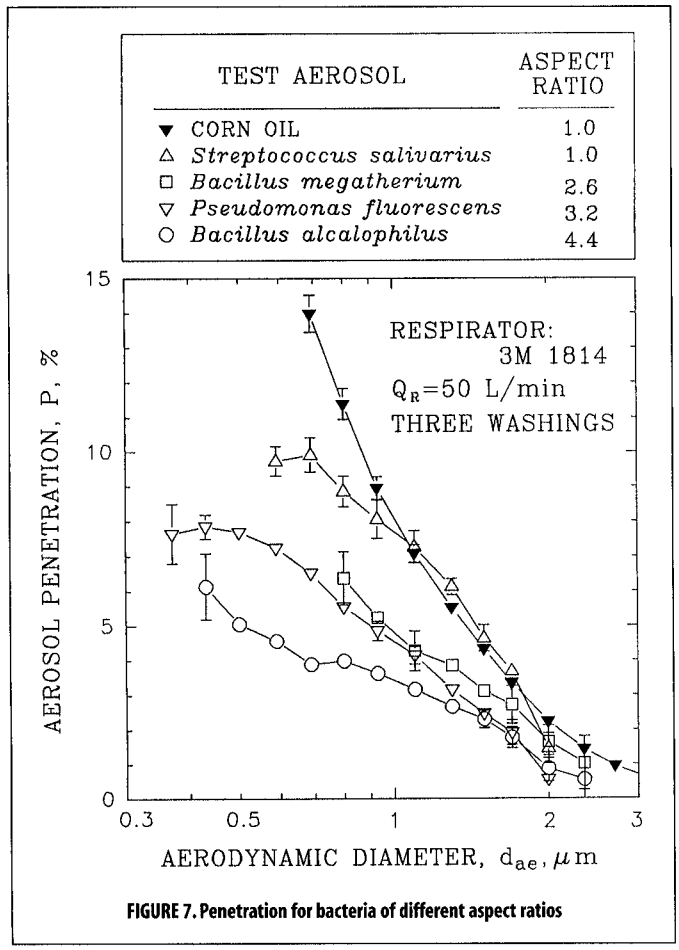

FIGURE 7. Penetration for bacteria of different aspect ratios

CONCLUSIONS

The Aerosizer, a relatively new aerodynamic size spectrometer, effectively and dynamically measures bacterial penetration through surgical masks and respiratory protection devices. It measures bacteria larger than about 0.5 μm in aerodynamic diameter with a

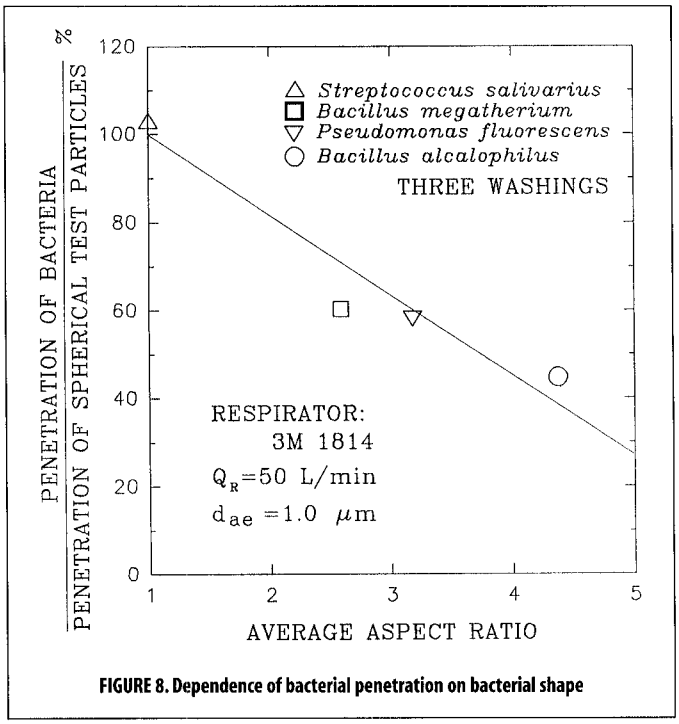

FIGURE 8. Dependence of bacterial penetration on bacterial shape

standard deviation of less than 10%. The number of bacterial washings during preparation does not significantly affect the aerodynamic size distribution of the test bacteria. Tests with an optical size spectrometer that measures down to 0.1 μm have shown that some bacterial washing is desirable to separate the bacterial mode from the mode of residue particles resulting from the evaporation of nebulized droplets not containing bacteria and composed of growth medium and slime.

Comparison of the penetration data for bacteria with those for spherical test particles has shown that tests with spherical test particles will always give the higher penetration values, i.e. the most conservative assessment of collection efficiency. In this study the collection efficiency of nonspherical bacteria was always higher than that of the spherical test particles. For a given aerodynamic diameter the penetration of bacteria through the filter media of surgical masks and respiratory protection devices decreases with increasing aspect ratio of the bacterial dimensions. The bacterial penetration of *Pseudomonas fluorescens*, which is similar in size and shape to *Mycobacterium tuberculosis*, is between 50 and 60% of that of spherical test particles of the same aerodynamic diameter. Since the dependence on aspect ratio was observed with the less efficient surgical mask and with the more efficient dust/mist respirator, and since considerations of aerosol physics postulate such a dependence, the finding of aspect ratio dependence is likely to be applicable to a wide range of filter materials used in respiratory protection devices. As there is little physical difference between the filter materials used in health care respirators and those used in industrial environments, this finding is of relevance to respirators used in both types of environment. While not tested for such conditions, it is projected that a respirator with 95% efficiency against spherical particles (5% penetration) has 97 to 97.5% efficiency against rod-shaped *Mycobacterium tuberculosis* (2.0 to 2.5% penetration). A respirator that is 90% efficient against spherical particles will, therefore, be about 95% efficient against *Mycobacterium tuberculosis.*

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