METHOD FOR EVALUATING EFFECTIVENESS OF SURGICAL MASKS

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Received for publication October 7, 1961

ABSTRACT

GREENE, V. W. (University of Minnesota, Minneapolis) AND D. VESLEY. Method for evaluating effectiveness of surgical masks. J. Bacteriol. **83**:663–667. 1962.—A portable isolation box, provided with a filtered air supply and a means of access for a test subject's head, was attached to an Andersen Sampler and used to measure orally expelled bacterial contaminants before and after masking. This technique yielded more detailed quantitative information than was obtained by either sedimentation plates or Andersen sampling in an unconfined space. During talking, unmasked subjects expelled more than 5,000 bacterial contaminants per 5 ft^3; 7.2% of the contaminants were associated with particles less than 4 μ in diameter. Masked subjects expelled an average of 19 contaminants/5 ft^3; 63% were less than 4 μ in diameter. Mask efficiencies varied according to particle size of the contaminants. This technique is adaptable for routine evaluation of an individual's contribution to environmental contamination.

Although a great deal of work has been done to evaluate the efficacy of face masks (Rockwood and O'Donoghue, 1960), relatively few attempts have successfully measured the quantitative bacterial contribution of nasopharyngeal expulsions to the atmospheric environment. Jennison (1942) reviewed this subject, and attempted to enumerate and characterize these expulsions by means of high-speed photography. Most studies, however, employed agar plates or glass slides exposed at various distances in front of and below the source of droplets to catch contaminated particles which either settle or impinge upon them. This technique fails to measure the very small droplets and droplet nuclei which are not projected any appreciable distance by virtue of their own kinetic energy (Wells, 1955). Furthermore, critical tests of mask effectiveness should exclude normal airborne contaminants from the sample and should control contamination from sources, such as hair, clothing, etc., that are uncontrollable by masks. Hirshfield and Laube (1941) developed an experimental chamber which was a first step toward accomplishing controlled environmental and quantitative sampling. Guyton, Buchanan, and Lense (1956) refined the techniques for measuring absolute efficiencies of masking materials as bacterial filters, and also studied the effectiveness of masks against inspiring artificially disseminated spores. Their data, however, do not yield information relative to the practical employment of masks as protectors of the environment against normal nasopharyngeal expulsions of the wearer.

The recent development by Andersen (1958) of a sampler designed to collect airborne particles in several categories of decreasing particle size suggested the possibility of constructing a modification of Hirshfield and Laube's chamber which would: (i) estimate the total contribution of orally expelled bacteriological contaminants in known volumes of air; (ii) estimate the relative proportion of these contaminants associated with different particle sizes; (iii) and estimate the relative efficacy of face masks against the organisms associated with different categories of particle size.

MATERIALS AND METHODS

Sampling chamber. The sampling chamber was a plywood box (5 ft × 16 in. × 16 in.) mounted vertically on an angle iron frame (Fig. 1). A high-efficiency (> 99%) fiberglass filter formed the top surface of the box. A fixed metal port projected from the tapered bottom of the box, and served as a connection to the air sampler. A sliding "guillotine-like" panel with a flexible plastic collar was provided to permit entry of the subject's head and neck, at a point 4 ft from the sampling port. A glass window was constructed on one side of the chamber for psychological comfort. The only supply of air during a test was

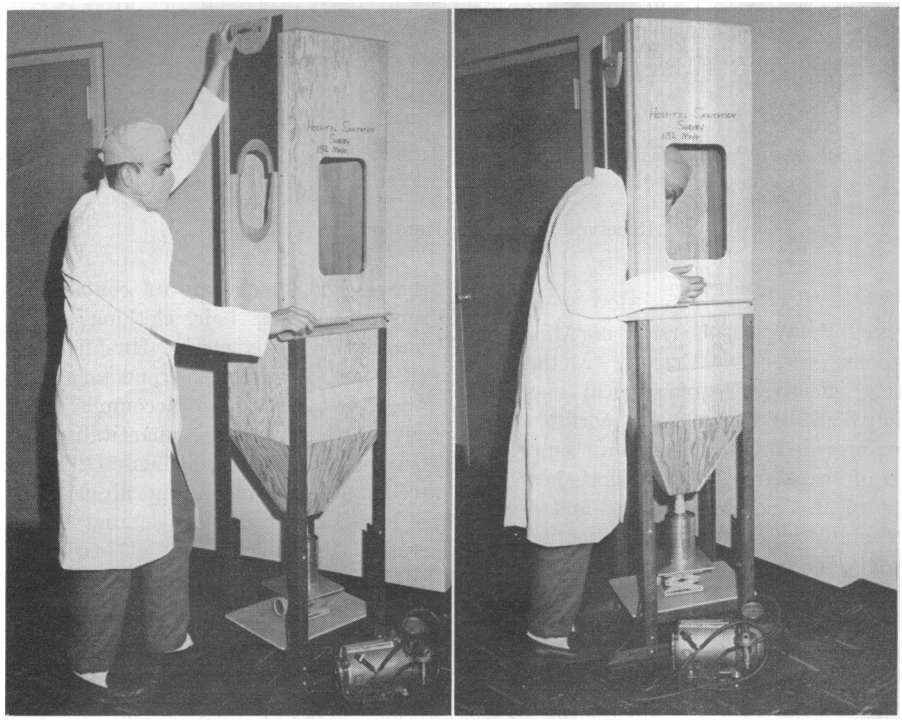

FIG. 1. *The sampling chamber. (Left) Subject preparing to enter sampling chamber. (Right) Sampling chamber in use.*

filtered through the fiberglass, and the only source of contamination was the subject. When proper capping was observed and suitable entry precautions taken, a silent subject contributed less than one contaminant/ft^3.

Test procedure. The panel was closed and the air exhausted from the chamber for 5 to 10 min by means of the sampler pump, to remove any ambient contamination. Subsequently, the air sampler was attached and a "background" sample was taken. The subject then inserted his head into the chamber, lowered the panel until the collar was snug around his neck, started the air sampler which was preset to sample 1 ft^3/min, and distinctly pronounced the words "sing and chew" at 10-sec intervals for 1 min. Air sampling was then continued without further disturbance for 4 min after talking terminated.

Samples were collected on blood agar [Trypticase soy agar (Baltimore Biological Laboratory) plus 5% defibrinated human blood] with an Andersen Sampler; the samples were incubated at 37 C for 24 hr, and then at 20 C for an additional 24 hr. Counts were calculated according to the positive hole conversion table (Andersen, 1958). The masks employed in this study were typical of those routinely used in the surgery suites of the University of Minnesota Hospitals, and consisted of two layers of thin muslin containing an inner lining of 4-oz outing flannel. All tests were performed in an operating theater at 25 C and 51% relative humidity.

Supplementary trials. In an adjacent theater, an identical trial was performed, using the Andersen Sampler in an unconfined space. The sampler was located on an instrument tray 18 in. from the subject, who enunciated the words "sing and chew" in the same time sequence as above and directed his speech toward the sampler.

In a third theater under similar environmental conditions, the subject enunciated the same word pattern, directing his speech through an 18-in. trajectory toward a series of exposed blood agar petri dishes with 500 cm^2 of surface. The dishes were exposed during the initial 1 min of speech and were left open for a subsequent 4 min of quiet time.

The subjects participating in these trials were taught to enunciate the speech pattern in such a manner as to yield consistent and uniform air-

TABLE 1. *Airborne microorganisms expelled during talking recovered* on sedimentation plates*

Subject	Masked	Unmasked
Subject 1		
Average (4 trials)	7	4700
Range	5–11	3900–5700
Subject 2		
Average (4 trials)	9	2500
Range	5–13	1900–3300
Subject 3		
Average (4 trials)	6	4200
Range	4–11	3500–5400
Subject 4		
Average (4 trials)	14	1940
Range	4–23	950–3800

* Contaminated particles/500 cm² after 5 min.

borne contamination. Preliminary trials served as practice sessions to develop uniformity. During the actual tests upon which this report is based all trials were carried out as uniformly as possible by four subjects on each of four separate occasions. Masks, when employed, were freshly changed for each individual trial.

RESULTS

Sedimentation plates. The numbers of bacteria that are orally expelled during simple speech and deposited on 500 cm² of surface are shown in Table 1. The total contamination ranged between 950 to 5,700 colonies from unmasked subjects and between 4 to 23 colonies from the same subjects wearing fresh masks. These results agree with those reported in the literature, regarding both total counts and individual variability. Jennison (1942) considered the contamination which results during speaking to be associated with larger droplets than those expelled during sneezing or coughing, with the average droplet being larger than 100 μ in diameter. However, he pointed out that the number of smaller droplets expelled, even during talking, is greater than was previously expected, and that these particles become airborne and difficult to sample with sedimentation plates. Furthermore, the distribution of contamination on a given series of sedimentation plates was not uniform, but differed, apparently according to each test subject's manner of speech. Thus, a person who speaks out of the side of his mouth might heavily contaminate the peripheral dishes on one side, while leaving the other dishes relatively free from contamination. In any event, trials which evaluate masks by means of sedimentation plates necessitate the employment of large surface areas of test media to compensate for the variations in speech idiosyncracies.

Sampling chamber with Andersen Samplers. Table 2 illustrates the usefulness of the sampling chamber technique. Since the box was aerodynamically designed to collect both the heavy droplets, which settle quickly by gravitation, as well as the droplet nuclei, which would normally remain suspended in the air, the total numbers of contaminants recovered are higher than those obtained on the sedimentation plates. Each of the four subjects, in each of the four trials, expelled more than 5,000 contaminants/5 ft³ of air while enunciating the test sequence of words. There was also surprising uniformity of

TABLE 2. *Airborne microorganisms expelled during talking recovered* from sampling chamber*

Subject	Total		Small particles†	
	Masked	Unmasked	Masked	Unmasked
Subject 1				
Average (4 trials)	24		16	371
Range	13–37	>5000	6–26	213–555
Subject 2				
Average (4 trials)	27		21	170
Range	10–68	>5000	3–64	42–347
Subject 3				
Average (4 trials)	10		4	390
Range	5–18	>5000	3–5	20–786
Subject 4				
Average (4 trials)	15		7	513
Range	8–32	>5000	2–15	204–832
Average of all subjects and all trials	19	>5000	12	361

* Contaminated particles/5 ft³.

† Contaminated particles (less than 4 μ in diameter) trapped on Andersen stages 4, 5, and 6.

TABLE 3. *Apparent mask efficiencies according to Andersen data*

	Total particles expelled/5 ft³	Particles <4 μ diam expelled/5 ft³	Proportion
			%
Unmasked	>5000	361	<7.2
Masked	19	12	63.2
Efficiency	>99.6%	96.7%	—

TABLE 4. *Effectiveness of sampling chamber for enumerating airborne contaminants expelled during talking*

Particle size	Andersen sampler results in sampling chamber (contaminants/5 ft³)		Andersen sampler results in unconfined space (contaminants/5 ft³)	
	Subjects masked	Subjects unmasked	Subjects masked	Subjects unmasked
μ				
>8	3.3	>2500	10.4	385
4–8	4.0	>2500	14.3	407
<4	11.8	361	9.5	207

results when these subjects were masked, the standard deviation being less than ±16 colonies/5 ft³.

With these data it is possible to obtain some idea as to the spectrum of particle sizes with which this contamination is associated. Obviously, the overwhelming proportion of expelled bacteria from the unmasked subject is in droplets with a mean diameter of more than 4 μ. However, a considerable number of particles of smaller size are also liberated during talking. This quantitative evidence supports the photographic information presented by Jennison (1942).

A comparison of apparent mask efficiencies against large and small particles is shown in Table 3. These calculations illustrate the well-known axiom that face masks are more efficient against the large droplets than against the droplet nuclei. Of greater interest perhaps is the realization that 63.2% of the particles recovered from a masked subject are less than 4 μ in diameter, whereas less than 7.2% of the expelled bacteria from unmasked subjects fall into this category. The exceptionally high efficiencies demonstrated by these masks against total contaminants might be attributed to the use of freshly laundered masks for each trial, and to the very short duration (1 min) of each speaking sequence.

The need for a sampling isolation chamber is illustrated in Table 4. It is apparent that the chamber serves to confine the expelled organisms into an easily sampled environment, on the one hand, and serves to exclude ambient airborne contaminants, on the other. The dilution of orally expelled bacteria in an unconfined space would tend to lower the count from the unmasked subjects. Similarly, a small number of extraneous contaminants might completely confuse the calculation of mask efficiencies, considering the small number which are actually expelled through the mask.

DISCUSSION

The basic problem of surgical mask efficacy has been under study since the early years of the century. In recent years the concern with post-operative and other hospital-acquired infections has intensified interest in masking as part of an over-all effort to define the role of various environmental and other factors in the epidemiology of infections. A great deal has been learned about the effectiveness of masks, both in protecting the wearer and in protecting the environment from the wearer. However, most of these studies utilized droplet sedimentation on nutrient plates as the criterion of mask efficiency, and thus failed to measure the small particles which might be important in the transmission of infection. Furthermore, most studies failed to exclude normal airborne contaminants unrelated to oral expulsion.

Critical studies of mask efficiency which employed artificial aerosols yielded valuable information about the filtering capacity of masks, but did not simulate the normal orally expelled microflora and the saliva droplets in which they are incorporated. Consequently, most of the mask efficiency ratings which are available in the literature are not directly related to actual practical conditions.

Therefore, the procedure described in this report might be useful by providing information which is both volumetric in nature and which approximates the actual conditions under which a mask is worn. Furthermore, data are presented which describe the particle sizes of orally expelled aerosols that might be expected in a controlled environment, and which are based on the normal microbial flora of human subjects. From these experiments it can be seen that so called "mask efficiencies" in themselves have little value unless complete control of the environment and specific knowledge of particle size association can be provided.

By use of the procedure described here, it will in future, perhaps, be possible to provide more detailed information concerning the relative effectiveness of various types of masks. Information might also be obtained concerning mask efficacy during periods of silence, talking, coughing, sneezing, etc., and relative efficiency after wearing for various time intervals.

ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation of R. Klug, Minnesota Mining and Manufacturing Co., and of R. P. Singh and P. Pedersen of the University of Minnesota.

This investigation was supported in part by research grant 3019 from the National Institute of Allergy and Infectious Diseases, U. S. Public Health Service.

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