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Study of surgical masks

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A STUDY OF SURGICAL MASKS

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Introduction

There is a constant danger of contamination of open wounds of surgical patients by direct spray of micro-organisms from the nose and mouth of the operating personnel. Efforts to control this hazard include the usage of surgical masks. As will be shown, many investigators have attempted to evaluate the efficiency of surgical masks.

In 1960, I was assigned, under a research grant, to work on a project to develop a meaningful bacteriological testing procedure for comparing various surgical masks as to their efficiency under rigorous conditions. These procedures were then to be used to obtain data on the Minnesota Mining and Manufacturing mask as a background for its clinical evaluation.

After working with a static flow method of testing and a cough plate method of testing, a new sampling box method was followed.

The purpose of this paper is to: 1) present historical evolution of testing of mask efficiency; 2) present materials, methods and results of the two testing procedures done as a research project; and 3) present the materials, methods, and results of a new method of testing the efficiency of surgical masks.

Historical Evolution of Mask Testing

The first published advocacy of the use of surgical masks was made by Mikulicz in 1897. (1) He described the use of a surgical mask consisting of a single layer of gauze. He felt that the mask had the advantage of covering not only the nose and mouth, but also the beard. In the same year, Flueggs, who was a colleague of Mikulicz, demonstrated the significance of bacteria-laden droplets sprayed from the nose and mouth during speech. (2, 3) Ordinary conversation could disseminate bacteria 4 to 5 meters from the mouth of the speaker.

Hubner, working in the Mikulicz Clinic, did some of the earliest testing of masks. (3, 4) He tested the masks by varying the number of layers of gauze and the distance between the mask and the mouth. He concluded that the ideal mask should consist of a double layer of narrow-meshed hydrophilic gauze. After six month's trial by the entire surgical staff, this mask was adopted for routine use.

Berger, of France, in 1899, published the development of a mask consisting of six layers of rectangular gauze which was permanently attached to the operating room gown while the upper border was tied around the head by two strings. (3, 5)

After these early publications concerning advocacy of usage of surgical masks, much attention was directed to the prevention of wound infections in surgical patients. This interest in

prevention of wound infections eventually led to actual testing of masks in regard to their efficiency. Little was actually written concerning testing of efficiency of masks until 1918. In that year Weaver wrote that his group at the Durand Hospital used masks to protect the examiner from infection from the patients (See figure 1.1). (6) He felt that the mask not only protected the healthy person from infection and from becoming a carrier, but also prevented a carrier from spreading infections to others.

In 1918, Weaver published results of a test done at the Durand Hospital. (7) This is one of the earliest publications of test methods and results. Using a hand atomizer, solutions of organisms (Bacillus prodigiosus) were "thrown" at agar plates. The plates were alternately left open and covered by mask material. Weaver concluded that the efficiency of the gauze as a filter was in direct ratio to the fineness of mesh and the number of layers used.

At that time more interest was developing toward the advocacy of usage of surgical masks, so more studies of efficiency testing began to appear in the literature. Early efforts were directed toward testing masks of varying type of cloth and numbers of layers.

Capps, in 1918, wrote that gauze masks had been introduced at Camp Grant, to be worn by the physicians, nurses, and ward men. (8) When this method reduced the incidence of infections they also required the patients to be masked in order to prevent the

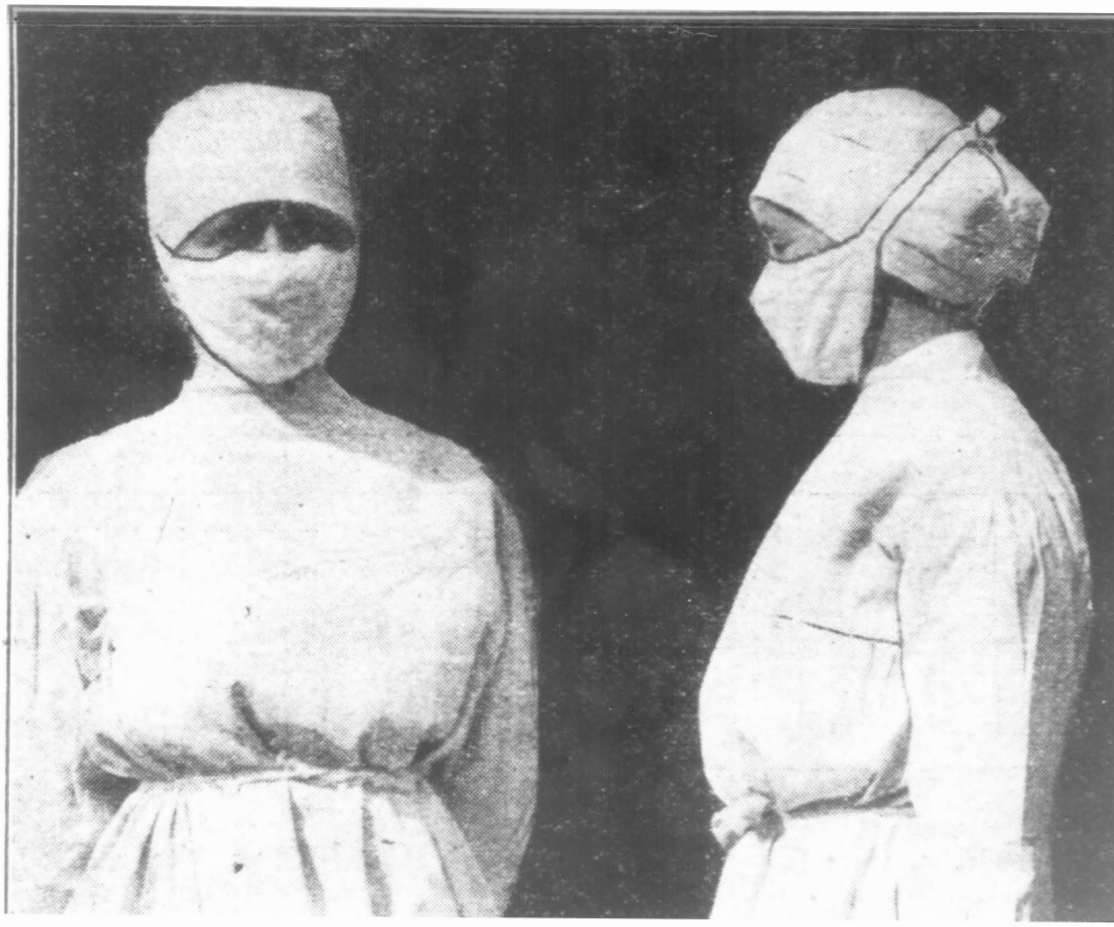

Figure 1.1. The Durand Hospital mask: Three layers of gauze with a mesh of 40 threads by 44.

spread of cross infection from patient to patient. This further reduced the incidence of cross infection. A set of rules was made for patients to follow in wearing masks.

Also in 1918, Doust and Lyon did a study by having a subject talk, speak loudly, and cough toward agar plates. (9) Plates were placed at varying distances before the subject. During ordinary speech, organisms usually projected less than four feet; but during coughing organisms could extend to 10 feet. They studied the effects of coarse gauze, medium gauze, and buttercloth in preventing the passage of organisms from the mouth of the subject. They concluded that rough and medium gauze were relatively inefficient as compared to buttercloth.

Haller and Calwell performed three experiments using a method wherein a subject coughed toward a blood agar plate held twelve to fourteen inches from the mouth. (10) They first covered the mouth of the subject and in another test covered both the subject's mouth and the agar plate. They attempted to determine how many superimposed layers of gauze were effective and which type of gauze was most effective. The amount of gauze placed in the superimposed layers necessary to give full complete protection when the mask was worn over the face of the one infected lay very close to the equivalent of 300 strands of cotton fiber to the square inch. They stated that gauze B and B (32 by 26) should be used in three layers. They also stated that they had shown conclusively that no

more organisms penetrated the mask after it had been worn for 30 minutes than when it was first applied to the face, provided, of course, all other factors remained constant.

Weaver then published another article in 1919, of tests wherein the subject's mouth was covered in some cases and the open Petri dishes were covered in others. (11) He concluded that gauze masks will filter bacterial spray from air. Its efficiency is in direct proportion to the fineness of mesh and the number of layers employed. Three layers of gauze with a mesh of 40 threads or more will remove almost all bacteria-carrying droplets.

Leete used a method similar to that of Weaver. (8) Using a DeVilbus atomizer No. 16, he sprayed Staphylococcus aureus through various masks covering Petri dishes. (12) He concluded that a really protective mask would have to consist of six or eight layers of muslin or similar material and would need to be attached in an airtight manner by means of an elastic band gripping all round the head and fitted with airtight eye-pieces very much after the manner of the gas mask in use in the Army. Other conclusions were as follows:

A. The finer the mesh the better the efficiency.

B. A wet mask is completely inefficient; the dampening effected the permeability. He recommended that masks be changed when they were worn for any length of time.

In 1920, Kellog designed an apparatus which used vacuum

pressure to draw air toward agar plates. (13) This apparatus was placed four feet in front of the subject whose mouth and throat had been sprayed with a suspension of Bacillus prodigiosus. The subject then coughed toward the apparatus. After numerous experiments it was decided that the coughing process was too variable and uncertain so various types of atomizers were tried, both with compressed air with various pressures and with the ordinary rubber bulb. He found that five layers of extremely fine gauze, which would be impossible for comfortable use, gave an efficiency of only 57 per cent. Therefore, he stated that masks had not demonstrated to have a degree of efficiency that would warrant their compulsory application for the checking of epidemics.

Through the 1920's the importance of using masks was stressed. Masking was generally accepted but there was some question of mask material.

Walker, in 1930, tested efficiency by having students read unmasked for 15 minutes with open Petri dishes 1½ feet from the mouth. (14) He then replaced the Petri dish and read for another 15 minutes with a mask in place. If the count in the dish used when the subject was masked showed a great increase in number of colonies over that of air control, the mask was deemed not "germ-proof". Of the 40 masks considered for testing, 7 were finally tested. None of the seven masks tested were "germ-proof". Therefore, Walker proposed a new mask: a six inch piece of rubber placed between 2 layers of gauze. This mask was considered

"germ-proof". This was one of the first attempts to improve the simple gauze in varying types and numbers of layers.

In the same year Mellinger designed a new mask: a 14 karat, gold filled wire frame with paper waxed on both sides of this extending to below the chin. (15) This is one of the deflector types of mask which protected from immediate flow of air from the nose and mouth but which certainly allowed contamination from around the edges of the masks. Kaplin in 1930 designed a similar mask using washed x-ray film as the deflector. (16)

In 1933, Blatt and Dale published results of their study. A dust proof testing tunnel two feet high formed by a hood of cardboard over a table 3 feet by 6 feet was used. (17) In actual testing the subject was instructed to cough with pursed, partly closed lips, exhaling completely with each cough, making the paroxysms as nearly uniform as possible. The subject was instructed to cough six times toward this target. Three open agar plates were then placed on the floor of the sterile chamber; respectively 1 foot, 3 feet, and 5 feet from the subject, who sat with her face at the mouth of the tunnel while she coughed six times over these plates. For four minutes after each test, the plates were allowed to remain in the tunnel closed by sterile curtains at each end, while air suspended particles settled on them. They concluded that there is a great difference in the number of organisms expressed by the cough of different individuals under like

experimental conditions. Based on their data, they concluded that:

1. The ordinary gauze mask was both uncomfortable and bacteriologically ineffective.
2. Their cellophane, gauze deflection mask was inexpensive, easily put together, quite comfortable, effective, and practically germ proof as shown by their experiments and control. See Figure 1.2.

Cann, in 1932, performed a study wherein the subjects were placed in an enclosed room-draught free. (18) Then blood agar plates four inches in diameter, were exposed for periods of time up to 5 minutes. It was concluded that the standard obstetric mask (16 thicknesses of gauze), when worn correctly, was an efficient barrier to droplet infection.

In 1935, Meleney reported on a study of infections in operating rooms. (19) He found that masking with 4-ply gauze masks reduced the number of organisms deposited on a blood agar plate held in front of a person so masked, to approximately the number deposited on a control plate some distance away.

In 1937, Gauthier used a small metal box with a window at the top and 12 air-tubes sealed by gauze bands with opening for the head of the operator. (20) Four Petri dishes were placed in the box. Each operator read for five hours. They found that the

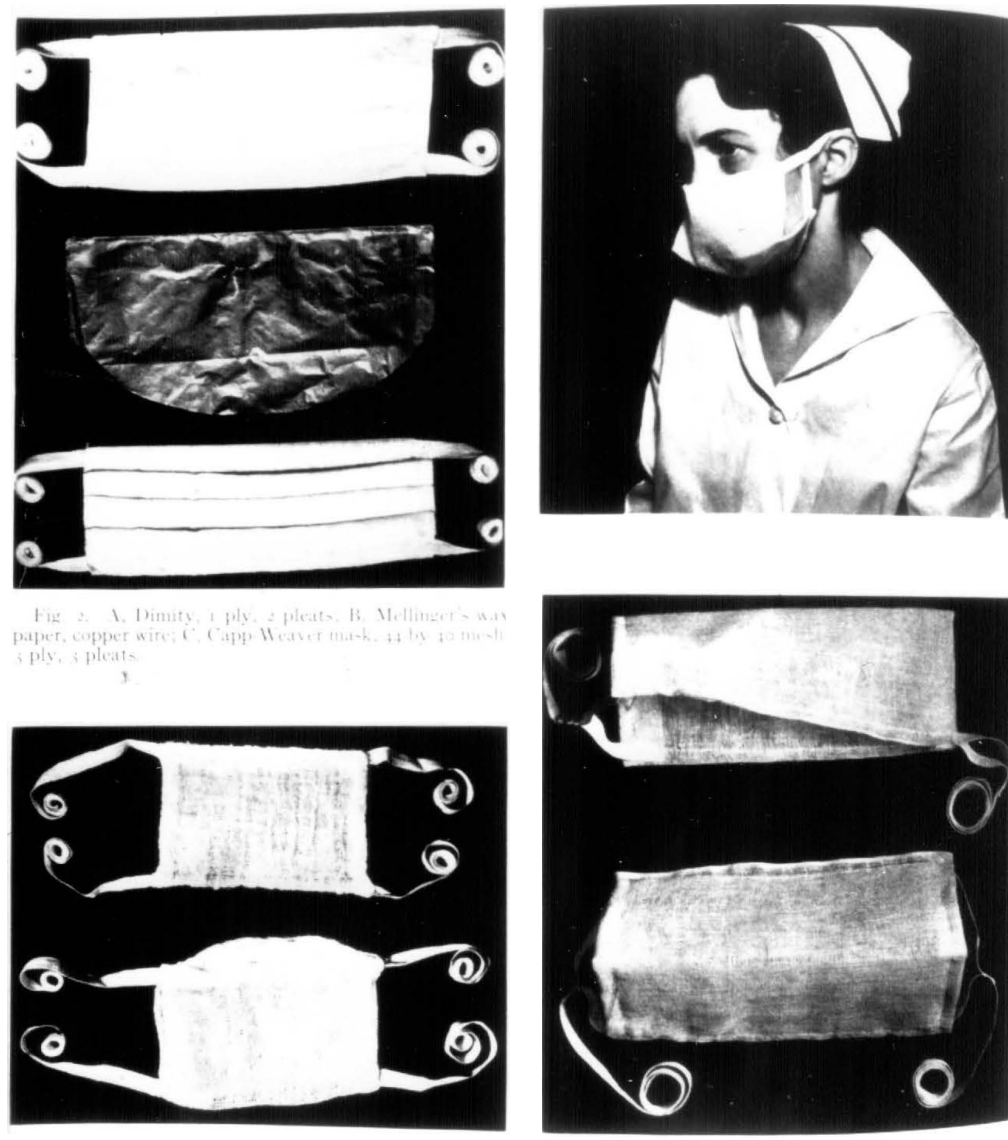

Figure 1.2. The Blatt and Dale cellophane mask is pictured in the upper right hand and lower right hand corners of this set of pictures.

"Jel" masks--a combination of gauze and filter were more efficient than the Canadian mask--two layers of gauze or the American Mask--eight layers of gauze. See Figure 1.3.

The "Jel" mask was tested again by Frappeir, along with the "Mephisto" mask. (21) An enclosed room was used with open agar plates in place to receive organisms from the mouths of the subjects with and without masks in place. Subjects read for 15 minutes. The "Jel" mask was 98.21 per cent efficient and "Mephisto" mask was 94.31 per cent efficient. Therefore, they felt that this was sufficiently significant to call the attention of the surgical profession and others interested to the "Jel" mask.

Waters, in 1936, designed a mask of a cellulose derivative--"plastacele"--which, with incorporated cotton pledgets, was found to be efficient. (22) This mask and a 4-ply gauze mask were tested by a cough plate method. Alaska flannel was placed between two layers of 44 by 40 mesh gauze by Ante, in 1941, feeling that this provided an accepted mask. (23) A very simple deflector type mask was described by Ulmar in 1943 consisting of an ordinary paper napkin, two small spring paper clips, or safety pins, and two rubber bands. (24) This was suggested to be used on all patients on whom chest examinations were being done.

Engelfried and Farrer, in 1943, reported on a method of testing using an apparatus which they had designed. (25) Negative pressure pulled air laden with bacteria through various thicknesses of gauze.

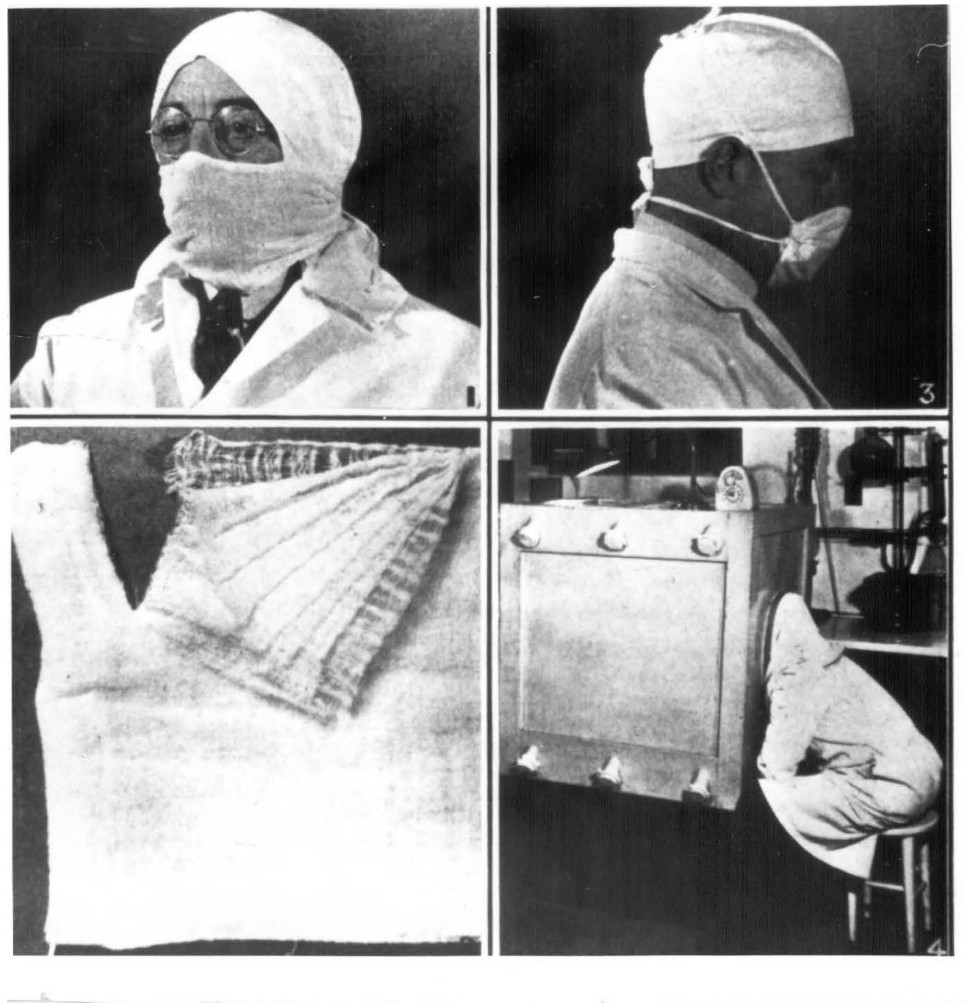

Figure 1.3. Upper left - "Mephisto" mask (Canadian mask) two layers of gauze. Filter mask.
Upper right - "Jel" mask--combination of gauze and filter.
Lower left - American mask - eight layers of gauze. Filter mask.
Lower right - Testing box used by Gauthier.

They felt that six layers of 40 by 44 strand gauze would be most practical for a satisfactory mask. By finding that the filtering efficiency of a gauze mask depended upon the denier of the weave, they designed a new mask using six layers of 40 by 44 gauze (see Figure 1.4). (26)

More recently, Guyton used a method whereby an attempt was made to force organisms through test material by the use of a vacuum pump which drew an aerosol of organisms (Bacillus prodigiosus) through an apparatus. (27) The suspension of organisms was vaporized by a Vaponephrin nebulizer. The organisms passing through were stopped by Millipore membranes and counted. They felt that maximum efficiency was dependent upon an adequate peripheral fit as well as efficient filter material.

Again there was a period of time wherein there were few articles published concerning efficiency. In 1957, Byrne and Okeke reported a study which is similar to some of those already mentioned. (28) The subjects held blood agar plates 18 inches from the mouth, talking and not talking, with and without a mask. Their figures indicated that when the students talked, the masks cut the colony counts in half, but they were still higher than the counts obtained by not talking even without a mask. They felt that silence was more valuable than masking.

A new mask was designed by Kisner and Hitchcock in 1958. (29) (See Figure 1.5.) This was a new plastic mask--diverting the flow

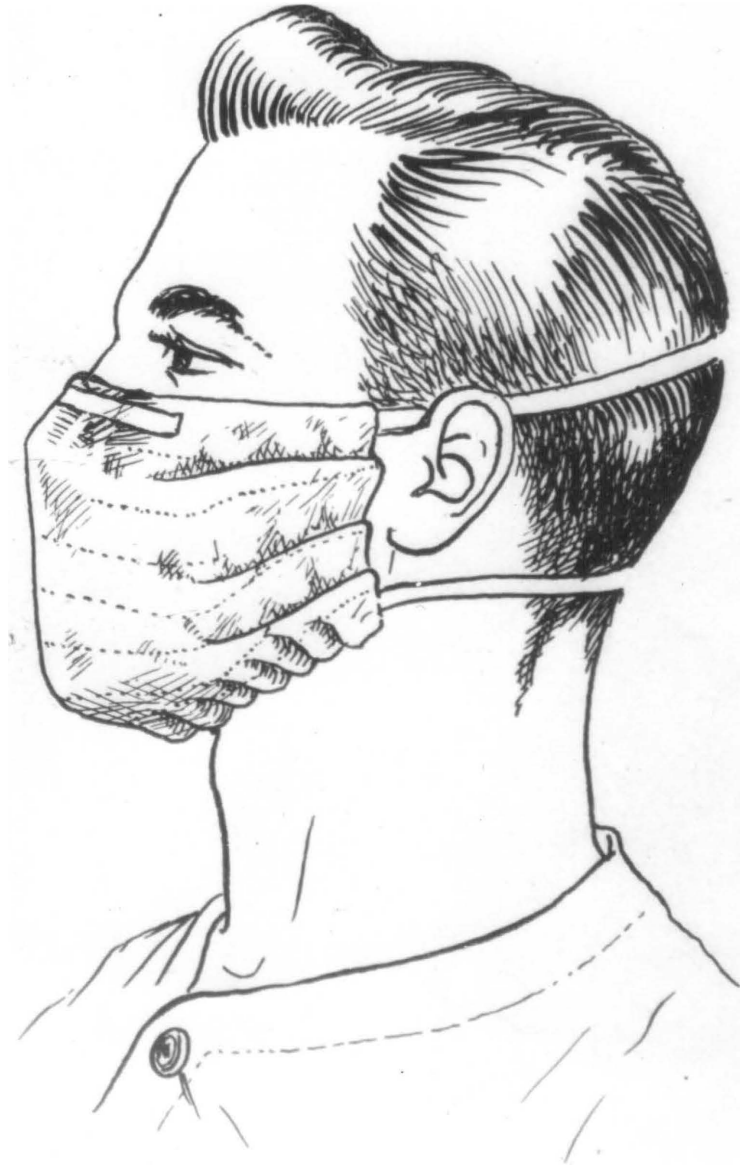

Figure 1.4. Mask designed by Engelfried and Farrer--six layers of 40 x 44 strand gauze. This is a filter mask.

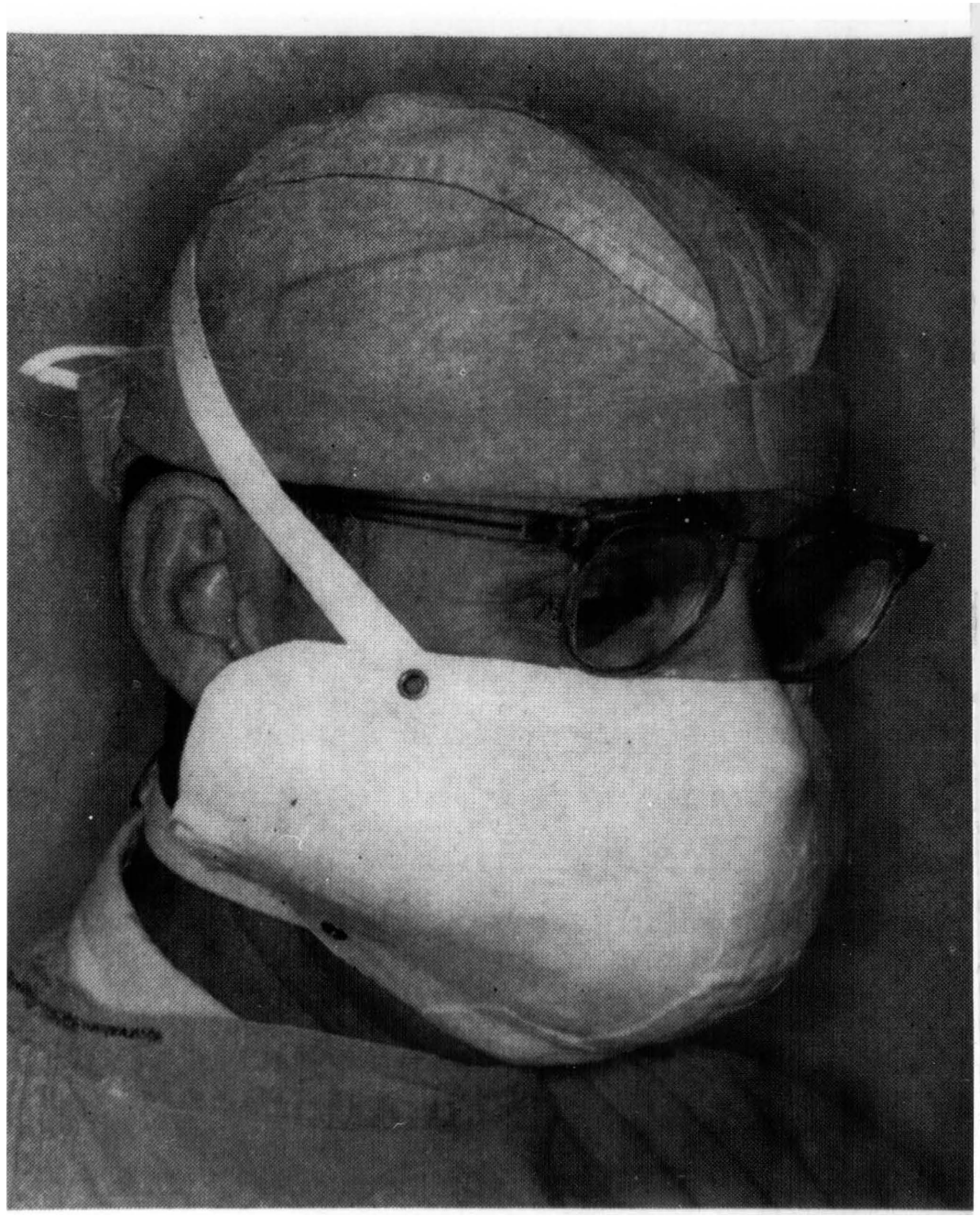

Figure 1.5. Kiser-Hitchcock mask--a combination of deflector and filter mask.

of breath backward on either side, with filter material near the outlets to catch the organisms deflected. They tested this mask by holding plates of agar one foot from the mouth of the subject and a plate near the flow of air from the mask outlet. They found the mask to be efficient, comfortable, permitting conversation and prevented fogging of glasses.

In a study by Adams, Fahlman and Lord, in 1959, subjects breathed over plates for 30 minutes. (30) A slit sampler was used. All air exhaled passed over a plate being rotated in a slit sampler. Their studies showed the best results of single or double gauze to be about 20 per cent. This level dropped to less than 10 per cent efficiency after 10 minutes of wearing, if there was coincidental conversation. A new fitted, filter mask was found to be more efficient. The fitted mask showed that only two organisms passed through while the gauze mask of double thickness showed many organisms.

A large, horizontal box was used in a study by Shooter in 1959. (31) The subject sat with his head in the box through a hole in the bottom. Numerous plates of blood agar were placed around the inside of the box. Fifteen minute tests were run with and without masks. Their figures indicates that these investigators had some difficulty in getting large counts in these tests. All three masks tested reduced the number of organisms in front of the mouth to a level close to that found for silent

unmasked volunteers, and perhaps more importantly, none of the culture plates in front of the mouth had more than 10 colonies per plate as compared with a rate of 21.7 per cent for the unmasked talkers. They then suggested that there is a good case for the retention of surgical masks in operating theatres, and in the wards if a fresh mask can be provided for each dressing.

A review of the literature was done by Rockwood in 1960. (32) He felt that there had been no published results on testing masks concerning lengths of time and the efficiency of masks after varying lengths of time. He performed a test wherein the participants repeated the sentence, "Petunias that grow tall are known as tall flowering trees". This was repeated four times every 15 minutes over a blood agar plate which was held six inches from the mouth. The experiment lasted three hours. Curity (Bauer and Black) gauze masks were used. They found that there was no significant increase in the number of colonies up to a three hour period in any of 12 tests.

In 1961, Thomas reported on another study. (33) The subject put on the mask under investigation and sat on a laboratory stool in a small draught-proof room. Separate tests were performed with the subject reading aloud, talking aloud, repeating the words, "forty-four, forty-four, etc.", and coughing. Samples of air were collected in three ways: a) three blood agar plates were exposed on the bench one foot below and 1, 2, and 3 feet in front of the

subject's mouth; b) single plate was held vertically immediately in front of the subject's mouth; c) the subject coughed immediately in front of a 7½ inch funnel connected to a slit sampler. Another experiment was performed by having each mask secured with an elastic band over the mouth of a 2½ inch funnel and a measured volume of contaminated air was drawn through it (or through a control funnel with no mask) by means of a slit sampler. Contaminated air was derived from two sources: 1) an aerosol of Serratia marcescens and 2) normal laboratory air. They found that with the latter method the disposable masks were more efficient filters than cotton masks. When cotton masks were laundered the resistance increased but, as with shrinkage, the greatest change occurred on the first occasion the masks were laundered. After laundering 50 times the air resistance of cotton masks was still less than half that of paper masks. In the experiments with human subjects the paper masks were much less efficient than cotton masks. The explanation was that in normal use a mask represents a combination of baffle and filter and whereas a cotton mask fits snugly to the face, offers little resistance to the passage of air and therefore filters most of the air, a paper mask fits less well and offers greater air resistance, with the result that a great proportion of the air is deflected out at the sides of the mask.

In 1961, Musselman, et al., reported on their experiences with mask testing procedures. They tested the efficiency of various masks for filtering bacteria, using human subjects and agar plates. They found the results unreliable and not reproducible. A mechanical test was then adopted and used. These tests showed that gauze masks provide poor protection for the patient. A new mask* was tested by the mechanical test and was found to have excellent efficiency for bacterial filtration. There was 86 to 90 per cent efficiency in tests lasting from two to 30 minutes.

*Surgical mask No. 540.

Presentation of Project

The following is the presentation of the project to develop a meaningful bacteriologic testing procedure for comparing various surgical masks.

Initially, the project began with an effort to duplicate a procedure developed by T.H. Wall of the Medical Products Division of the Minnesota Mining and Manufacturing Company. In his procedure organisms were introduced into an air flow through a mechanical apparatus. At different points in the air flow various materials could be introduced to prevent passage of the aerosol of organisms. At the distal point, or outlet, a Millipore membrane* was placed to catch all the organisms passing through the test material. This method will be referred to as a "static flow" method.

In our procedure a closed system apparatus was designed for the mechanical testing. This apparatus will be pictured and described later. This test measured the efficiency of a material for filtering out bacteria by forcing through it a stream of air containing an aerosol of bacteria. Suspensions of Serratia marcescens were placed in a Vaponephrin nebulizer and an air current was passed through this to vaporize the solution. The concentrations of the suspensions were approximated by matching the turbidity with

*Produced by Millipore Filter Corporation, Bedford, Massachusetts.

known solutions. In some instances actual pour plate dilution counts were done.

At first we attempted to catch the organisms passing the proximal point in the apparatus (with and without test material in place) on agar plates (Tryptose-Glucose-Extract-Agar---TGEA). The agar plates were then emptied into a Waring blender with 100 cc. of physiologic saline and plated out in dilutions. For some unknown reason the organisms did not appear in adequate numbers on the dilutions. An attempt was then made to recover the organisms from the test material. Here again the organisms did not appear in consistently reproducible numbers.

After several trial tests with each of these methods it became apparent that the organisms could not be consistently recovered in reproducible numbers from either the agar plates or the test material.

It was then decided that the Millipore filters should be used at the distal point of the apparatus to catch the organisms passing the proximal point. This more closely simulates the method of Tom Wall and the method of Musselman, et al. (31) The materials and methods of this procedure will be shown on the following pages.

Materials

1. Apparatus. This apparatus is a modification of a Seitz filter. (Fig. 2.1 and 2.2) This was designed by David Rhea of the Department of Medical Microbiology. A brass tube was connected to one end of the filter, through which a current of air, at any desired rate of flow, can be introduced. Attached to the brass tube, through an opening on the side, is a glass, Vaponephrin nebulizer. By passing air through this nebulizer, organisms are introduced to the air flow and to the test material. There are two points in the system at which materials can be introduced to prevent passage of the organisms in the aerosol. The test material is placed at the proximal point. At the distal point a Millipore filter membrane is placed to catch any organisms which get through the test material.
2. Compressed air source. The laboratory compressed air supply was used.
3. Flowmeter. This was a Fischer-Porter glass flowmeter. It is pictured in Figure 2.2.
4. Vaponephrin glass nebulizer.
5. Bacteriological supplies.
   A. Test organisms used were Serratia marcescens from the stock of the Department of Medical Microbiology.

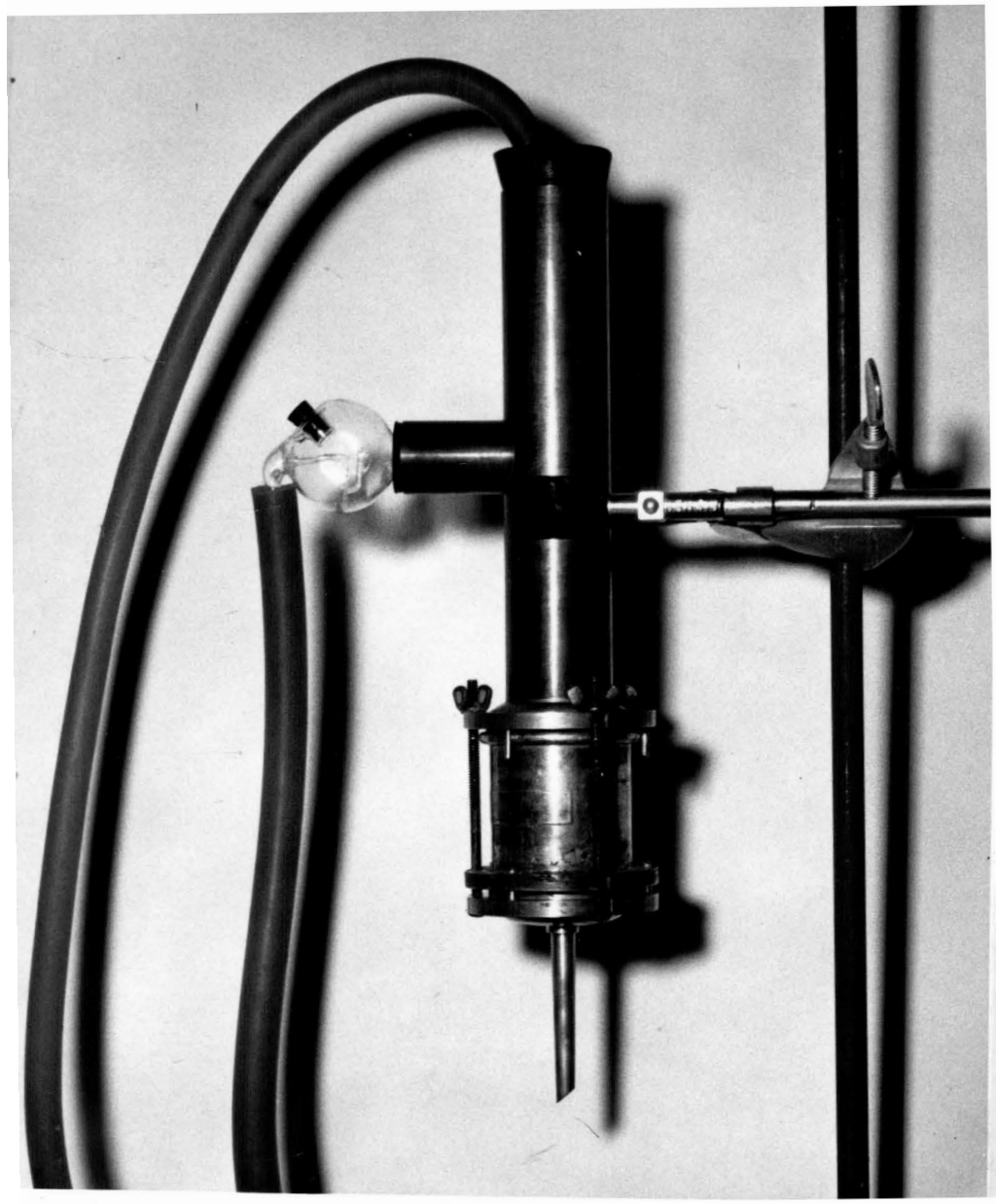

Figure 2.1. Mechanical testing apparatus, assembled.

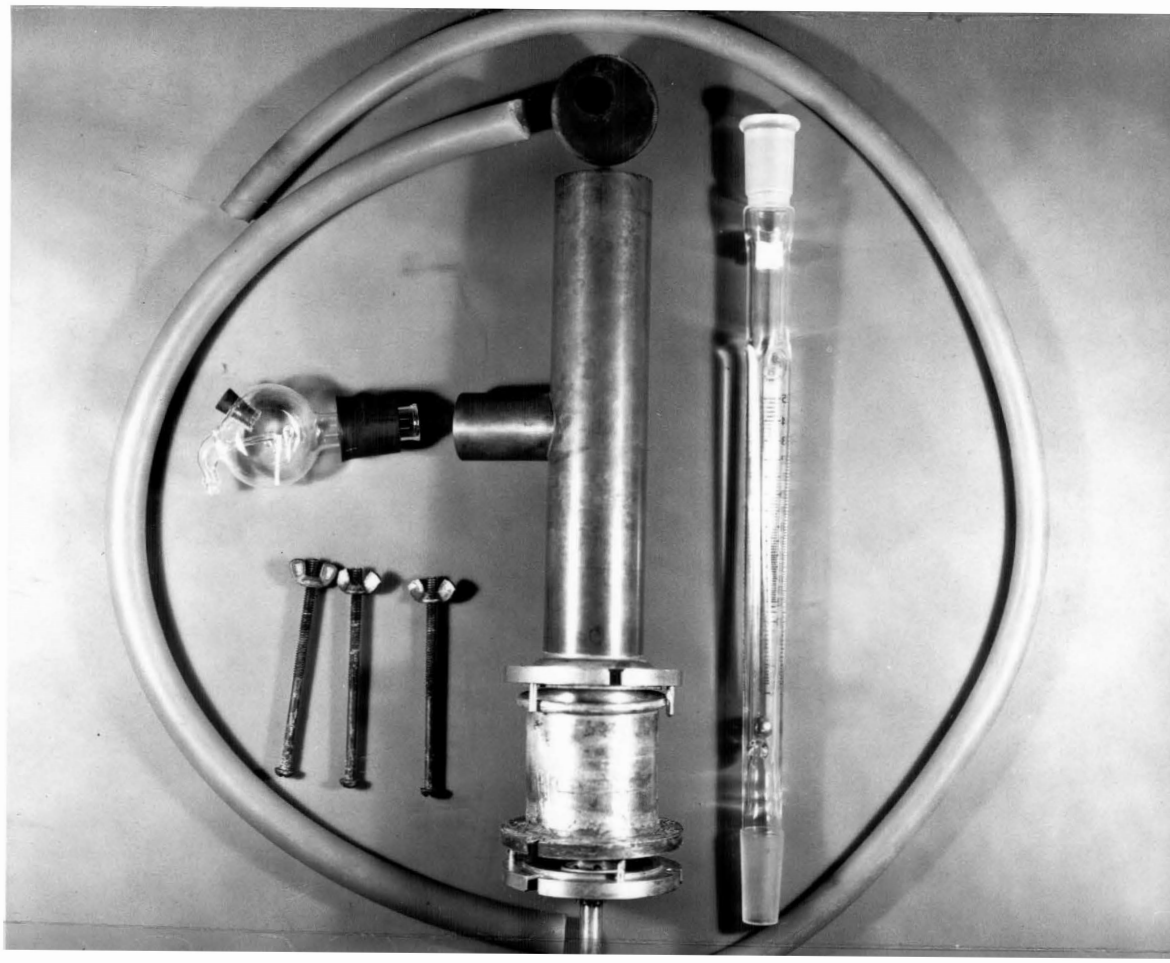

Figure 2.2. Mechanical testing apparatus, disassembled.

B. Suspension. A solution of Serratia marcescens was prepared by adding 15 cc. of isotonic saline to an 18 hour growth of the organisms, grown on a nutrient agar media. The turbidity of the solution was matched with a nepholometer which then indicated approximately 1,200,000,000 organisms per cc.

C. Membrane filter. Millipore membrane filter.

C. Incubation of membranes. Membranes were placed on TGEA media and were incubated for at least 24 hours or until the organisms were at a sufficient state to be counted.

E. Colony counts. These were done with a Cenco colony counter.

Methods

1. Initially the apparatus itself was autoclaved, cooled and assembled. The glass nebulizer was placed in the opening at the side of the brass tube.
2. Petri dishes were filled with TGEA media and were made available for plating the Millipore membranes.
3. Test material was taken from samples of No. 540 filter material and from gauze masks. The gauze masks were taken from the general supply of the University Hospital operating room.
4. The above mentioned test material, gauze or No. 540, was then placed in the proximal point of the apparatus.
5. A Millipore membrane was placed in the distal point.

6. Two cc. of the organism suspension was placed in the nebulizer.
7. A rubber tube from the compressed air source was attached to the apparatus. This flow was calibrated with the flow-meter to 10 liters per minute. Another tube was connected to the nebulizer from another compressed air source and this was set at 2 liters per minute.
8. Tests were run for times varying from 2 minutes to 30 minutes.
9. After the test runs were completed the membrane filters were removed and placed on the TGEA plates without forming bubbles.
10. Control tests were performed by having only the membrane filter in place for runs of either 15, 30, or 60 second intervals. This gave the number of organisms passing through the apparatus with no test material in place.

Bacterial Counts

The colonies of bacteria were counted where they grew on the Millipore membranes. At times the bacteria were too numerous to be counted. In those cases the number of organisms per positive square was estimated and this number was multiplied times the number of positive squares.

Calculation of Results

From the control runs with no test material in the apparatus the number of organisms passing through the apparatus and being caught on the Millipore membrane were counted and averaged to a standard time--either 2 minutes or 30 minutes.

For each test run or each day's tests the number of organisms passing through the apparatus with the test material in place was divided by the average of the control counts.

This then gave the percentage of organisms trapped on the Millipore membrane, or the number of organisms passing through the test material.

This percentage, subtracted from 100, then gave the per cent efficiency of the test material. Using data from 8-2-60 the calculation of results is shown:

Control count--corrected to 2 minute run:

$$\begin{aligned} 233 \times 8 &= 1864 \\ 212 \times 8 &= 1696 \\ 522 \times 4 &= \underline{2088} \\ &\quad 5648 \end{aligned} \qquad \text{Average: } \frac{5648}{3} = 1883$$

Test count--two minute run

186

Resulting calculation of efficiency:

$$\frac{\text{(Test count)}}{\text{(Control count)}} = \frac{186}{1883} = 0.098 \text{ or } 9.8\%$$

efficiency: 90.2%

Results

In the following table the results of the tests with this method will be given.

Date	Filter	Time[1]	Air Flow[2]	Colony Count	Effic.
8-1-60	control	¼	12 L.	9392	
	control	¼	"	3852	
	No. 540[3]	2	"	860	96.1%
	No. 540	2	"	849	96.1%
	No. 540	2	"	396	98.2%
8-3-60	Control	¼	"	1864	
	control	¼	"	1696	
	control	½	"	2088	
	No. 540	2	"	186	90.2%
8-4-60	control	¼	"	7672	
	control	½	"	17940	
	control	½	"	9880	
	No. 540	2	"	3952	89%
	No. 540	2	"	2045	94.2%
	No. 540	2	"	2800	92.1%
	control	¼	"	8328	
	control	¼	"	31400	
	control	½	"	13600	
	No. 540	2	"	4200[4]	92.2%
	No. 540	2	"	4000[4]	92.6%
	No. 540	2	"	4400[4]	91.8%
8-8-60	control	¼	"	1576	
	control	¼	"	120	
	control	½	"	228	
	No. 540	1	"	54	91.6%
	No. 540	2	"	224	65.1%
	No. 540	2	"	241	62.4%
	control	¼	"	7632	
	control	¼	"	8376	
	control	½	"	5136	
	No. 540	2	"	164	97.7%
	No. 540	2	"	164	97.7%
9-27-60	Samples of gauze material were used. Both the control counts and the test counts were too high to count.				
9-28-60	control	½	"	2592	
	control	¼	"	3696	
	control	¼	"	3232	

Date	Filter	Time[1]	Air Flow[2]	Colony Count	Effic.
9-28-60	1 gauze[5]	2	12 L.	2000[4]	37%
	1 gauze	2	"	1710[4]	47%
	1 gauze	2	"	2000[4]	37%
	1 gauze	2	"	1800[4]	43%
	1 gauze	2	"	1260[4]	61%
9-28-60	control	½	"	8400[4]	
	control	¼	"	13440[4]	
	control	¼	"	13440[4]	
	No. 540	2	"	600	94.9%
	No. 540	2	"	490	95.9%
	No. 540	2	"	435	96.4%
9-29-60	control[6]	¼	"	50760	
	control[6]	¼	"	25800	
	control[6]	½	"	8040	
	No. 540[6]	30	"	141	99.5%
	No. 540[6]	30	"	128	99.54%
	No. 540[6]	15	"	184	99.35%
	No. 540[6]	5	"	186	99.34%
9-29-60	control[7]	½	"	2280	
	No. 540[7]	5	"	228	89.57%

[1]Time in minutes.

[2]Combined total from inflow and air through nebulizer.

[3]Surgical mask No. 540.

[4]Indicates that the counts were estimated by multiplying the number of organisms per positive square times No. of positive squares.

[5]This gauze material was taken from random samples of single gauze masks used in the operating room at University Hospital. These masks had been laundered.

[6]These runs were done with a 1:8 dilution of the original solution, to run longer tests. Standardized to 30 minutes.

[7]These tests were done with a 1:16 dilution of the original solution, to run longer tests. Standardized to 30 minutes.

Discussion of Static Flow Method

This method of testing is similar to methods used by other investigators. (9, 25, 27) It is not a study of clinical usage. It also does not measure what happens to a mask and its efficiency during varying lengths of time in operating room conditions.

However, this modified static flow method does measure the mechanical filtering efficiency of the material tested and, since large numbers of organisms were used in the control and test runs, it also measures the potential of the masks. We feel that this method is an acceptable method for testing the potential of the masks.

From the results of this test one can see that only three of the 23 tests done on the No. 540 material showed efficiencies of less than 90 per cent. On the other hand only one of the five tests on the single gauze masks showed efficiency over 50 per cent. Therefore, we feel that there is a significant loss of efficiency for the single gauze mask when it is measured by this method.

As can also be seen from the results, there is variability in the numbers of organisms recovered in both the control and test runs. With larger numbers of test runs a more accurate estimate of mechanical filtering efficiency could be made.

Several observations were noted from this study:

1. The concentration of the organisms in the suspension of the aerosol is difficult to control and measure. In our study no

two solutions could guarantee the same concentrations. Therefore, control counts of the numbers passing through without masks were done in each series of tests.

2. In some cases the numbers of organisms on the plates were too high to count and an estimation had to be made.
3. No observation of pressure drop across the points of placement of the Millipore membranes and test materials was done.
4. With the limited numbers of tests done in this portion of our study, it appears that the surgical mask No. 540 has a higher percentage of efficiency than the single gauze.

Since this method of testing does not measure the efficiency under clinical conditions, we decided to study another testing method.

Presentation of Cough Plate Method

The following is the presentation of a cough plate method of testing used in the 1960 summer project. This was an attempt to test the mask efficiency by determining the numbers of organisms passing through the masks while being worn by volunteers. The specific types of organisms were not determined.

Materials.

1. Horizontal, enclosed box. This box is 4 feet long, 2½ feet wide at one end, 20 inches wide at the other end, and 19 inches high. There is a hole in the bottom of the box near the narrow end. For the testing procedure the subject placed his head through this hole. There is also a piece of rubber matting around the hole. This rubber matting fits snugly around the subject's neck. The sides of the box are made of plexiglass. One side of the box is hinged so that it can be raised for placement of the sieve sampler and open plates. There is a large filter at the wide end of the box for passage of air. The box was placed on angle iron legs so that the subjects could sit down during the tests. This box is pictured in Figure 2.3.
2. Old model surgical hoods. These were designed to fit the wearer's head, allowing the bottom edge to fit under the wearer's chin. These were autoclaved after each test run.
3. Sieve sampler. This was also autclaved between each test run.
4. Petri dishes were filled with blood agar media.

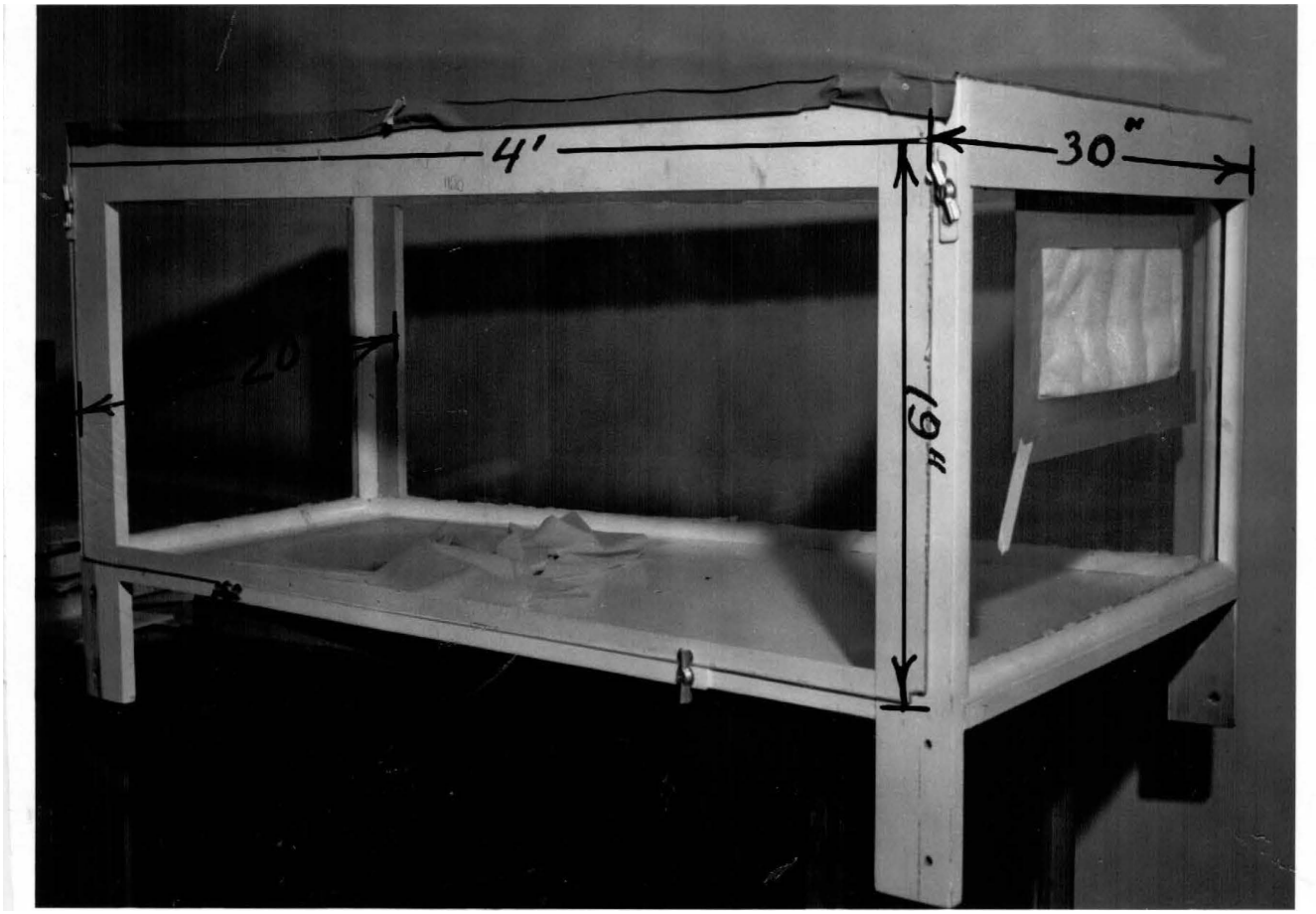

Figure 2.3. Horizontal, enclosed box--used in cough plate method of testing.

5. Vacuum pump. This was adjusted to draw one liter per minute.
6. Number 8300 masks--a product of the Minnesota Mining and Manufacturing Company.

Methods

1. The inside of the box was swabbed down with Lysol. The pump was then turned on to clear the air in the box of the smell.
2. The subject donned the surgical hood and placed his head through the hole in the bottom of the box and through the rubber matting.
3. With as little contamination as possible the side of the box was lifted and the plates were placed. One open plate was placed on either side behind the subject's head. One open plate was placed next to a sieve sampler which was placed 14 inches directly in front of the subject's face. The plate and the sieve sampler placed before the subject were actually the significant ones for the testing while the two plates behind the head served as air controls for each run. The sampler was connected by a rubber hose to the vacuum pump.
4. Each test was run for 20 minutes and plate counts were done at 24 and 48 hours. The condition during the testing will be indicated in the results. Where talking is indicated the subject read aloud from any source. This source was usually medical journals.

Results of the cough plate method

Here following are the results of the cough plate method.

Date	Condition	Time	Subject	In Sampler	By Sampler	Rt.	Left
7-25	Sil, NM	20"	F.T.	12-14*	0-1	1-1	3-4
	Sil, M**	"		---	---	---	---
	talk, NM	"		8-8	30-37	0-1	3-4
	talk, M	"		6-8	0-0	---	---
	control	"		2-2	0-0	---	---
7-26	Sil, NM	"	J.D.	8-12	3-3	2-2	3-4
	Sil, M	"		5-8	3-5	2-2	3-3
	talk, NM	"		21-37	9-11	1-4	1-2
	talk, M	"		15-19	5-7	0-1	2-2
	control	"		2-6	1-1	1-1	0-0
7-20	Sil, NM	"	B.U.	3-6	1-1	---	---
	Sil, M	"		5-6	2-6	---	---
	talk, NM	"		2-8	5-6	---	---
	talk, M	"		17-21	3-4	---	---
	control	"		3-5	0-0	---	---
7-21	Sil, NM	"	D.M.	5-8	3-5	2-2	3-3
	Sil, M	"		6-8	0-0	1-1	0-0
	talk, NM	"		8-11	66-68	0-1	0-1
	talk, M	"		15-19	5-7	0-1	2-2
	control	"		1-1	3-3	3-3	0-1
7-22	Sil, NM	"	J.S.	6-11	8-8	3-3	1-2
	Sil, M	"		---	---	---	---
	talk, NM	"		61-75	126-141	16-19	4-6
	talk, M	"		17-24	2-4	6-8	5-5
	control	"		0-0	0-0	0-0	0-1

Date	Condition	Time	Subject	In Sampler	By Sampler	Rt.	Left
8-4	Sil, NM**	20"	F.T.	0-0	0-0	2-2	0-3
	Sil, M	"		7-14	2-2	0-2	1-1
	talk, NM	"		1-1	51-53	1-1	0-0
	talk, M	"		8-15	1-1	1-1	0-1
	control	"		1-4	2-2	0-0	0-0
8-5	Sil, NM	"	J.O.	11-11	1-1	0-0	0-1
	Sil, M	"		16-23	2-2	0-0	2-2
	talk, NM	"		1-1	6-7	3-3	2-2
	talk, M	"		36-55	9-10	2-3	2-3
	control	"		19-25	2-3	1-1	0-1

*The first number indicates the actual total count in each of the plates after 24 hours of incubation. The second number indicates the total count after 48 hours of incubation.

**On these test runs the pump was inadvertently not turned on.

---This indicates that these portions of the tests were not run.

The above abbreviations are: Sil, NM--Silent, No mask
Sil, M--Silent, Mask
Talk, NM--Talk, No mask
Talk, M--Talk, Mask

The control counts were obtained by placing the plates in position and turning the pump on for 20 minutes. The subjects did not have their heads in the box during the control runs.

Discussion of cough plate method

This method is similar to those used by other investigators. (16, 19, 28) Where talking is indicated the subjects attempted to talk in a normal tone of voice. As can be seen from the figures in the above table, it was difficult to obtain large numbers of organisms from the subjects even in 20 minutes of talking without a mask. On 7-20-60, 7-23-60, 8-4-60, and 8-5-60 talking with a mask in place resulted in more organisms on the plates in the sampler than did the tests with no mask in place.

Although the temperature and humidity were not measured inside the box during each test, the subjects reported that there was difficulty in breathing toward the end of the 20 minute test and that the air became very warm. It was decided that longer test runs would be unpleasant and uncomfortable for the subjects.

It was felt that larger numbers of organisms should be obtained to accurately evaluate masks by those methods. Since we were unable to consistently obtain large numbers of organisms from our volunteers we decided to abandon this method and search for a more accurate and reproducible method of testing masks under clinical conditions.

Presentation of new sampling chamber method

A new method of testing was sought which would evaluate masks under conditions of actual use. This new method would have to be well controlled and would have to contain the least number of variables possible. This new method and the procedure for running these tests will be described on the following pages. Four different types of masks were tested: 1) single gauze*, 2) double gauze*, 3) Aseptex**, and 4) No. 540**. The single gauze, Aseptex and No. 540 masks are pictured in Figure 3.0. The double gauze mask is made by placing two of the single gauze masks together.

The following new testing method is essentially the same procedure as that described by V. W. Greene at the University of Minnesota. (35) We did, however, use a full set of plates in the Anderson sampler. The testing involved three separate procedures which will be referred to as parts A, B, and C. Part A was used as a preliminary study to see if subjects could be trained to produce constant "sneezes" and to decide how many "sneezes" to use in each test in the subsequent investigations.

*Most of the single gauze and double gauze masks tested were Johnson and Johnson types, but a few of the Curity types were also used.

**The Aseptex and No. 540 masks are both products of the Minnesota Mining and Manufacturing Company.

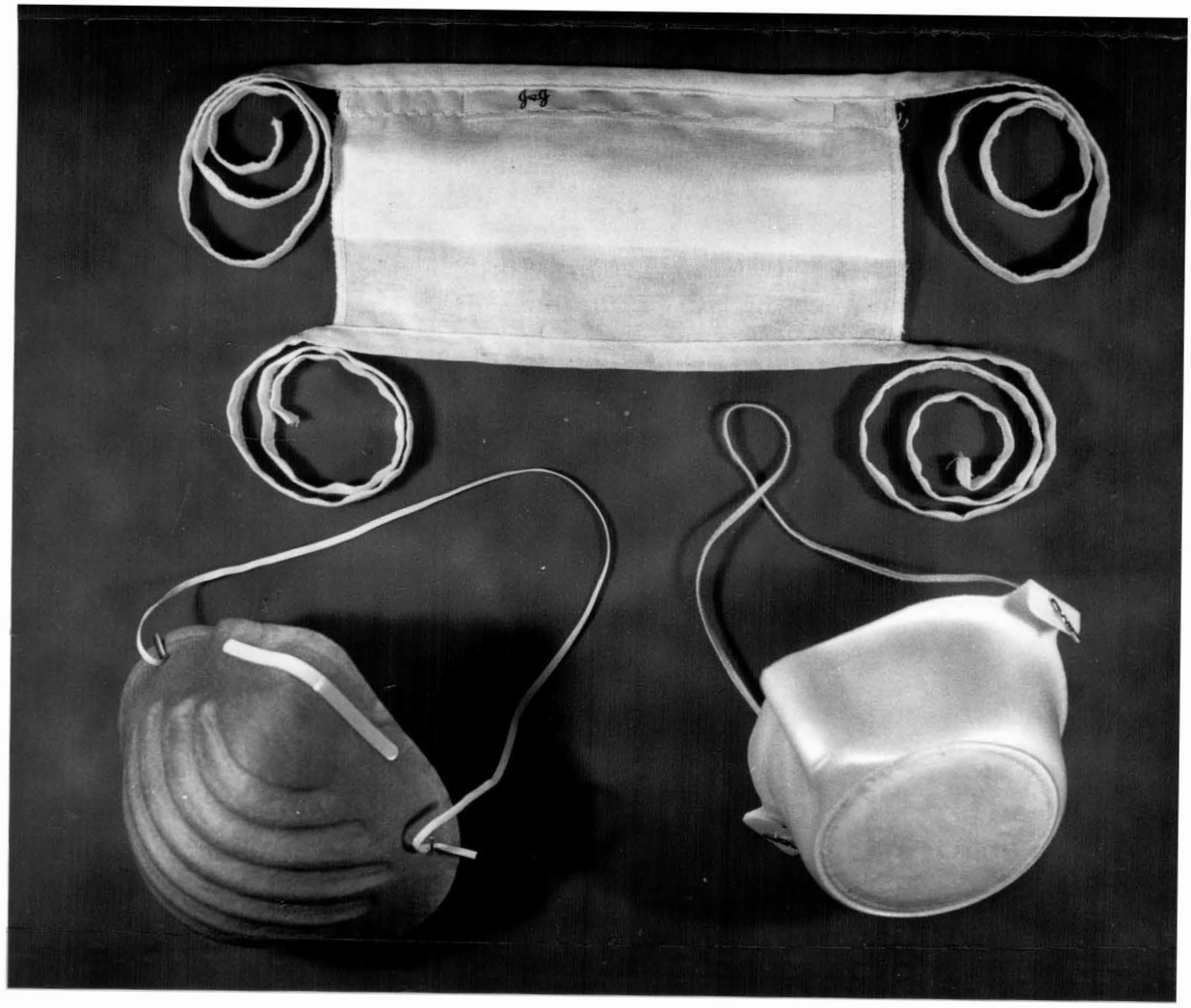

Figure 3.0. Masks tested by sampling chamber method.
Top: Single gauze mask. Double gauze masks consisted of two single gauze masks put together.
Bottom left: Aseptex mask.
Bottom right: No. 540 mask.

Part B involved testing of masks after their use in the operating room. Part C, which we originally thought would be the most reliable test, involved testing of masks after they were worn for varying lengths of time by volunteer subjects. The materials and methods of testing will be described below.

Materials

1. Sampling chamber: (Figures 3.1 and 3.2) This is a plywood box 5 foot by 16 inches by 16 inches, mounted vertically on an angle iron frame. A fiberglass filter formed the top surface of the box. At the bottom of the box the area is tapered so that the outlet is approximately one inch in diameter. This area served as the connection to the air sampler. At a point four feet from the sampling port there is a sliding panel with a flexible plastic collar. This provided entry of the subject's head and neck. The only supply of air during a test was filtered through the fiber-glass filter and the source of contamination was the subject.

2. Sampling device: An Anderson sampler was used. This sampler collects organisms from the box onto blood agar plates. It allows separation of particle size in the air drawn from the box.

3. Vacuum pump: This is a pump designed to be used with the Anderson sampler. It is calibrated to draw one cu. ft. per minute through the sampler. This was checked by means of a flow meter.

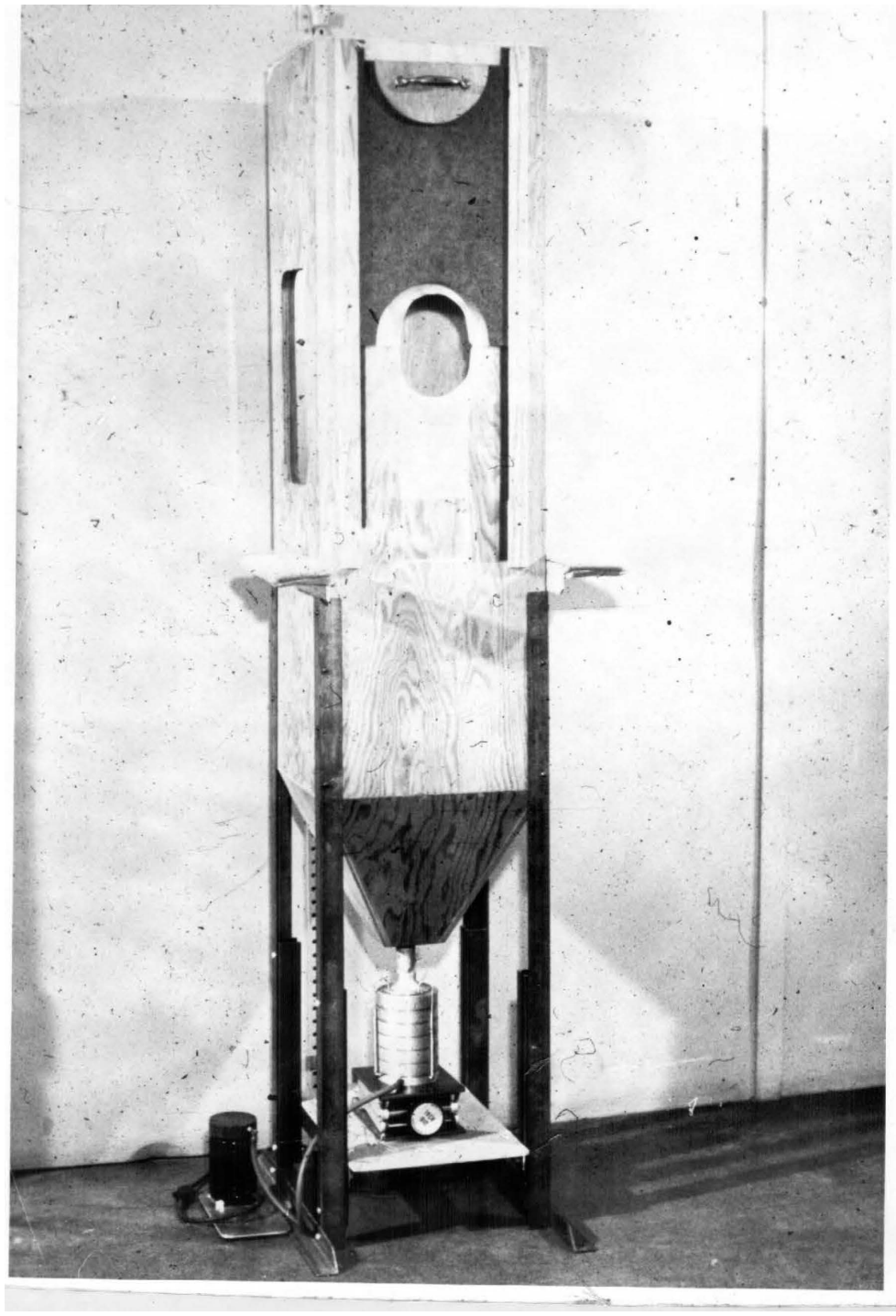

Figure 3.1. Sampling chamber with Anderson sampler and vacuum pump in place.

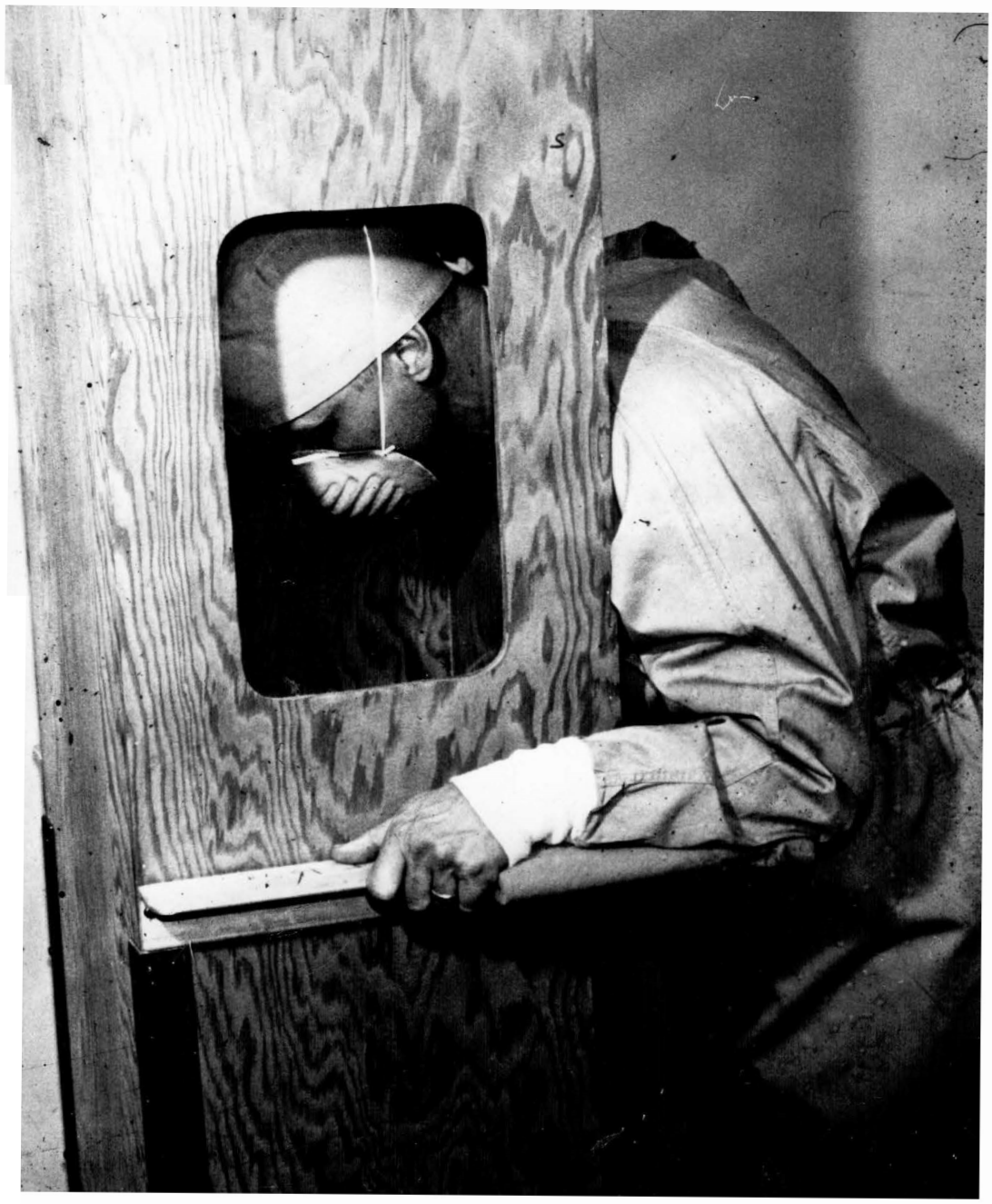

Figure 3.2. Sampling chamber with a subject in place for a test run.

4. Media. Trypticase soy blood agar base. (BBL) Five per cent blood cells were added, using outdated units of blood from the blood bank. Using an automatic pipette, 27 cc. of blood agar were dispensed into Petri dishes designed for use in the Anderson sampler.

Methods

Three separate procedures were done and recorded under three different parts. These will be separately described under methods.

Part A

Four different groups of 10 volunteers consisting of medical students, student medical technicians, and student nurses were used in this part. Blood agar plates were placed on a table 12 inches below the subject's head. The subject was directed to distinctly pronounce the words, "sing and chew" at 10 second intervals for one minute.

Two subjects from each group of 10 were selected by drawing numbers from a hat to participate in tests using the above described sampling box.

All of these runs were done unmasked. The subject inserted his head into the chamber, lowered the panel until the collar was snug around his neck. The pump was then turned on. The subject was instructed to distinctly pronounce the words, "sing and

chew", at intervals of either 10 seconds, 15 seconds or 30 seconds for one minute. At the end of the one minute, the subject removed his head from the box, closed the lid, and the pump was restarted and run for another four minutes.

The blood agar plates were then removed from the Anderson sampler and incubated for 24 hours at 37 degrees Centigrade and 24 hours at room temperature.

Part C

Twenty subjects were selected from the volunteers from Part A on the basis of their ability to produce a relatively constant number of organisms per test without masks. This group of twenty was divided into groups of four subjects each. In the subsequent tests of part C two of each group of four wore double gauze masks and the other two wore Aseptex masks.

In every control and test run in this part the subjects said, "sing and chew", at 10 second intervals for one minute. The subjects inserted their heads into the chamber, lowered the panel and pronounced the phrase as in the previous part.

A control test was done first on each subject without a mask. Each of these control tests was followed by a test with masks on, using another identical box. One minute tests were then done on each subject at 1, 2, and 3 hour intervals. At the end of the three hour period, each of the subjects performed another one minute control run.

Each of the groups of four participated in two types of activity during the procedures. One type of activity was having the subjects remain as quiet as possible during the three hour period. The other type had the subjects read aloud for 10 minutes from any text source during the one hour intervals between the tests. At the end of the reading periods the subjects said "sing and chew", vigorously.

After each of the control and test runs the blood agar plates were removed from the Anderson sampler and incubated and counted as before.

Part B

This procedure was ultimately decided to be a good, clinical in-use test. Surgeons, assistants, and medical students wore masks of each of the four types tested in and during the course of operations at the University Hospital.

Each of the subjects was trained with the use of a hand mirror. They practiced the phrase, "sing and chew", directing their voices toward the mirror and were considered good subjects when they produced a fine spray of droplets on the mirror.

Participants were assigned one of the masks before they entered the operating room. They then went about their duties with no limitations concerning the mask.

As the participants left the operating room they were asked

to proceed to one of the sampling boxes. With mask in place, the subject said "sing and chew" at 10 second intervals for 1 minute. At the end of the one minute the subject removed his head and closed the panel. The air sampler pump was turned on again and run for a period of four minutes.

The subjects then removed their masks and stepped to the other identical sampling box. The same procedure as above was then done, without a mask.

After each of these runs the blood agar plates were removed from the Anderson samplers and incubated and counted as before.

Results of sampling chamber method

The results of this method will be presented under parts A, B, and C.

Part A

This was the preliminary study designed to see if subjects could be trained to produce constant "sneezes" and to decide how many sneezes to use in each test of the subsequent investigations. Table 1 shows the trend of counts from varying numbers of sneezes. If all sneezes were identical, there should have been a simple ratio of 1:2:3 in the data from 2, 4, and 6 "sing and chew", respectively. This ratio is shown by the overall average. However, the individual variability is so great that in some cases more colonies were counted from only two sneezes than from six subsequent sneezes by the same person.

Table 1

	Number of "sing and chews" 2	4	6
Subject A*	46	77	95
B	86	112	53
D	16	38	33
E	36	36	23
F	32	44	35
G	21	90	92
H	33	14	44
Subtotal	270	411	375
Subject C	4290	4960	9306
Total	4560	5371	9681
I**	67	55	110
J	164	257	217
K	142	189	379
L	141	344	358
M	17	29	131
N	135	490	622
Subtotal	666	1346	1817
O	66	260	2102
P	47	196	1610
Total	779	1820	5529
Grand Total	5339	7191	15210
Both Subtotals	936	1775	2192
Average of those 13	72	137	168
Median of those 13	46	77	95

Actual counts with various numbers of "sings and chews".

*A through H were done with 2 "sing and chews" first, then 4, and finally 6.

**I through O were done with 6 "sing and chews" first, then 4, and finally 2.

From this larger group of volunteers 20 were chosen to participate in Part C, on the basis of their ability to produce fairly constant numbers of organisms per sneeze.

From this preliminary study it was decided that the best number of "sing and chews" per minute in the subsequent parts would be six, that is, sneezes at 10 second intervals for one minute.

Part C

This part of the procedure turned out to be less contributory than expected. We found that some of the results were not acceptable because the subjects had removed the mask at some time during the three hour period. By the end of the three hour periods the volunteers had become irritable and uncooperative. Since some of the results were unreliable, inconsistent and variable no graphs or tables of these results were made.

Part B

We subsequently found that Part B contained the most significant and reproducible results. The bulk of the material gathered was done with this part of the experiment.

In this study, any test in which the control count was so small that bacteria which could have gotten in from sources outside the mask could have amounted to more than 10 per cent of the control were considered outside the range which should be included in the

analysis. Control data showed an average count of only 18 organisms recovered from plates exposed by having test subjects hold their heads inside the box for the same length of time as that required by an actual test, but remain perfectly quiet. For the control data there were 3 one minute runs with double gauze, 3 runs with Aseptex, and 6 runs with subjects unmasked. In these control runs the data gave the same average number (18) from the six subjects when they were all wearing masks as when none of them wore masks. Therefore, the controls for the actual testing procedures had to be over 180--more than 10 per cent of the average counts in the control data. Out of 155 tests, 13 had to be excluded from the analysis because the control was not even ten times the blank and 6 more had to be excluded because the test count was more than four times the grand average for test counts on that type of masks. This left tests on a total of 136 masks, 44 single gauze, 40 double gauze, 42 Aseptex, and 10 No. 540 masks to be included in the analysis.

Table 2 shows the average count of the particles allowed to go through a mask, grouped according to the type of mask and the length of time worn. The tests for each type of mask were divided into four or five equal groups. As can be seen by the table, the particles were grouped and collected by different particle size in the Anderson sampler.

Table 2

Time in Min.	Micra* over 8½	5-10	3-6	2-3.5	1-2	under 1	under 2	Total from tests	Total in control
Single gauze									
72	91	127	93	87	42	4	46	445	4221
87	72	104	82	78	45	5	50	387	3253
132	89	94	104	72	36	4	40	399	5046
210	39	57	59	47	27	5	32	235	3099
Double gauze									
83	16	10	7	6	6	1	7	46	4641
116	25	11	7	8	7	2	9	60	4641
156	13	8	5	5	8	3	11	40	3180
204	19	16	11	8	7	3	10	64	4120
263	19	13	11	10	10	3	13	65	3417
Aseptex									
91	15	10	9	10	10	4	14	57	4395
133	12	10	6	6	10	4	14	49	4316
160	23	14	13	14	10	2	12	78	4930
200	16	7	5	8	8	4	12	49	3717
326	13	6	5	5	6	3	9	38	2837
No. 540									
109	11	7	7	7	5	3	8	39	6750

This table shows the average test count for masks of various types when grouped according to the length of time worn.

*These numbers are the micra of particle size according to the level the organisms accrued in the Anderson sampler.

Figure 3.3 shows the "average per cent through" of each group plotted against the average length of time for which masks in that group were worn in the hospital operating room. Table 2 and Figure 3.3 show that there is only a small loss in efficiency with time for any of the masks. In fact, by Table 2 and Figure 3.3, both the double gauze and the Aseptex masks still show an average efficiency above 98% after average exposure of 4 and 5 hours, respectively. However, as can be seen in Figure 3.3, the efficiency of the single gauze seems to improve with increase in time. The decreases in efficiency of the double gauze and the Aseptex were as expected. One can only say here that with more test samples a decrease in efficiency of the single gauze mask might be shown. This again suggests the variability in numbers of organisms collected in the samples and is a strong point in favor for doing many more test samples.

The comparative filtering efficiency of various lengths of time worn is shown in Table 3. These percentages are calculated for each type of mask and the percentage figures indicate the efficiency through the hours listed. Table 4 also shows the filtering efficiency but this table indicates the total efficiency for each type of mask tested.

Several graphs have been prepared to compare the efficiencies of these masks.

Figure 3.4 shows the actual total numbers of microorganisms

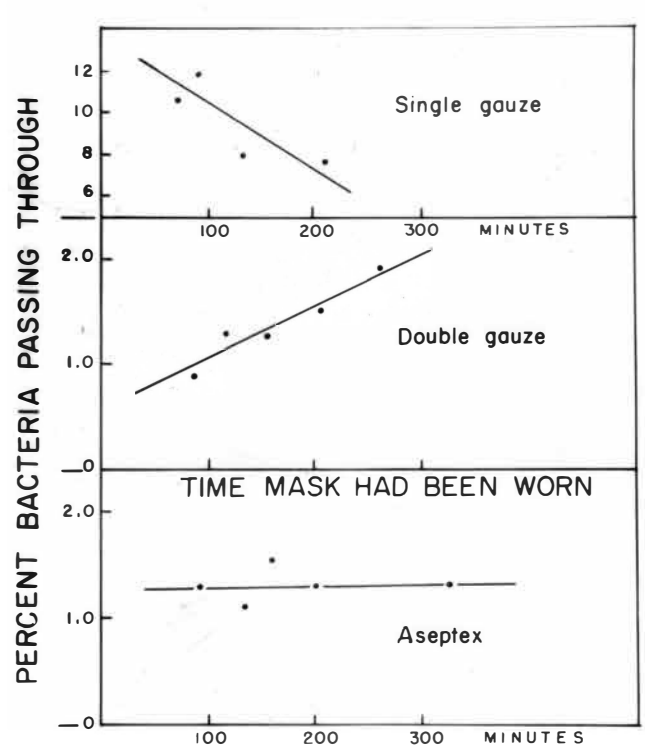

Figure 3.3. This graph shows the percentage of bacteria passing through according to the time worn.

Table 3

	Time in Hours						
	0-1	1-2	2-3	3-4	4-5	5-6	7-8
Single gauze in %		88.4	90.5	85.8	96.7		
Number in sample		28	7	8	1		
Double gauze in %	99.3	98.2	96.4	97.4	97.5	94.4	
Number in sample	2	10	10	9	7	1	
Aseptex in %	99.4	99.2	97.2	97.3	96.6	95.7	95.6
Number in sample	1	3	17	14	2	1	3
No. 540 in %		98.8	99.5	99.9			
		8	1	1			

This shows the comparative filtering efficiency of various lengths of time worn.

Table 4

	Efficiency	No. samples
Single gauze	85.6%	44
Double gauze	97.4%	39
Aseptex	97.3%	41
No. 540	98.9%	10

This shows the total filtering efficiency. The times varied from 45 minutes to 7½ hours.

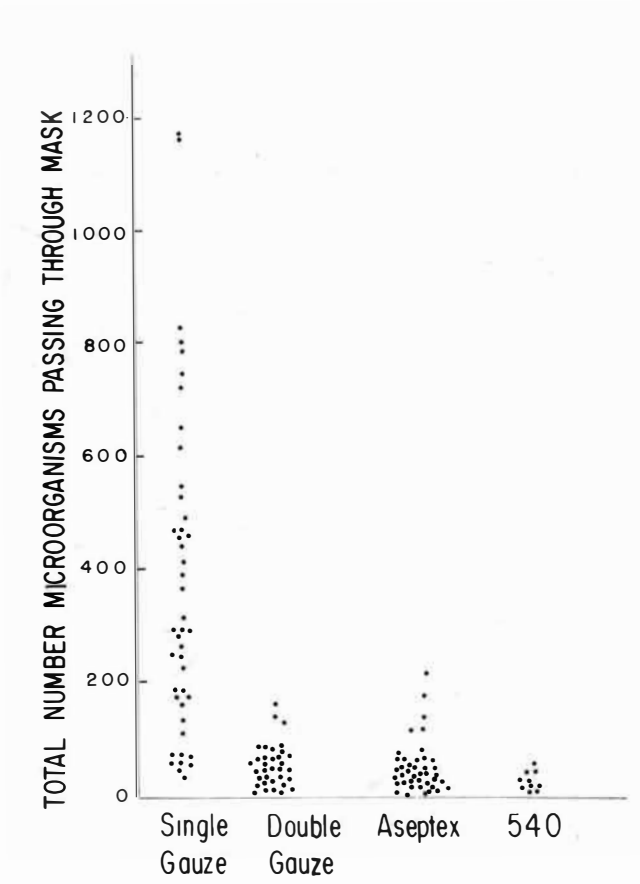

Figure 3.4. This graph shows the actual numbers of organisms passing through the masks.

passing through each of the masks during each run. As can be seen by this graph, there is a great amount of variability in the total numbers of microorganisms passing through the single gauze mask. There is much more consistency in the numbers for the other three masks.

Since we had previously noted variability in the numbers of organisms recovered in the tests, an attempt was made to establish the most consistent estimator, that is, the measure with the least amount of variability. Figure 3.5 shows the comparison of four methods considered. The X-value is the ratio, expressed as per cent, of the test count for one particular mask to the corresponding control count for a single mask. The aX-value is an expression of the average of the test counts. The mX-value is simply the median of the test counts. The Q-value was found to be the most consistent estimator, as shown in Figure 3.5. The Q-value is the ratio of the average test count to the average control count. Instead of showing the total numbers of microorganisms passing through the masks, as in Figure 3.4, Figure 3.5 has the efficiency expressed in per cent. With any of the four estimators there is comparatively less efficiency in the single gauze mask.

By using the Anderson sampler we were also able to determine particle size distribution. This comparison was done only on the single gauze, double gauze and Aseptex masks. The

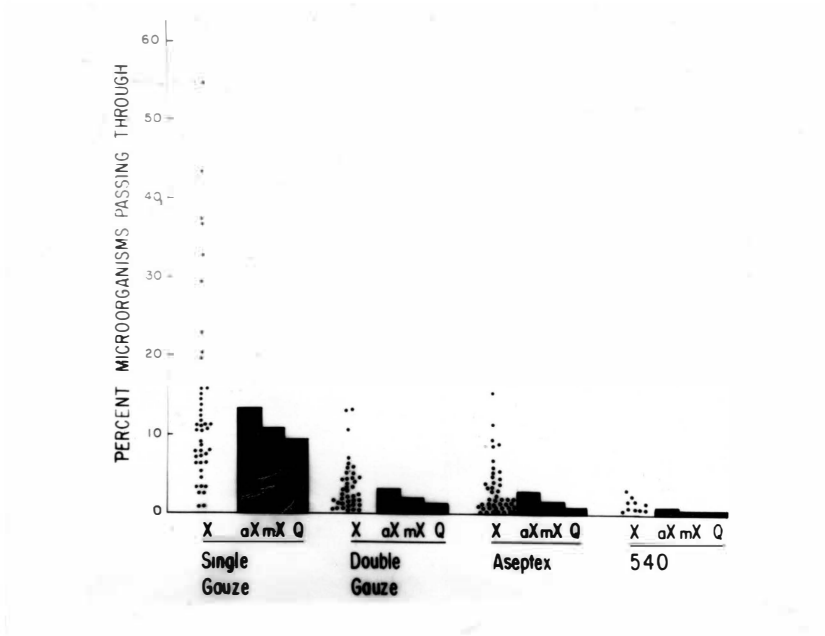

Figure 3.5. Relative effectiveness by 4 different estimators.

X--Ratio of test count for one particular mask to the corresponding control. Count for a single mask.
aX--Average of per cent passing through.
mX--Medium of per cent passing through.
Q--Ratio of average count to average control count.

distribution was found to be quite similar in the three groups of tests. This is also found in the controls accompanying tests on each of the three masks. This is seen in Figure 3.6. Each bar represents the per cent, in the respective size range, of the total number of organisms collected in either the tests or control. One might expect the greater variability in the pattern for particle size distribution in the mask tests because there are fewer particles in each sample.

Discussion

Although parts A and C did not contribute directly to efficiency determinations, they did show the variability of the number of particles expelled from the mouth and nose of the volunteer subject. This was seen even when the subjects attempted to exactly duplicate each "sing and chew".

Part B ultimately provided a more convenient procedure with the most significant and reproducible results. It also provided a larger number of test runs in a short period of time.

Since the average figures of per cent passing through the masks were variable, a consistent estimator was sought. This resulted in the establishment of the Q-value which is the ratio of the average test count to the average control count.

From these tests the results show that double gauze masks are much more effective in preventing passage of bacteria than single gauze, with Aseptex about the same effectiveness as double gauze,

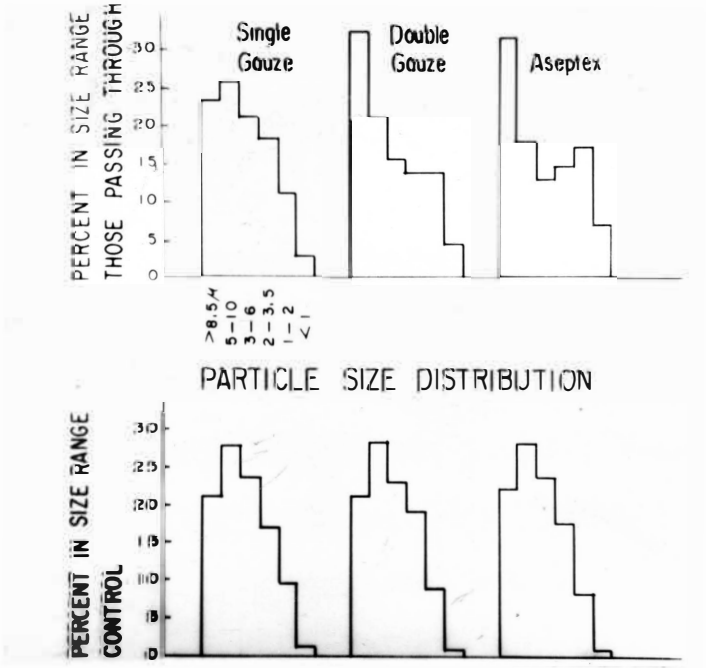

Figure 3.6. This graph shows the comparison of the percentages of the particle sizes for the tests and controls.

and No. 540, with fewer samples, the best of those tested.

In general this method of testing is a good clinical in-use method. However, there is still the inevitable human variability in numbers of organisms expelled from the mouth and nose. The relative efficiencies of the masks tested can be shown by our results since, as nearly as possible, the tests were run in the same manner for each mask. Ideally, there should be a much larger number of test runs in order to make the calculated efficiencies more accurate.

Summary

There is always danger of contaminating open wounds during surgery. Efforts to prevent contamination include the wearing of surgical masks.

Since the earliest published advocacy for usage of surgical masks by Mikulicz in 1897, many different investigators have attempted to test mask efficiency. In the early 1900's cough plate methods were mostly used. (9, 10, 11) After the advocacy of wearing masks became accepted, another type of testing was found--the attempt to force organisms through mask material. (25, 27) This method measured the mechanical filtering efficiency.

There were variances of opinion as to the actual values of efficiency of various masks. However, most investigators favored the use of some type of mask. (13, 14, 17) Several new types of masks were developed as a result of these investigations. These have been either deflector masks (15), filter masks (23), or a combination of both. (29)

During this study two factors were of most concern: 1) the type of testing used, and 2) the validity of the results.

In 1960, I began working on a project to develop a meaningful bacteriological testing procedure for measuring efficiency of various surgical masks under rigorous conditions.

We first studied various static flow devices, These forced

organisms through mask material. These methods of testing measure the mechanical filtering efficiency and the potential of the masks, but do not evaluate the mask in actual clinical use. We observed that surgical mask material No. 540 was much more efficient that the single gauze material. The single gauze measured less than 50 per cent efficiency in removal of micro-organisms under the test conditions.

In an attempt to evaluate masking materials "in clinical use" several techniques were studied. First a cough plate method was done. In the actual testing procedure the subjects talked for periods of 20 minutes. In our results we found that the numbers of recovered organisms were quite small, the individual test runs were quite variable, and that longer test runs would be quite uncomfortable for the subjects.

Subsequently, a second test method was used--one which more accurately measured the efficiency of masks in clinical use. This test was also more reliable and reproducible, with fewer variables.

In one variation of the testing procedures volunteers wore masks for a period of 3 hours. The masks were tested for one minute during each hour. For the test the subjects repeated the phrase, "sing and chew", every ten seconds for one minute while they held their heads in a vertically enclosed box. In this test the results were variable and only a small number of tests were done. The subjects usually became uncomfortable and uncooperative

during the latter part of the three hour period.

Ultimately, and in another variation, we tested the masks worn by persons actually participating in operations at the University of Nebraska Hospital. At the conclusion of an operation the technician asked two or three of those involved to test his mask by the procedure outlined. The masked subject was asked to put his head into the sampling chamber and repeat the phrase, "sing and chew", every 10 seconds for one minute. He then removed the mask and stepped to an identical box and repeated the test.

The results were calculated on tests of a total of 136 masks, 44 single gauze, 40 double gauze, 42 Aseptex, and 10 No. 540 masks.

The results showed that the double gauze masks are much more effective in stopping bacteria than single gauze, with the Aseptex as effective as double gauze, and the No. 540 the best of those tested. The total filtering efficiency of double gauze was 97.4%, of Aseptex 97.3%, and of No. 540 98.9%. Even though there was a total filtering efficiency of 85.6% for the single gauze mask, there was marked variability of individual results. This efficiency for the single gauze mask in the sampling chamber method is in marked contrast to the average efficiency of less than 50% in the static flow method.

We also examined the distribution of particle size by means

of the Anderson sampler. There was no marked variation of particle size distribution between the test runs and the control runs. The slight variation of distribution in the test runs might be due to smaller numbers of organisms recovered as compared to the controls.

The results of the sampling chamber method appear to be quite reproducible with few variables. Ideally a much larger number of test runs should be done for a more precise evaluation.

It should be emphasized that, although the total per cent efficiency of the single gauze mask is 85.6% by the sampling chamber method, there is less than 50% efficiency by the static flow method. Therefore, both the sampling chamber method and the static flow method show a significant loss of efficiency for the single gauze mask. There are at least three other masks that are much more efficient than the single gauze mask.

Conclusion

1. Literature review reveals that there are two main types of testing of mask efficiency: a) the cough plate method and b) the attempt to force organisms through masks.

2. Our cough plate method showed too much variability and inconsistency and was discarded. We were also unable to do longer test runs with this method.

3. Our modification of the static flow method is a good measure of potential efficiency of masks.

4. The new sampling chamber method of testing is a good measure of clinical in-use efficiency of masks.

5. By testing masks with both the static flow method and the new sampling chamber method, an evaluation of both potential and clinical in-use efficiency of the mask can be made.

6. Single gauze masks show marked variability of and low percentage of efficiency. There are many masks which are better than single gauze.

7. Particle size distribution for both tests and controls in the sampling chamber method was found to be quite consistent.

8. A larger number of tests for both the static flow and sampling chamber method would be valuable in a more precise evaluation of efficiency of masks.

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