AN EXPERIMENTAL STUDY OF THE EFFICACY OF GAUZE FACE MASKS.

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Masks have not been proved efficient enough to warrant compulsory application for the checking of epidemics, according to Dr. Kellogg, who has conducted a painstaking investigation with gauzes. This investigation is scientific in character, omitting no one of the necessary factors. It ought to settle the much argued question of masks for the public. : : : : : : : : : : : : : :

THE recent epidemic of influenza brought forcibly to attention the use of the gauze mask as a protection against infection. The supposition that influenza is a droplet-borne infection suggested to many the idea of controlling its spread by requiring the wearing of face masks, and accordingly the measure was adopted in many towns and cities, principally in California. Unfortunately for the rational application of such a measure little was known of the requirements for the proper making of a gauze mask, although during the year 1918 four or five articles on the protective value of masks had appeared. One of these by Weaver* detailed his experiences in diminishing infections among the nursing staff at the Durand Hospital by the use of masks of two layers of gauze (quality not mentioned). The incidence of scarlet fever and of the carriage of diphtheria seemed to be markedly lessened, although the results are somewhat diminished in value by the fact that the experiment was not a controlled one; comparisons were made between two periods of time, during one of which the mask was used and during the other it was not. Capps* at Camp Grant tried the mask to prevent infection in ambulances and among patients while temporarily outside of cubicles. He gives no information as to the quality of gauze or number of layers and no figures or specific comparisons, and his conclusions are, that after masking, no cases of scarlet fever appeared in the wards whereas there had been just before a series of six consecutive cases. Haller and Caldwell† conducted some bacteriological experiments to determine the protective value of different layers and meshes of gauze. They found that 300 strands to the inch (the sum of the warp and the woof multiplied by the number of layers) were necessary, when worn by the person coughing in the experiment, to stop the planting of colonies on agar plates, and that 220 strands were sufficient when placed over the plate instead of over the mouth of the cougher. They gave no detailed tables of their experiments, and took no account of the possible leakage around the edge of the mask, which occurs in actual practice, nor of the influence of aspiration of droplet-laden

* Weaver, The Value of the Face Mask and Other Measures. Jour. A. M. A., Jan. 12, 1918.

* Joseph A. Capps, The Face Mask in Control of Contagious Diseases. Jour. A. M. A., March 30, 1918.

† David A. Haller and Raymond C. Caldwell, The Protective Quality of Gauze Face Masks. Jour. A. M. A., Oct. 12, 1918.

air through the gauze. Doust and Lyon* also reported on some bacteriological experiments in which they used *Bacillus prodigiosus* in the mouth of the cougher. They found that colonies passed easily through ten layers of coarse and also of medium gauze, but not through three layers of butter cloth. Their results do not agree with those of Haller and Caldwell, who found that seven layers of medium gauze "gave complete protection." Masking of plates was not reported on.

If we grant that influenza is a droplet-borne infection, it would appear that the wearing of masks was a procedure based on sound reasoning and that results should be expected from their application.

Studies made in the Department of Morbidity Statistics of the California State Board of Health did not show any influence of the mask on the spread of influenza in those cities where it was compulsorily applied, and the Board was, therefore, compelled to adopt a policy of mask encouragement, but not of mask compulsion. Masks were made compulsory only under certain circumstances of known contact with the disease and it was left to individual communities to decide whether or not the masks should be universally worn.

The reason for this apparent failure of the mask was a subject for speculation among epidemiologists, for it had long been the belief of many of us that droplet-borne infections should be easily controlled in this manner. The failure of the mask was a source of disappointment, for the first experiment in San Francisco was watched with interest with the expectation that if it proved feasible to enforce the regulation the desired result would be achieved. The reverse proved true. The masks, contrary to expectation, were worn cheerfully and universally, and also, contrary to expectation of what should follow under such circumstances, no effect on the epidemic curve was to be seen. Something was plainly wrong with our hypotheses.

We felt inclined to explain the failure of the mask by faults in its application rather than by any basic error in the theory of its use. Consequently, *Bulletin No. 31** of the Board of Health brought out the fact that where it was sought to control influenza by compulsory wearing of masks certain obstacles developed. These were:

First, the large number of improperly made masks that were used.

Second, faulty wearing of masks, which included the use of masks that were too small, the covering of only the nose or only the mouth, smoking while wearing, etc.

Third, wearing masks at improper times. When applied compulsorily masks were universally worn in public, on the streets, in automobiles, etc., where they were not needed, but where arrest would follow if not worn, and they were very generally laid aside when the wearer was no longer subject to observation by the police, such as in private offices and small gatherings of all kinds. This type of gathering with the attendant social intercourse between friends, and office associates seems to afford particular facility for the transfer of the virus. If, as seems probable, the virus is droplet-borne, this form of contact, where people are conversing with one another, would, of course, be much more dangerous than crowd association of strangers, even under the circumstances of gathering in churches and theatres. We were not satisfied, however, with this seemingly perfectly satis-

*Brewster C. Doust and Arthur Bates Lyon, Face Masks in Infection of the Respiratory Tract. Jour. A. M. A., Oct. 12, 1918.

*Influenza—A Study of Measures Adopted for the Control of the Epidemic. W. H. Kellogg, M.D.,

factory explanation. We felt it to be imperative, if the mask were not to be permanently discredited, that more definite information be obtained concerning its uses and limitations. If, as we believed, the gauze mask is useful as a protection against certain infections, it would be unfortunate if its uncontrolled application in influenza should result in prejudicing critical and scientific minds against it. That there was danger of this is evidenced by many letters received from prominent sanitarians all over the country. It was, therefore, determined to carry out a set of experiments that should demonstrate finally just what type of mask should be used against droplet-borne infections, and what measure of protection could be expected through their use.

It is the object of this paper to set forth these experiments, and it is believed that they are fairly complete, so far as it is possible by laboratory methods alone to arrive at a conclusion. It will remain for future controlled experiments in contagious disease hospitals to dispose of such questions as conjunctival entry of virus, hand infection, etc.

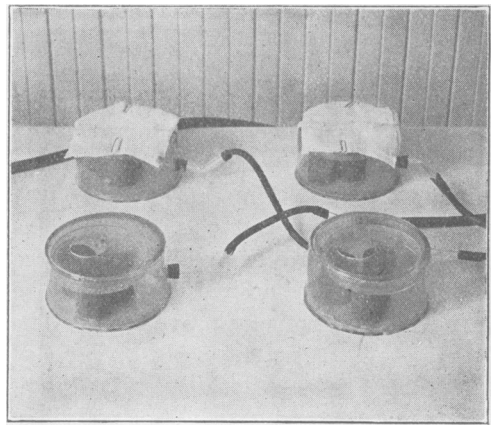
All previous laboratory experiments with which we are familiar have overlooked certain conditions in the practical application of masks which might have an important bearing on the true facts. It occurred to us that the mere settling by gravity of micro-organisms through layers of gauze stretched over petri plates did not simulate at all the natural conditions of forcible aspiration through the gauze that obtains during inhalation by a masked individual.

Another possible source of error which it was desired to investigate was the possibility of droplet laden air passing around the edges of a mask and then entering the nostrils without filtration. A long series of preliminary experiments was necessary, much of which will be passed over without description as being of little interest, although of extreme importance as a foundation for the later decisive operations.

The first procedure that occurred to us, as it has to others, was the inoculation of plates, both covered with gauze and uncovered, by coughing over them at various distances. It was soon determined that an artificial enrichment of the secretions was necessary, and this was secured by spraying the mouth and throat of the cougher with a suspension of *Bacillus prodigiosus*. It was also decided, after many tests, to abandon the inoculation by coughing, as it was found that no degree of uniformity could be maintained. The counts varied enormously from one moment to another. Consequently, controls were rendered of less value and an undesirable variation was shown between individual experiments.

For the purpose of imitating, as closely as possible, natural conditions of forcible suction through the gauze, an arrangement was constructed from a glass dish $2\frac{1}{2}$ inches deep and $4\frac{3}{4}$ inches in diameter with ground edges and having for a cover a glass plate having a round groove ground on one face to fit tightly the edge

FIGURE 1.



of the dish. In use, this cover, sealed on with paraffine, served as the bottom of the apparatus, and a $1\frac{1}{2}$-inch hole was bored through the bottom, now the top, of the covered dish. (See Fig. 1.) A small hole, one-half inch in diameter, was bored through the side of the dish for the attachment of a suction tube. Petri plates were placed, uncovered, inside this jar and supported on large corks, which are plainly shown in the illustration, opposite the large hole which could be masked or not, as desired.

In the earlier experiments straight and curved funnels for the attachment of gauze masks were inserted in the large opening of these jars, but later these were abandoned and the gauze placed directly over the opening in the jar. In the use of these funnels, which are shown attached to the jar in Fig. 2, it was noted that there is a great diminution in the number of bacteria passing through them on the gentle suction current as compared to the number entering directly through the hole over the open plate. The reduction was more marked with the curved funnel than with the straight one, suggesting that possibly a tube with several bends would, if breathed through, check the passage of bacteria as well as a close gauze filter.

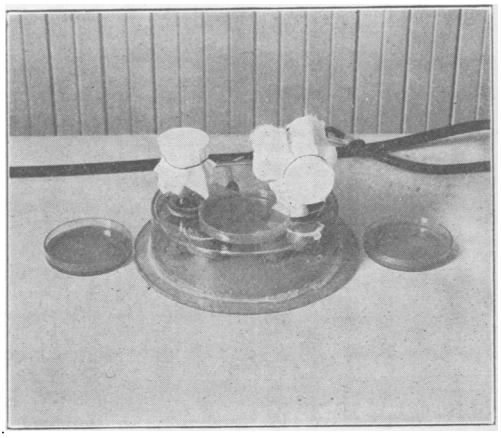
EXPERIMENT NO. I.

First set. No mask on cougher.

Location of plate	Colonies, 48 hours room temperature
Inside jar under straight funnel	21
Inside jar under curved funnel	5
Outside front	137
Outside right side	98
Outside left side	47
Outside back	79
Second set. Cougher masked.	
Inside jar under straight funnel	9
Inside jar under curved funnel	3
Outside front	11
Outside right side	16
Outside left side	11
Outside back	19

The preceding table is an example of the results obtained with the apparatus placed four feet in front of the cougher, who was masked with six layers of 40 by 17 mesh gauze in one experiment and not masked in the other. Besides one plate under each funnel, a curved and a straight one, which were not masked, four plates were placed entirely outside in a vertical

FIGURE 2.



position, one in front of, one behind, and one on each side of the jar.

After numerous other experiments, it was decided that the coughing process was too variable and uncertain, and various types of atomizers were tried, both with compressed air with various pressures and with the ordinary rubber bulb. Example of results:

EXPERIMENT NO. II.

DeVilbiss atomizer No. 15.
Saline suspension of 48-hour culture of *Bacillus prodigiosus*.
Plates in jars.
Vacuum pump, attached to jars instead of having assistant inhale through the tube as previously done.

	Distance from atomizer		
	1 ft.	2 ft.	3 ft.
Without mask	5,280	31	0
Mask, 6 layers, 20 by 17	1,380	20	..

In the following experiment a suspension of *B. prodigiosus* in light paraffine oil was used in attempting to get more uniform counts in the controls, which, with the use of saline spray, were frequently too thickly planted to be easily counted:

EXPERIMENT NO. III.

Mask made of gauze having 20 woof and 17 warp threads to the square inch—6 layers.
Atomizer—DeVilbiss No. 15.
Pressure—From compressed air pipe, about 40 pounds pressure.
Culture—*B. prodigiosus* 48-hour growth suspended in paraffine oil, sprayed at plates for 30 seconds allowing 4½ minutes for the droplets to settle.
Incubation—24 hours, 37° C.

	Distance from atomizer					
	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
No mask	12,000*	10,000*	6,756	4,548	3,372	3,120
Mask, 6 layers..	1,566	1,050	816	562	426	384
Mask, 5 layers..	1,314	1,248	624	222	282	174
Mask, 4 layers..	5,596	2,976	1,692	1,290	846	576
Mask, 3 layers..	10,560	7,360	4,248	3,504	2,472	1,378

* Number estimated.

Many details of these experiments are unrecorded in this article as being of little interest, essential facts only being presented.

As illustrating these omissions we would mention a long series of experiments to find the proper air pressure to use and the time of exposure, and those experiments leading up to the rejection of atomizers of the nebulizing type, such as DeVilbiss No. 49. As an illustration one of the final experiments for determining distances and pressure is given.

EXPERIMENT NO. IV.

Filtered oil suspension of 48-hour culture of *B. prodigiosus*.
Pressure—43 pounds.
Atomizer—DeVilbiss No. 15.
Time—just turning on and off, allowing 5 minutes for settling.
Spray comparable to a sneeze.
Suction pump attached to each jar during spray and settling time.
Rate of suction gauged to correspond as nearly as possible to normal rate of inspiration.
No gauze over opening in jar.

	Distance from atomizer		
	3 ft.	4 ft.	5 ft.
Plates outside jar	2,676	2,704	2,976
Plates inside jar	663	831	1,260

EXPERIMENT NO. V.

Same as Experiment No. IV, but with gauze having a mesh of 24 by 18 threads to the square inch over the inlet to the jars.
Number of layers—6.
Distance from atomizer—5 feet.

	Colonies
Control plates outside of suction jars	4,764
Control plates inside jars, no gauze	2,468
2 layers of gauze	1,830
3 layers of gauze	1,280
4 layers of gauze	544
5 layers of gauze	674
6 layers of gauze	369
7 layers of gauze	454
8 layers of gauze	63
9 layers of gauze	42

EXPERIMENT NO. VI.

Same as preceding, but allowing exposure of three minutes instead of five.

Distance from atomizer—4 feet	Colonies
Control plates outside of suction jars	2,694
Control plates inside of suction jars	409
2 layers of gauze	358
3 layers of gauze	420
4 layers of gauze	344
5 layers of gauze	338
6 layers of gauze	294
7 layers of gauze	184
8 layers of gauze	167

EXPERIMENT NO. VII.

Filtered oil suspension—48-hour culture of *B. prodigiosus*.
Pressure—43 pounds.
Atomizer—DeVilbiss No. 15.
Time—Just turning cock on and off allowing 5 minutes for settling.
Suction—25 pounds on jars during spray and time for settling.
Gauze—42 by 44 threads to the square inch.

	Distance from atomizer	
	4 ft.	5½ ft.
No gauze	366	421
Outside plates (no suction)	4,400	5,280
2 layers of gauze	329	684
3 layers of gauze	391	699
4 layers of gauze	251	372
5 layers of gauze	114	264
6 layers of gauze	12	22
7 layers of gauze	4	7
8 layers of gauze	5	4
9 layers of gauze	9	12

EXPERIMENT NO. VIII.

Same as preceding, but allowing three minutes for settling instead of five.

	Distance from atomizer	
	4 ft.	5½ ft.
No gauze	211	127
Outside plates (no suction)	3,594	1,836
2 layers of gauze	50	20
3 layers of gauze	29	8
4 layers of gauze	20	18
5 layers of gauze	25	13
6 layers of gauze	0	0
7 layers of gauze	0	1
8 layers of gauze	0	0
9 layers of gauze	1	0

EXPERIMENT NO. IX.

Filtered oil suspension—48-hour culture of *B. prodigiosus*.

Pressure—43 pounds.

Atomizer—DeVilbiss No. 15.

Time—Just turning cock on and off, allowing 5 minutes for settling.

Suction on jars during spray and time for settling.

Gauze—60 by 72 threads to square inch.

	Distance from atomizer	
	4 ft.	5½ ft.
No gauze	871	172
Outside plates (no suction)	4,572	5,724
1 layer of gauze	1,771	1,110
2 layers of gauze	897	250
3 layers of gauze	133	127
4 layers of gauze	26	12
5 layers of gauze	18	14
6 layers of gauze	35	7
7 layers of gauze	21	6
8 layers of gauze	25	8
9 layers of gauze	17	4

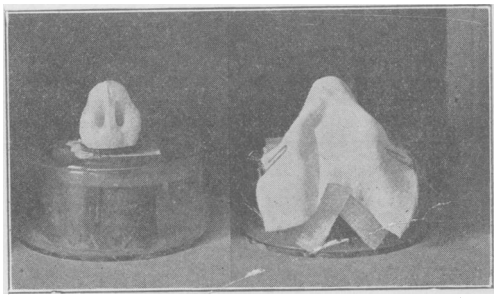
It was noted from a study of experiments V and VI that gauze of medium texture, namely 24 by 28 threads, has no notable restraining effect up to eight layers, agreeing with Doust and Lyon's experience that ten layers of medium gauze were penetrated in their coughing experiments. Experiments VII, VIII and IX are of more importance as they deal with fine and extra fine gauze (butter cloth). Haller and Caldwell found that a total of 220 strands (warp plus woof times layers) to the inch practically stopped the passage of organisms when applied over petri plates, and Doust and Lyon concluded that three layers of butter cloth would filter *B. prodigiosus*. They do not give the mesh of this butter cloth, but presumably it corresponded to the 42 by 44 thread gauze in our experiments Nos. VII and VIII, in which we found that with the element of aspiration introduced, as in the natural use of masks, even five layers did not give a sufficient reduction in count to make such a mask of value. Furthermore, our experiment No. IX in which the very best and finest cloth of 60 by 72 strands to the inch was used, demonstrated that under the natural conditions of aspiration of droplet-laden air through the mask, four layers, which would be extremely difficult to breathe through, are required to obtain a degree of filtration which would hold out any hope of useful result in practice.

The following series of experiments were to determine the possibility of the passage of droplet-laden air around the edges of a close mask instead of through it, and also to simulate other physical conditions attending the wearing of the mask. In these experiments artificial noses of paraffine were made for the purpose of securing the closest approach possible to the natural physical conditions of the wearing of masks by persons.

Figure 3 illustrates these artificial noses which are attached to the glass jars, within which are placed the petri plates immediately behind the passages through the paraffine.

Various combinations with the models

FIGURE 3.



were tried. In experiment No. X a nose without nostrils was used in addition to the regular one, for the purpose of establishing the leakage around the edges of the mask. The tabulation of results shows the restraining influence of the nasal passages as the counts are larger where the air passes directly into the aspiration jar instead of by way of the nasal passage. Another outstanding feature of this test is that there is little difference in results obtained with different layers within the range of the number that would be acceptable from a standpoint of comfort.

Experiment No. XI (see Fig. 4 and Table I), was conducted with different types of gauze and varying numbers of layers. An inspection of the table of results in Set 1 shows that an increase of efficiency was noted with the increase of the number of layers and that the results were better in column C where the air was required to pass through the mask and no opportunity existed for passing around the edges, as was the case in column A where the mask was placed over the nose. The difference, however, was not very material showing that the

EXPERIMENT NO. X.

Filtered oil suspension—48-hour culture of *B. prodigiosus.*
Pressure—43 pounds.
Atomizer—DeVilbiss No. 15.
Time—Just turning cock on and off allowing 3 minutes for settling.
Suction during spray and time for settling.
Gauze—60 by 72 threads to the square inch.
Large jar—two holes—one covered by wax nose with nostrils; other open with wax nose without nostrils just above hole.
Distance from atomizer—5 feet.
Jar standing vertically.

Layers of gauze	No nostrils	Nostrils
No gauze	762	150
Outside plate	2,630	..
5 layers	54	15
6 layers	81	20
7 layers	35	13
8 layers	18	15
9 layers	12	9 patch
10 layers	3	8

EXPERIMENT NO. XI.

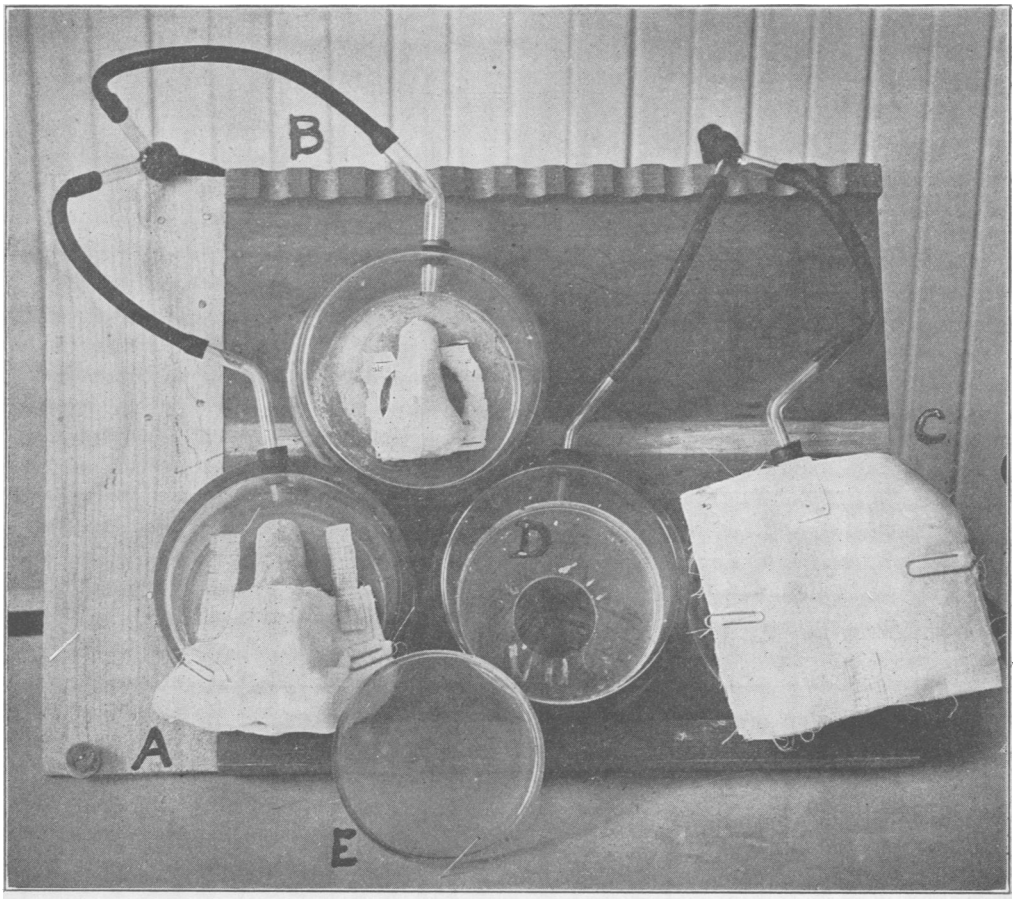
Filtered oil suspension—48-hour culture *of B. prodigiosus.*
Pressure—43 pounds.
Atomizer—DeVilbiss No. 15.
Time—Just turning cock on and off allowing three minutes for settling.
Gauze—60 by 72 threads to the square inch in Set 1 and 24 by 28 in Set 2.
Distance from atomizer—5 feet.
Suction on all jars during spray and time for settling.
All jars standing vertically.

TABLE I

EXPERIMENT No. XI.

	A	B		C	D		E
	Masked nose	Unmasked nose	Per cent of Efficiency	Gauze over jar—no leakage around edges	Open plate	Per cent of Efficiency	Outside of jar
Set 1—Gauze 60 x 72 threads to square inch.							
9 layers of gauze	0	10	100	0	200	100	1,000
8 layers of gauze	1	56	98	1	73	98.7	1,122
7 layers of gauze	37	160	77	64	183	70	1,265
6 layers of gauze	35	154	77	5	117	95	1,230
5 layers of gauze	127	300	57	109	407	70	1,260
Set 2—Gauze 24 x 28 threads to square inch.							
10 layers of gauze	39	654	94	34	992	96	1,776
9 layers of gauze	42	790	94	240	1,716	86	1,980
8 layers of gauze	patches						
8 layers of gauze	296	681	56	190	684	72	2,042
7 layers of gauze	450	1,980	77	189	1,440	86	Too many to count
6 layers of gauze	666	1,089	38	466	695	32	2,690

FIGURE 4.



A. Hole in top of jar covered by wax nose with nostrils and gauze mask.
B. Hole in top of jar covered by wax nose with nostrils. No mask.
C. Hole in top of jar covered by gauze mask attached by adhesive.
D. Hole in top of jar, not covered.
E. Plate outside of jar—no mask.

principal source of lack of efficiency is in the forceful aspiration of air through the mask. This table also shows that five layers of this extremely fine gauze, which would be impossible of comfortable use, gave an efficiency of only 57 per cent.

Conclusions.

1. Gauze masks exercise a certain amount of restraining influence on the number of bacteria-laden droplets possible of inhalation.

2. This influence is modified by the number of layers and fineness of mesh of the gauze.

3. When a sufficient degree of density in the mask is used to exercise a useful filtering influence, breathing is difficult and leakage takes place around the edge of the mask.

4. This leakage around the edges of the mask and the forcible aspiration of droplet laden air through the mask is sufficient to make the possible reduction in dosage of infection not more than 50 per cent effective.

5. It remains for future controlled experiments in contagious disease hospitals to determine whether the wearing of masks of such texture as to be reasonably comfortable are effective in diminishing the incidence of infection.

6. Masks have not been demonstrated to have a degree of efficiency that would warrant their compulsory application for the checking of epidemics.

A STUDY OF THE TOXICITY OF DIPHTHERIA BACILLI ISOLATED FROM IMMEDIATE CONTACTS.

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The members of the community at large are not often sources of diphtheria infection and we must look elsewhere to find the factors of greatest danger. School children do not furnish the source of infection. These investigators point to convalescents and contacts as being the probable distributors of the virulent bacilli. : : : : :

THE relation of the carrier of the diphtheria bacillus to the spread of this disease has been the object of much research, and the percentage of true diphtheria bacilli, both from the standpoint of morphology and of virulence has been determined in several distinct groups of the population.

The percentage of morphologically true diphtheria bacilli has been studied by the Massachusetts State Board of Health,[1] which found that 3 per cent of persons not known to have been exposed to infection harbored morphologically true diphtheria bacilli, while the organisms were present in from 8 to 50 per cent of those exposed to diphtheria. Park[2] found that 9.7 per cent of 330 healthy persons showed morphological diphtheria bacilli but only 2 per cent of these were virulent.

The percentage of persons in the general population harboring morphologically true diphtheria bacilli (classified according to Westbrook's types) was also studied by Goldberger, Williams and Hachtel[3] during the winter of 1913 and 1914 in Detroit. For nearly a year prior to the commencement of this investigation diphtheria had been unusually prevalent in Detroit, but the percentage of cases markedly decreased about three weeks before the collection of cultures began, so that the investigation really resolved itself into a study of the diphtheria carriers at large in a typical population shortly after a time of increased prevalence of the disease. They made cultures from a representative portion of the population, cultures from the nose and throat of 4,093 healthy persons being examined; 38, or 0.928 per cent, were found to harbor morphologically true diphtheria bacilli. Nineteen pure cultures of the diphtheria bacillus were isolated and 2 of these were found to be