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AERIAL INFECTION*

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For many years it was widely held that smallpox could be conveyed for a mile or more by aerial convection, and there are still some who hold this view. It is now believed that alleged instances of long-distance transmission do not bear critical examination: some fault in isolation technique allows the disease to be conveyed by undetected vectors. But aerial convection should not be dismissed too lightly, for phytopathology provides abundant evidence of long-distance dissemination of plant pathogens.

Extramural Aerobiology

The atmosphere contains vast numbers of living and dead particles derived from, and dependent upon the nature of, the soil, its flora and fauna. Many seeds and pollens are specially adapted for aerial transmission; smaller living particles such as fungi, spores, bacteria, and viruses need no such adaptation to remain suspended. The number remaining air-borne depends on such meteorological factors as the vertical and horizontal movements of the air, and upon precipitation, which in turn is governed by size, shape, and density of the particles. Viability depends on the nature of the particle, its ability to survive desiccation, extremes of temperature, and the lethal effect of radiation; in this connexion the protection provided by the non-living particle on which organisms are often carried is of some importance. This state of suspension of particles and their rate of settling are worth closer examination.

Because of the resistance of the air, particles do not fall with increasing velocity, but reach a constant velocity when a balance is struck between accelerating and resisting forces. Stokes's law expresses the constant velocity of descent of a small suspended sphere in terms of its radius and density, and the density and viscosity of the fluid medium through which it is falling. In perfectly still air the rate of fall of, say, a staphylococcus 1 micron in diameter (i.e., 1/1000 mm.) would be about 1 cm. in 5 minutes; and of a small-sized droplet of mucus 50 μ in diameter about 18 in. a minute. In the presence of a steady wind with a velocity of 10 miles an hour the staphylococcus would be carried for a distance of over 900 miles before reaching the earth from a height of 10 metres; the 50 μ droplet would be carried for a third of a mile. If there were a rising current of air with a velocity in excess of the fall the particles would be carried up—the smallest to great heights. The air for a mile up contains vast numbers of bacteria and spores; above two miles the number decreases rapidly, but Armstrong (1936) found them in the stratosphere 70,000 ft. up. Over large masses of water the number of terrigenous organisms decreases rapidly, but specimens have been collected 130 miles out to sea; on the other hand, viable marine organisms have been collected 30 miles inland. Organisms are present in rain and have been found in falling snow in Antarctica—far from their place of origin. There is an aerial cleansing action in precipitation which is worth remembering. Climatic factors, then, govern the transport of aerial organisms; indeed, meteorological

investigations are of the utmost importance in the epidemiology of some plant diseases. Wind plays a great part: the spores of wheat-stem rust, a destructive fungous disease, have been carried in large numbers for such enormous distances as 1,000 miles in such a short time as 48 hours, to give rise to outbreaks of rust a week or 10 days later (Stakman, 1942). Jacob (1940) maintained that the horizontal distance over which micro-organisms can be transported is almost limitless, although their effective range is determined by their ability to survive. Terrigenous organisms of the air are remarkably resistant. They survive exposure to direct sunlight, heat, and dryness for days or weeks, although, paradoxically, they die rapidly on exposure to sunlight after isolation in the laboratory. The effect of humidity on survival is disputed: Wells (1936) found ultra-violet radiation to be 10 to 20 times more germicidal in dry air than in humid air, but Renschler (1940) decided that relative humidity does not increase the resistance of air-borne bacteria. There is, then, no reason why human pathogens should not be carried over considerable distances; but as they have never been recovered from the upper air or marine air, the inference is that they do not long survive exposure. Compare the absence of pathogenic bacteria over the sea with pollen grains, which may be found hundreds of miles from land in numbers in inverse ratio to the distance from the source.

Intramural Infections

This brings me to the first important point I want to stress, which is that, in my opinion, most human respiratory infections take place indoors. Such diseases are still the greatest cause of morbidity and mortality, and if we can be sure that they are always intramural events we can direct our energies for their control along narrower channels.

That pestilential air was a vehicle of contagion and infection was believed hundreds of years before the germ theory of disease was propounded. Perhaps the most surprising period was the first 35 or 40 years of this century, during which time the theory of air-borne diseases was practically abandoned. It started with Flügge's (1897, 1899) description of infectious droplets. They explained so many problems of contact infection that they came to be accepted as the mode of transmission of most respiratory infections. Since droplets rapidly fall to the ground within a few feet of their source it was assumed that the infector and the infectee had always to be in close proximity. Certainly for most of my professional life fever practice was based on the hypothesis that practically all cross-infections were attributable to hands or droplets, although the behaviour of chickenpox seemed to contradict this from time to time; smallpox, of course, was in a class by itself. Not until Wells and Wells's (1936) exposition of droplet nuclei did "aerial infection" reappear.

Now that the term is reintroduced we must be clear what we mean by it. Long-distance aerial transmission is of course excluded, but there has been a tendency to exclude droplet infection also, limiting the term "air-borne infections" to those occurring more than 4 ft. from the source (Cruickshank, 1940). Our terminology of the modes of infection is confused and requires clarification. The average examinee states that direct

* Presidential address given to the Fever Group, Society of Medical Officers of Health, on Nov. 24, 1944.

contact is the commonest mode of spread of infectious diseases, but has a very hazy conception of what the term means; when pressed it usually transpires that close proximity to the patient in time and space is meant, not contact in the sense of touching. I should like "contact" restricted to "touching," but I doubt if it could be displaced from its use as a noun to indicate a person exposed to infection. "Aerial infection" should embrace all those modes of transmission in which the path of the infective agent lies through the air—those which pass through a circle in Fig. 1. Droplets, their nuclei,

of 46 metres or 152 ft. per sec. The duration of the sneeze is about 1/10 of a second. The atomization is more efficient—i.e., the droplets become smaller—as the velocity of the air-stream increases and the size of the orifice decreases; among other factors influencing size of droplets are surface tension, viscosity, particulate inclusions, and evaporation. Droplets vary from 7μ to $1,000\mu$ or more, but commonly two-thirds of them are smaller than 100μ (i.e., 1/10 mm.). This is an important figure, because Wells (1934) considers 100μ to 200μ as the dividing-line between droplets likely to fall and those likely to remain suspended.

Bourdillon and Lidwell (1941) estimated the number expelled by a vigorous sneeze at 100,000, but Jennison (1942) gives an average figure of 20,000, with a low limit of 4,600 for a weak, stifled sneeze. These figures are enormously higher than those for coughing and talking. In coughing, the droplets are produced chiefly in the pharynx, and only a few dozen or a few hundred escape because the mouth is kept open. Flügge (1921) also distinguished bronchial droplets expelled during coughing from oral ones. In talking, the number of droplets expelled depends on the consonant enunciated: explosives such as "p" and "t" cause a few hundred, and vowels practically none. Theoretically, a particle $1,000\mu$ (or 1 mm.) in diameter, ejected from the mouth with a velocity of 152 ft. per sec., will reach the floor 15 ft. away; the smaller the particle the less its kinetic energy and the shorter the distance it will go. Using the technique of flash photography, Jennison (1941) showed that few of the particles from a sneeze fell more than 2 or 3 ft. away. Many remained air-borne. The smaller the droplet the more easily was it suspended. In this connexion it is of great importance to appreciate that droplets become much smaller after expulsion. Within a quarter of a second a droplet of water 150μ in diameter is completely evaporated in still air (Jennison, 1942). As most sneezed droplets are smaller than this it follows that within a fraction of a second most of them have evaporated to sizes which permit them to remain suspended as droplet nuclei.

I have not been able to find a definite statement as to the size of a droplet nucleus, but I would infer it to be less than 5μ , each particle consisting of individual bacteria or minute masses of organisms or viruses on a small quantity of the vehicle. Bacteria in the air act as condensation nuclei, and the vehicle is usually a film of water, the thickness of which depends on the humidity of the air (ZoBell, 1942). Wright (1940) says the whole nucleus is very little larger than the included bacteria or other particles. To support a droplet 10μ in diameter an air current with an upward velocity of less than 1 ft. per minute is required. As the average movement in a naturally ventilated room is about 25 ft. per minute adequate lifting force is available for most small droplets, which are readily dispersed throughout the room by convection currents. The deposition of suspended particles on to the floor takes place not at a constant rate but at a geometrically decreasing one: about 16% of air-borne bacteria are still suspended 8 hours after their introduction (Phelps, 1942).

Another point of great interest is the site in the respiratory tract on which inhaled particles are deposited. Hatch (1942) maintains that infection cannot gain entrance to the deepest part of the tract unless the particles carrying the organism are below a certain minimum size. The larger ones are caught in the nose and upper respiratory tract and are removed by ciliary action; a number of the smaller ones manage to reach the alveoli of the lungs. While droplets can infect the upper respiratory tract, only droplet nuclei, he maintains, can cause pulmonary infection. Dust clouds raised by sweeping have a rapid settling rate, and probably few such particles reach the alveoli. By contrast, the average diameter of dust particles normally suspended (as distinct from those raised) is smaller than a bacterium, and Hatch (1942) thinks the idea of bacteria being attached to such particles is erroneous. It is also important to maintain a proper perspective of the degree of contamination of droplets and dust. Although the total number of organisms of all types is comparable with the number of droplets, specific pathogens are relatively few. As for dust particles, their number is enormously in excess of the number of bacteria. Yaglou and Wilson (1942) counted 1,000,000 dust particles per cu. ft. of air as compared with two bacteria.

FIG. 1.—Paths of infection. (From Harries and Mitman's *Clinical Practice in Infectious Diseases*, 1944.)

dust, and direct discharges may pollute the air. In the case of droplets the infection is transmitted immediately to the infectee; with the others there is not necessarily this proximity in time and space. "Direct infection" or, if you prefer to retain the term, "direct contact" could then be used for transmissions which occur when infector and infectee touch, as in kissing, copulation, contact with discharges or the infected hands of an attendant. "Indirect infection" by mediate means implies the contamination of inanimate objects such as fomites and food (those in rectangles in the diagram) and their conveyance, sometimes at a much later date, to the infectee, who may be a considerable distance away.

Droplets Expelled by Sneezing

To me, one of the most surprising disclosures was the extent to which sneezing adds to the bacterial load of a room. Compared with the gentle bacterial showers which coughing, talking, and laughing bring, sneezing contributes veritable intramural storms. Another unexpected revelation was the origin of the droplets expelled during sneezing: photography makes it clear that they are almost all derived from the mouth, and few or none from the nose. After a sudden inspiration, often with extension of the head, the forcible expiration begins with a quick flexion of the head, a narrowing of the mouth, and the expiration of air at high speed over the secretions of the mouth and pharynx, which are atomized and forced out through the narrowed orifice at a maximum jet velocity

Counts in the open have shown one micro-organism per 100 or more dust particles.

Interchange of Respiratory Flora

In contrast to extramural purity there is abundant evidence of pollution of intramural air by the nasopharyngeal organisms of human occupants (*vide* Harries and Mitman, 1944). The greater the number of occupants the higher the bacterial counts. It has long been recognized that overcrowding promotes infection, but it is not so well known that a fourfold increase in ventilation will reduce the count of an overcrowded room by only 21%, whereas if the occupants are few in number the same air exchange will reduce the count by 65% (Yaglou and Wilson, 1942).

I have for long regarded overcrowded public transport vehicles as the most fruitful venue for the interchange of respiratory flora. The Government's slogan should have been, "Is your *dangerous* journey really necessary?" for the flying droplet is much more lethal than the flying bomb. In a recent Scottish White Paper on the distribution of new houses it was stated that failure to link housing with industry had been the most serious error in general housing distribution policy in the inter-war years. I agree, and when houses of the future are sited near places of work there will be eliminated those expensive, exhausting, time-consuming, and health-destroying journeys which take place in overcrowded transport vehicles. A cinema I regard as much safer; overcrowding is forbidden, not for hygienic reasons but because of fire risk—a rare contingency, but one for which expensive allowance is made, since a single conflagration is so much more apparent than a thousand inflammations. I propose to say little on the other factors which add to the bacterial load of a room. The general cleanliness of a room, the degree and nature of the occupants' activities, and the amount of respiratory infection interest us particularly, for they are responsible for the heavy bacterial load of hospital air.

I would like to say a few words about controlling the rate of additions of organisms to a room. The public have responded well to the Ministry of Health's propaganda for respiratory hygiene. The use of the pocket-handkerchief during coughing and sneezing is more widespread than it has ever been. It is impossible to measure the effect of this one change when so many others are taking place simultaneously, but I believe it has materially influenced the incidence of respiratory disease. I might add that I am not particularly fond of the washable pocket-handkerchief, but I do not see a satisfactory substitute yet. Nor do I like the hospital blanket, and I look forward to the day when blankets are no longer made. Despite the reports of the success of oiling bedclothes and floors, I am not greatly impressed by those results with which I am personally familiar, and the method is not free from drawbacks, because some oils used are dermatitic. So long as this possibility remains I am sure the method will not be widely used. Covers for blankets are a compromise of which I have no experience. I was glad, however, to read an account by Chapple (1942) of an infants' ward with a special air-conditioned annexe for premature infants. In the incubator the infant was allowed to lie naked and uncovered: not only had the blankets gone, but so had all the other bedclothes and the bed linen too. This is an advance. I have always wanted to try it on sick people, but it requires an elaborate air-conditioning system and makes nursing uncomfortable.

Air-conditioning does not ensure the degree of disinfection of the atmosphere which might be expected. Increase in the number of air changes will not necessarily reduce the bacterial count; if air is re-circulated, as it often is to conserve heat, it may even increase it. Both washing and filtration of incoming air will substantially reduce the bacterial count of an empty room, but *not*, be it noted, of an occupied one; and the more occupants the greater the pollution. If the spray water used for washing the air is re-circulated the bacterial load may actually increase; for this reason disinfectants are occasionally used for washing. Ultra-violet radiation in the mixing chambers or in the ducts of air-conditioning plants has also been used, but it has drawbacks, such as absorption of the radiation by the walls and interference with the efficiency of the lamps by dust.

Masks I cannot dwell upon: the subject is too big and was discussed recently by Bourdillon. I favour the more extensive use of masks, but am satisfied that an efficient and comfortable one has not yet been devised.

Germicidal Radiation

The oldest method of eliminating intramural infection of the air is by ordinary ventilation. Wells (1936) laid down standards of what he calls sanitary ventilation and maintains that good ventilation cannot be obtained by ordinary methods because the number of turnovers required (100–500 per hour, according to him) is impossible by ordinary or mechanical means. He therefore introduced irradiation of the upper air with ultra-violet light with the object of destroying as many bacteria as would be removed by good sanitary ventilation. McKhann *et al.* (1938) first tried U.V.R. across a corridor as a barrier to infection between two contiguous rooms. Since then a considerable literature has appeared. The method has been much more extensively used in America than here, where Andrewes (1940) reported adversely upon it because of its ineffectiveness in the presence of dust. Nevertheless, experimental and clinical reports are impressive. Wells (1943) reported a marked fall in the incidence of measles and chicken-pox over periods of 3 to 6 years in three schools with irradiated classrooms. In infants' homes Barenberg *et al.* (1942) and Rosenstern (1942) obtained considerable reductions in respiratory cross-infections, as did del Mundo and McKhann (1941) in an infants' hospital. Hart (1942) investigated the importance of air-borne pathogenic bacteria in the operating theatre. The most rigid, aseptic, surgical technique failed to prevent contamination of some of the clean wounds. With ultra-violet irradiation he was able to secure a considerable reduction in the percentage of such infections and no deaths from wound sepsis over a period of 5½ years. He considered it the simplest and most effective method of eliminating such infections and one which could be used without evident danger to the patient or the properly protected personnel.

There is, of course, no essential difference in the management of aerial infection in operating theatres, surgical wards, or fever hospitals. The practice has appeared in this war of applying fever principles to surgical wards. It was long known from experience that it was undesirable to nurse clean and dirty surgery in the same ward. Now it is known that not only hands but air must be considered. In a busy surgical ward it is almost impossible to suspend all other activities while dressings are being changed, and in my own hospital I have been considering using a separation ward solely for dressings with the object of minimizing aerial infection. I have little doubt that a good deal of the success of the coagulation and Bunyan-bag methods of the treatment of burns and the closed-plaster treatment of wounds is due to exclusion of aerial infection.

Let me return to germicidal radiation and remind you of the position of ultra-violet rays in the electromagnetic spectrum.

Starting with the longest wave-lengths there are first wireless waves whose length is expressed in metres or centimetres; then infra-red rays and visible light measured in microns or thousandths of a millimetre; these are followed by ultra-violet, x- and γ -rays whose wave-lengths are expressed in ten-millionths of a millimetre—i.e., in Angström units (A.U.). The U.V. light band includes wave-lengths from 4,800 A.U. to 2,000 A.U., and the longer waves have different properties from the shorter ones—e.g., maximum pigmentation is produced at 3,850 A.U., whereas maximum germicidal action is obtained at 2,650 A.U. To obtain radiation of these different wave-lengths, different U.V. lamps are required. For germicidal effect a low-voltage, low-vapour-pressure, "cold" mercury-vapour lamp is required, not the type used for ultra-violet therapy. Its main emission band is at 2,537 A.U., which is close enough to the required 2,650 A.U. to be 70% efficient (see Fig. 2). These lamps are simple, slender tubes, resembling the corresponding lighting tubes, and are as easy to change. To give an example of the rating: a common germicidal lamp has a power of 15 watts, an effective length of the burner of 15 in., an overall length in the holder of 18 in., and a tube diameter of 1 in.; the approximate lamp amperage is 0.3 and voltage 56. The temperature of the special glass for transmitting the radiation does not exceed 120° F. Such a tube gives a radiant flux of 25 μ W/cm² at 1 metre and its average life is about 2,500 hours. Irradiation of the upper half of a 4,000 cu. ft. room by one of these lamps is equivalent to 45 air changes per hour in terms of Wells's sanitary ventilation. These lamps, like

all U.V. lamps, deteriorate, and the end of the life of the tube is regarded as having occurred when the output has fallen to 66%. The limitations of U.V.R. must be accepted. U.V. lamps have practically no penetrating power, so that their efficiency is materially lowered in a dusty room. The Council of Physical Therapy of the

FIG. 2.—Main emission band from a germicidal lamp (2,537 Å.U.), shown with the graphs of bactericidal and erythral effects of ultra-violet radiation. (After Buttolph, 1942.)

American Medical Association has accepted such lamps for disinfecting air only in hospitals, nurseries, and operating rooms as an adjunct to other methods of asepsis; for the safety of occupants they have accepted an intensity of $20 \mu\text{W}/\text{cm}^2$ at 1 metre from the lamp as standard.

U.V.R. for aerial disinfection can be used in three ways. By being directed upwards it produces an irradiated ceiling; natural convection currents carry the organisms upwards, where the air is disinfected by the radiation. The radiation may also be directed downwards to form "curtains" around beds and "barriers" across corridors. Lamps which combine the functions of irradiating the ceiling and producing a barrier are known as direct-indirect types in contrast to the simple indirect type directed upwards. Lamps may also be introduced into air-conditioning plant in the way I have already described.

Dynamics of Crowd Infections

Wells *et al.* (1942) attribute their success in preventing school epidemics to an improvement in the sanitary ventilation, bringing it above a critical level and thereby raising the threshold density of susceptibles. This last term was introduced by McKendrick (1940) into his interesting theory of the dynamics of crowd infections. According to him two factors govern epidemic spread—an actual density of susceptibles and a threshold density (see Fig. 3). When the number of

FIG. 3.—Relation of threshold density and density of susceptibles to epidemics. (After McKendrick, 1940.)

susceptibles is above the threshold an epidemic occurs. As the number of cases rises, the density of susceptibles falls. When it equals the threshold value the epidemic is at its peak.

Thereafter, the density of susceptibles having fallen below the threshold, the conditions for epidemic spread no longer obtain and the outbreak exhausts itself when the density is as much below the threshold as it was originally above it. Thus the number of people affected in any outbreak is double the difference between the two densities. It will be clear that an epidemic can exhaust itself long before all the susceptibles are affected, and this agrees with experience. Anything which lowers the density of susceptibles or raises the threshold will either prevent an epidemic or limit its extent. Wells, by improving the sanitary ventilation with U.V.R., diminished the infectivity of the disease and thereby raised its threshold. This conception opens up wide possibilities. If respiratory diseases are indeed intramural events we must, when we rebuild our hospitals after the war, ensure that our architects and engineers incorporate those features which will allow full use to be made of our new knowledge of aerial infection and its control.

Summary

On physical grounds there is no reason why human pathogens should not be carried over great distances and up to considerable heights; but as they have never been recovered from upper air or marine air the inferences are that they do not long survive exposure and that most human respiratory infections take place indoors.

The theory of air-borne infection was practically abandoned for 40 years until Wells described droplet nuclei.

The term "aerial infection" includes all modes of transmission in which the path of the infective agent lies through the air.

Coughing, talking, or laughing contributes gentle bacterial showers to the air, but sneezing causes veritable intramural storms. Of the tens of thousands of droplets expelled from the mouth during a sneeze, about two-thirds remain air-borne. Only droplet nuclei and the finest dust particles are small enough to penetrate to the lungs.

Contamination of air in overcrowded rooms cannot be effectively countered. Overcrowded public transport vehicles are the worst places for the interchange of nasopharyngeal flora; when housing is more closely linked with industry many such journeys will be unnecessary. The Ministry of Health's campaign for respiratory hygiene has already influenced the amount of respiratory disease.

Hospital blankets are an abomination and the results of oiling bedclothes and floors are not impressive.

Air-conditioning does not ensure the degree of disinfection of the atmosphere which might be expected. The use of masks should be extended, but a comfortable and efficient mask has not yet been devised. Trials with germicidal ultra-violet radiation for air purification in children's homes, nurseries, hospital wards, and operating theatres are impressive. The chief limitations of this radiation are its poor penetrating power and its ineffectiveness in the presence of dust.

The new knowledge of the control of aerial infection should be incorporated in post-war rebuilding of hospitals.

REFERENCES

- Andrewes, C. H. (1940). *Lancet*, **2**, 770.
 Armstrong (1936). Quoted by ZoBell.
 Barenberg, L. H., *et al.* (1942). *Aerobiology* (A Symposium), Washington, D.C., Amer. Ass. for Advancement of Sci., p. 233.
 Bourdillon, R. B., and Lidwell, O. M. (1941). *Lancet*, **2**, 365.
 Buttolph, L. J. (1942). *Aerobiology* (A Symposium), Washington, D.C., Amer. Ass. for Advancement of Sci., p. 171.
 Chapple, C. C. (1942). *Ibid.*, p. 251.
 Cruickshank, R. (1940). *Lancet*, **2**, 54.
 del Mundo, F., and McKhann, C. F. (1941). *Amer. J. Dis. Child.*, **61**, 213.
 Flüge, C. (1897). *Z. Hyg. InfektKr.*, **25**, 179.
 — (1899). *Ibid.*, **30**, 107.
 — (1921). *Z. Tuberk.*, **34**, 212.
 Harries, D. H. R., and Mitman, M. (1944). *Clinical Practice in Infectious Diseases*, 2nd ed., Edin., p. 522.
 Hart, D. (1942). *Aerobiology* (A Symposium), Washington, D.C., Amer. Ass. for Advancement of Sci., p. 186.
 Hatch, T. F. (1942). *Ibid.*, p. 102.
 Jacob (1940). Quoted by ZoBell.
 Jenson, M. W. (1941). *Sci. Mon.*, N.Y., **52**, 24.
 — (1942). *Aerobiology* (A Symposium), Washington, D.C., Amer. Ass. for Advancement of Sci., p. 106.
 McKendrick, A. G. (1940). *Edin. med. J.*, **47**, 117.
 McKhann, C. F., Steeger, A., and Lang, A. P. (1938). *Amer. J. Dis. Child.*, **55**, 579.
 Phelps, E. B. (1942). *Aerobiology* (A Symposium), Washington, D.C., Amer. Ass. for Advancement of Sci., p. 133.
 Renschler (1940). Quoted by ZoBell.
 Rosenstern, I. (1942). *Aerobiology* (A Symposium), Washington, D.C., Amer. Ass. for Advancement of Sci., p. 242.
 Stakman, E. C. (1942). *Ibid.*, p. 1.
 Wells, W. F. (1934). *Amer. J. Hyg.*, **20**, 611.
 — (1943). *Amer. J. publ. Hlth.*, **33**, 1387.
 — and Wells, M. W. (1936). *J. Amer. med. Ass.*, **107**, 1698, 1805.
 — and Wilder, T. S. (1942). *Aerobiology* (A Symposium), Washington, D.C., Amer. Ass. for Advancement of Sci., p. 206.
 Wright (1940). Quoted by ZoBell.
 Yaglou, C. P., and Wilson, W. (1942). *Aerobiology* (A Symposium), Washington, D.C., Amer. Ass. for Advancement of Sci., p. 129.
 ZoBell, E. (1942). *Ibid.*, p. 55.