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Recent progress in control of air-borne infections

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INTRODUCTION

In confined spaces occupied by persons breathing and rebreathing a common air supply, there exists a potential hazard of respiratory infection from air-borne pathogenic bacteria and viruses. The hazard arises from the fact that the environment may become contaminated with micro-organisms from infected persons. Some of these organisms may gain access to the respiratory tract of susceptible individuals, giving rise to new infections.

Bacteria and viruses of human origin occur in the air in droplets, droplet nuclei, and in dusts. Droplets originate from secretions of the nose, throat, and mouth. When they are expelled during talking, coughing, spitting, and sneezing, the larger droplets quickly settle out of the air and desiccate on nearby surfaces. The smaller droplets lose their moisture by evaporation, and the dried residues, called droplet nuclei, float in the air and drift about with its currents. Dust in the air or on surfaces may receive contamination from droplets and droplet nuclei, or from infected materials such as clothing and bedding. The bacteria and virus content of the air in these enclosed spaces is constantly being replenished from its occupants

and from dust that is stirred up by activities of the occupants and by air currents.

The objective of air sanitation is the reduction, removal, or inactivation of pathogenic organisms. At the present time there are four methods of accomplishing this objective: (1) Ventilation, controlled air currents, and mechanical barriers, (2) Suppression of dust, (3) Inactivation of bacteria and viruses in air by ultraviolet irradiation, and (4) Inactivation of bacteria and viruses by germicidal mists or vapors.

The effectiveness of these methods, however, can only be measured indirectly because of technical limitations. Two methods of measurement are available: (1) sampling the air for pathogenic micro-organisms and (2) clinical evidence of spread of infection occuring in a group of persons or animals living in a confined space in which some method of air sanitation is being used compared with a control group living in a similar untreated space. The second method is both elaborate and time consuming. It requires the knowledge and skill of engineers, physicists, bacteriologists, clinicians and epidemiologists.

Progress has been slow, chiefly due to the unwieldy means of measuring the effect of the various

methods of air sanitation; even so, much has been learned and the importance of the field has become clearly established.

EARLY HISTORY

In order to more fully understand the present methods of controlling physical environment, it is necessary, at this point, to briefly recall some of the theories that have governed their use in the past.

Four hundred years before Christ, Hippocrates wrote in his book, "On Winds", (1): "According to all appearances the cause of disease should be found in the air, when it enters the body in excess or in insufficient quantity or too much at a time, or when tainted by morbid maismas."

Since these early times air always has been assigned an important part as the cause of disease. Hippocrates described four elements as the cause of disease--fire, air, water and earth. Galen, 600 years later, taught the same doctrine, (2).

During the middle ages the teachings of Galen prevailed, and the scientific world was principally occupied with philosophical debates. Not until the writings of Fracastorius, (2), who described and named the Great Pox in his poem, "Syphilis sive Morbus Gallicus", do we find further contribution to ideas of air and disease. He divided contagious

diseases into three categories: (a) those that infect only by contact, (b) those that infect by contact and by fomites, and (c) those that infect not only by direct contact or through the agency of a residuary center or focus of infection, but also those that are capable of spreading their infective elements over wide areas. He also anticipated the germ theory by nearly 400 years when he stated his belief that contagious diseases were caused by "seminaria contagionum" or seeds of contagion, which were capable of reproduction and probably carried in the air.

It is at about this time that we find two great influences affecting scientific thought. First, the fetters of ancient tradition were being thrown off and the experimental method was being recognized. Harvey discovered the circulation of the blood. Many other great names of that period have been carried down to posterity because of their careful experimental observation--Malphigi, Fallopius, Extachius, Pacchioni, Wharton and many others. The second great influence upon scientific advancement was the development of the microscope. The first microscopist was Athanasius, who in 1658 published his "Scrutinum Pestis" which put forth the ideas of "contagia animata", or animals of contagion, (2). This was a step ahead of Fracastorius' theory of seeds of contagion.

Leeuwenhoek, (3), who first described micro-organisms in material scraped from his own teeth, demonstrated the presence of microscopic organisms in water that had been exposed to the air.

Pasteur, (4), reported his historical experiments in 1862 in which he had collected and studied floating "organized particles" from the air.

Lister, (5), being convinced by Pasteur's experiments, developed antiseptic surgery as it was first known. As disease particles were borne in the air and as the selfsame particles were found in pus from wounds, it seemed logical to believe that the pus or putrefaction was produced by organisms in the air that fell into the wound. He devised an elaborate operating room technique which provided for saturation of the air about the zone of the operating field with a finely divided carbolized vapor. Lister met with great opposition from his colleagues, not on the grounds that infection was or was not air-borne, but rather because his fellow surgeons did not believe that septic conditions were due to living, growing micro-organisms.

Lister also thought that these pathogenic bacteria came from putrefaction of the dead, and believed that emanations from these bodies were responsible for the spread of infection through the air.

Following the discoveries of Pasteur that bacteria actually lived in the air and also that bacteria caused disease, many scientists jumped to the conclusion that all living bacteria might be harmful to mankind and that all might be air-borne. What reasoning could be more logical than the hypothesis that all or most all diseases were spread through the medium of the air? Air-borne infections were shown to be quite a common occurence in other fields. It was easy to demonstrate that cheeses, wines, milk, meats, meat products and the like were infected by bacteria that travelled through the air. It had long been suspected that many plant diseases were transmitted through air-borne channels, and it seemed very likely that animal and human diseases were transmitted through this same vehicle.

An elaborate system was developed for sterilization of the environment of an individual who had suffered from infectious diseases. Various gaseous disinfectants were employed. Formaldehyde fumigation became the standard technique. The purpose of gaseous fumigation was not solely to disinfect the linen and bedding of the patient, but rather to kill any organisms that might remain in the atmosphere atmosphere after the patient had died or after he had been discharged from isolation.

Many instances were reported of infections, particularly smallpox, malaria and yellow fever, that had been carried long distances through the air. The conception of the role of the "carrier" in the spread of infection had not been developed; and it seemed the only possible source of numerous outbreaks of infections must be a transmission of the living agent through the medium of the air.

As knowledge of modes of infection increased, however, the former long list of air-borne diseases decreased correspondingly. The studies of Snow, (6), and Budd, (7), on the role of water in transmission of typhoid fever gave strong epidemiological proof that the most important vehicle of infection in this group of diseases is polluted water. This work was done long before the specific infectious agents of these conditions were discovered. To this early work was added the transmission factor of contaminated food as a source of gastro-intestinal infection. Much later, the importance of the "carrier" as a source of food and water contamination was determined. With the accumulation of further bacteriological and epidemiological evidence it was proven that food and drink are the chief sources of gastro-intestinal infections.

The concept of Smith that insects might serve as intermediate hosts in transmission of infection, (8), opened an entirely new field in epidemiology. Diseases, the transmission of which could not possibly be explained on any other basis than through the medium of the air, now were clearly explainable on other grounds. Malaria and Yellow fever are the foremost examples of what was once believed to be typical air-borne infections that were later proven to be mosquitoe-borne. One by one many of the diseases of man, of animals, and of plants as well that were formerly considered as typical air-borne infections were discovered to be transmitted through the medium of insects, or some other intermediate host.

The one remaining disease category that appeared to receive consideration as being air-borne was those spread through discharges of the respiratory tract. Included in this group were all the common communicable diseases of childhood, such as measles, scarlet fever, diphtheria, etc., as well as influenza, pneumonia, tuberculosis, cerebro-spinal meningitis, poliomyelitis, and the common cold. It is quite clear that, in a limited sense at least, these infections are always air-borne. The only question is the length of the radius that these infections will spread through

the air from the infected host. For many years it was believed that the infection radius was extensive and elaborate isolation and quarantine regulations were established to prevent the spread of infection from the patient to others through the air. Contagious hospitals were far removed from general hospitals, in fact, from all human habitation, because of the supposed danger of air-borne infection.

The work of Flugge, (9, 10), called attention to the fact that droplets of saliva are thrown off from the mouth during sneezing, coughing and loud talking, and appently demonstrated, through exposing culture plates at various distances from the subject, that these droplets quickly settled. He concluded that true air-borne infection other than within a few feet of the "infector" was unimportant.

In 1912, Chapin, (11), made a thorough review of the literature up to that time (some 208 articles) and his conclusions, based largely on the work of Flugge was that air-borne infection beyond the range of 3 feet was probably non-existant.

For the next quarter of a century following Chapin's studies, most authorities agreed that the radius of infection from the host is dependent only on (a) the distance that droplets of moisture from coughing

and sneezing will spread, and (b) the length of time that the infectious agent will live in the droplet after it has been expelled from the human host. Since the droplets fall to the ground almost immediately, the air itself was believed to play no part in transmission of infection.

The reversal of the conception of air-borne infection started in 1933, when there appeared the first of a series of articles by W. F. Wells of the Harvard School of Public Health, describing an air centrifuge he had devised permitting quantitative determination of bacteria in air with reproducible results under the same conditions. He concluded: "In the study of the bacterial sources of aerial contamination, experiments have been made to determine under what conditions bacteria are given off by persons confined in a limited space. This inquiry leads also to an investigation of the physical, chemical, and biological properties of droplets in connection with the theory of droplet infection." (12)

In 1934, Wells published two papers entitled "Droplets and Droplet Nuclei", (13), and "Viability of Droplet Nuclei Infection", (14). In the first paper he points out that although it is true that larger droplets ejected at the height of two meters, or,

roughly the height of a man, will fall to earth within a few feet of the source, smaller droplets evaporate so rapidly that they will evaporate before they will settle to the ground, leaving in the air, in a state of suspension, the bacteria or other particulate matter contained in the droplets. These so-designated "droplet nuclei" remain suspended indefinitely and are readily wafted by air currents. He finds that "somewhere between .1 and .2mm (diameter) lies the droplet size which identifies the droplets that evaporate and remain in the air as droplet nuclei with attached infection." Although temperature and humidity, and the presence of dissolved substances affect the rate of evaporation to a certain extent, droplet size is the predominating factor. To demonstrate the actual occurrence of such droplet nuclei, he adopted Tyndall's experiments, (15), on atmospheric dust by constructing a tight cylindrical tank 7 feet long, and of the same diameter along the axis of which was projected a powerful beam of light. Ports along the side of the tank gave a perpendicular site on the beam, revealing any suspended particles entering its path. When pure water was atomized into this beam it appeared like steam in cold air, which subsided completely when the spray ceased, with the light beam then completely invisible. When an atomized suspension of Bacillus subtilis was injected, a delicate

pale blue smoke band remained in the path of the beam. Even after this disappeared and the beam became invisible, Wells was able to collect living bacteria from the air by attaching his air centrifuge to the tank and, in fact, was able to recover bacteria from the interior of the tank a week after inoculation. From this Wells concluded that droplet infection is essentially localized and concentrated while infection broadcast by droplet nuclei is dispersed and dilute. Thus, it readily escapes detection by the instruments previously devised for atmospheric exploration.

In his second paper Well, (14), reports of testing in the same chamber atomized suspensions of pathogenic bacteria which are more delicate than B. subtilis. He found that he could recover pneumococci, streptococci, and diphtheria bacilli 24 hours after the original atomization, and concluded that the time and distance droplet nuclei may travel depend more upon the viability of the organisms in air than upon settling rates.

These experiments, then, clearly indicated that exposure of open plates, which was the bacteriologic procedure employed by early investigators and which led to the conclusion that viable organisms were expelled only a few feet by human beings, was an

unreliable method of determining the infectiousness of air since small particles do not settle and thus would not be registered on the plates; the plates catch only the larger droplets which fall to the ground close to the subject.

The next step was actual demonstration of infection in animals in such a manner that the micro-organisms or viruses definitely were carried by the air stream, with elimination of the possibility of direct droplet infection. These experiments, conducted by Wells and others, (16 - 23), involved successful transmissions of influenza to ferrets and mice, tuberculosis to rabbits, and poliomyelitis to monkeys.

With the development of these experimental techniques it was possible to experiment with agents which might prevent such air-borne transmission. Such experimentation has extended principally in four directions: (1) ventilation and physical barriers; i.e. cubicle and room partitions, (2) laying of dust and lint through application of oil to floors and bedding, (3) disinfection of air through ultra-violet radiation, and (4) disinfection of air through the use of disinfectant vapors.

VENTILATION

Simple ventilation by means of open windows has been a common hygienic practice for many years. Its use has been traditional in military barracks where it has been notable for its unpopularity among troops and the difficulty of its consistent enforcement, (24). British workers have recently reemphasized the desirability of open window ventilation in contagious disease wards, (25). Although it is probable that such measures may have considerable effect in reducing the bacterial contamination of the air, they are obviously expedients of limited value which are subject to variable climatic conditions and which may cause much discomfort.

While it is generally assumed that a sure way of reducing bacterial pollution of air in occupied rooms is by dilution with clean outside air, recent studies do not entirely confirm this view, (26). It was found that a large supply of outside air may fail to reduce the pollution and at times actually increased it by stirring up infected dust particles off the floor. The same study further revealed that the purification of air through washing, filtration, and forced ventilation is a relatively inefficient method of reducing the bacterial content of air in occupied spaces.

Under certain specialized conditions, the control of air currents and air conditioning either alone or in conjunction with physical barriers has been applied to the control of cross-infections in surgical dressing rooms, (27), in pediatric and premature infant wards, (28), and in animal colonies and laboratories of research institutions, (33, 34).

In 1940, McKendrick, (35), introduced the theory that the rate of spread of air-borne disease is a function of atmospheric density of susceptible occupants. A threshold density above or below which the number of new cases in each succeeding time interval will be respectively greater or less determines whether an epidemic waxes or wanes. Lowering susceptible density by immunization or raising threshold density by sanitary ventilation diminishes the rate of spread of contagon.

Based on this theory, Wells, (36), has postulated that the dramatic fall in upper respiratory infections in early summer is due summer ventilation which greatly dilutes enclosed atmospheric contamination. He believes that equivalent ventilation would be just as effective in the winter time; however this would require dilution of air 5 to 10 times as great as that in normal winter ventilation, (37). The economic

factors involved in such a procedure would increase the cost of heating far beyond the reach of institutions and home owners.

Nevertheless, a careful consideration of temperature, relative humidity, air currents, and rates of introduction of outside or recirculated air is fundamental to the effective application of the other more efficient means of air disinfection, (24).

DUST AND ITS CONTROL AS A MEANS OF DISINFECTION OF AIR

The bacterial content of dust found in homes, schools, factories, offices, and hospitals varies with the different environments. Saprophytic organisms usually predominate, but parasitic and pathogenic agents may be found in large numbers. Both healthy, (38, 39), and ill, (40), individuals more or less continually extrude bacteria into their environments in secretions and excretions. While dust in the outside atmosphere may not be dangerous, that which is found in intramural environments inhabited by human beings should always be considered a potential source of disease, (41).

Dust as a vehicle for the spread of disease agents has been studied particularly in relation to respiratory tract infections, skin infections, and secondary infections of burns and wounds. Large numbers of hemolytic streptococci, (42), staphylococci, (43), pneumococci, (44), diphtheria bacilli, (45), and tubercle bacilli, (46), have been demonstrated in the floor dust in hospital wards. These organisms have been shown to survive in the environment for long periods of time. Little is known concerning the survival of viruses in dust. Influenza A virus, however,

has been shown to survive in floor dust up to ten days without loss of its ability to produce infection in susceptible animals, (47). The great proportions of organisms expelled from the respiratory tract in droplets and droplet nuclei eventually settle to form a part of the bacterial component of dust. The relative importance in the spread of disease of droplets and droplet nuclei initially extruded in the air and those raised again as dust is not known. All three modes of spread probably occur, but vary in importance with different age groups of people, diseases, environments, and seasons of the year, (48).

Dust, which may carry pathogenic agents, is raised into the air by sweeping, bedmaking, and other activities, and eventually settles on all surfaces in enclosed spaces. Thus, the opportunities for spread of infection by direct or indirect contact with these "environmental reservoirs" are many. For example, in hospital wards streptococci disseminated through the air as dust-borne particles settle out on the furniture, food, toys, skin, hands, and clothes of the patients and hospital personnel, and again on the floor and bed surfaces, (41). Respiratory tract infections may be acquired from the inhalation of these dust-borne organisms, or by direct transfer from a dusty surface

to the nose and mouth by the hands, instruments, etc. In other situations they may settle onto exposed clean wounds and burns or be transferred to them directly from dusty surfaces by the hands, dressings and instruments, resulting in secondary infections, (41, 49, 50).

There is now ample data to show that dust is an important vehicle for the spread of certain diseases of bacterial and virus etiology in the laboratory, (51, 52), hospital wards, (50; 53, 54, 55), and army barracks, (49). It most likely plays an equally important role in the spread of infections in schools and homes. Ultra-violet light and germicidal vapors, which will be discussed later, have only a limited effectiveness against dried dust-borne organisms. Therefore the use of dust and lint control measures alone or in conjunction with these techniques is of importance.

Extensive studies by English, (56-58), and American investigators, (59-61), have shown that oil is the most highly effective and economical compound for the treatment of surfaces and fabrics for the suppression of dust and lint.

Techniques of Oiling Floors

Most oil companies make a special grade of floor oil which meets government specifications

concerning fire hazards and which is also suitable for use on floors for dust-control purposes, (62). The application of oil to floors in army barracks is a simple procedure and can be applied with unskilled help. The floors in army barracks are usually constructed of soft wood, which absorbs large amounts of oil--approximately one gallon per 200 sq. ft., (63, 64). The oil may be applied with a cloth mop, a rubber squeegee, or brushed on with a hair broom. Such floors maintain their dust-holding properties for as long as 8 months, provided they are cleaned only with hot water without soap or alkali, (63).

The oiling of hardwood, varnished or linoleum-covered floors requires more care. Just sufficient oil (one gallon per 1,000 sq. ft.) should be employed to leave a dust-holding surface but one which is not slippery and hazardous to the room occupants, (56). Such thinly coated floors, of course, will require repeated applications of oil to maintain their dust-holding efficiency. Oil may be applied to floors directly with a cloth, mop, or in the form of a sweeping compound (2 gallons of oil mixed with 100 pounds of sawdust, (59). The only disadvantage to the latter method is that it is difficult to remove all the sawdust from around the legs of desks, tables, beds, and corners of the room.

In one hospital, oil was successfully applied to linoleum-covered floors in a ward by daily mopping with 10 percent oil-in-water emulsion (T-13 formula), (61), and in another hospital study a non-oil, dust retaining compound composed of urea, ninol. and roccal was successfully employed by daily application to the floors, (65). Oiled floors should be cleaned only with warm water, without the use of soap and alkali.

Application of Oil to Bed Clothes

Data on oil-in-water emulsions for the application of oil to bed clothes and other fabrics were published in May 1944 by English workers, (66), and in December 1944 by the commission on Air-borne Infections, (59). With the employment of skilled help, both formulae were found to be satisfactory for the treatment of cotton and woolen textiles with oil. Further experience with these oil-in-water emulsions revealed certain definite disadvantages. The bed clothes treated by the English formula were found to be irritating to the bed occupants, while the woolen blankets treated with the Commission formula developed a rancid odor due to the oxidation of oleic acid, a constituent of the emulsion base, (60).

Further study of the application of oil to fabrics by the Commission on Air-borne Infections,

(60, 61), resulted in the development of an oil-in-water emulsion known as the "T-13 formula" which contains the following:

Materials	Parts by weight
Mineral oil (Fractol A)	87
Triton NE	13

T-13 oil-emulsion base is milk-white and has the consistency of face cream. When added to water it disperses spontaneously, producing stable oil-in-water emulsions of almost any desired concentration. This formula meets all the requirements of an ideal oil-in-water emulsion for the treatment of cotton and woolen textiles. T-13 oil-emulsion base can be prepared in large amounts and is stable in closed drums for long periods of time (18 months) under varying degrees of temperature. The T-13 oil-emulsion base is applied in the form of dilute emulsions as the final rinse during the routine laundry procedure without alteration in any of the steps in washing and drying of the textiles. The cost of treatment of textiles with the T-13 oil-emulsion base is not prohibitive, being approximately 1½ cents per lb. of woolens and 2/3 cent for cotton fabrics for the initial treatment, and for subsequent treatment 1/10 and 1/3 cent respectively. There is

evidence that woolen blankets may not require a subsequent treatment, as little or no oil is removed by washing with soaps and alkalis. The oil, however, is readily removed by the dry cleaning process, (61).

Cotton and woolen fabrics treated with the T-13 oil-emulsion base and containing from 2 to 5 per cent oil by weight are essentially indistinguishable from untreated material in appearance, texture, touch, and odor. Over 200 skin tests with the T-13 oil-emulsion base and extensive use of oiled blankets and sheets treated with this formula by a large number of army personnel over a long period of time have shown that it does not produce skin irritation. Treated blankets containing from 2 to 5 per cent oil by weight possess marked bacteria-holding properties for several months without retreatment. Periodic sampling of oiled and unoiled blankets in army barracks for hemolytic streptococci revealed 75 per cent less positive cultures and 95 per cent fewer organisms per culture from the oiled blankets than were obtained from the controls, (60, 63).

Effect of Oiling Floors and Bed Clothes on the Bacterial Content of the Air in Barracks and Hospital Wards

In army barracks during the periods of maximum activity when the men were getting up, dressing, sweeping, making beds, etc., oiling floors alone reduced by approximately 70 per cent the number of airborne bacteria compared to the number recovered from the air in the control barracks, (59, 63). Even though the total bacterial count in the air is greatly reduced in barracks by oiling floors alone, large numbers of hemolytic streptococci may be dispersed into the air from the unoiled bedding, (63). Oiled bedding plus oiled floors effected a further reduction to about 90 per cent of the bacterial counts in the control barrack. There was a similar percentage reduction in the numbers of hemolytic streptococci in the air of the test compared to the air in the control barracks, (63). In an army hospital ward, oiled floors and bedding reduced the numbers of beta-hemolytic streptococci by 86 per cent compared to the numbers obtained during periods when the dust suppressive measures were not employed, (65). In a study on the control of streptococcal infection on a measles ward, oiling floors alone was not sufficient to prevent large numbers of type specific streptococci from spreading about the wards. Oiling of floors, bed clothes, garments, and other articles

used on the test ward, however, effected a 90 per cent reduction in the bacterial counts in the air compared to the control ward, (67).

Similar studies were done by the commission on Air-borne Infections at Camp Carson, Colorado, from March to June, 1944, (64). Oiled floors alone as well as oiled floors and oiled bed clothes were tested. Group A, comprising approximately 3,800 men in each of the test and control units, was used to observe the effect of oiled floors alone in the incidence of respiratory disease in men living in barracks. The weekly hospital admission rate per 1000 was 4.0 for the test unit, and 5.9 for the control unit. These rates were too low to evaluate the use of oiled floors alone as a means of controlling respiratory disease. Groups B and C were employed to evaluate the use of oiled floors plus oiled bedding. In Group B there were approximately 1,600 men each in the test and control units, and the average weekly admission rate per 1000 for respiratory disease was 6.2 and 11.5 respectively. Group C was an organization composed essentially of new recruits with approximately 350 men each in the test and control units. The average weekly admission rate per 1000 for respiratory disease was 13.3 from the test, and

28 from the control unit. In Groups B and C, approximately 50 per cent of the hospital admissions for respiratory disease from the test and control units had throats positive for hemolytic streptococci. The number of cases and the difference in rates of admissions from the oiled barracks compared to the control were sufficiently great to conclude that oiled floors and bedding effected a significant reduction in the number of admissions for respiratory disease, (64).

A more detailed study on the control of respiratory disease in new recruits, employing oil to floors and bedclothes, was carried out jointly by the Commission on Acute Respiratory Diseases and the Commission on Air-borne Infections at Fort Bragg, North Carolina, from October 1944 to May 1945, (48).

During the first period of low endemic occurrence of respiratory disease there was suggestive evidence that the procedure reduced the incidence of hospitalized illness. There was little or no effect during the epidemic occurrence on acute undifferentiated respiratory disease. Hemolytic streptococcal infections and respiratory diseases of known etiology did not occur with sufficient frequency for the effect of the oiling procedures to be evaluated.

The difference in the results obtained at Camp Carson compared to those at Fort Bragg may have been due to the high incidence of streptococcal disease at the former camp, (48).

Only one hospital study has been reported which has attempted to evaluate the use of dust-suppressive measures for the control of streptococcal infections. This was carried out by the English, (67), on measles wards during the fall and winter of 1943. A preliminary 3 week period of employing oiled floors alone showed no reduction in the incidence of cross-infections on the test compared to the control ward. During the following 9 weeks, however, when dust-suppressive measures were applied to the floors, bed-clothes, garments and all other cotton and woolen fabrics, a marked reduction in streptococcal infections on the test ward occured. Group A type 6 streptococci were employed as the index of contamination of the wards and of cross-infections. During the 9 week period of study the cross-infection rate was 18.9 per cent on the test ward, and 73.3 per cent on the control, while the complication rate was only 2.8 per cent on the test ward, compared to 14.3 per cent on the control, (67).

Discussion

Oiling floors, bed clothes, and other textiles is a highly effective procedure for the control of dust, lint, and dust-borne bacteria. The action of the oil is a mechanical one only. Methods are now available for the treatment of surfaces and fabrics with oil which fall within the range of practicability with respect to simplicity of application and cost. Although the most important "environmental reservoirs" of pathogens found in hospital wards are the floors and bed clothes, all surfaces (floors, tables, desk tops, etc.), as well as all textiles (blankets, sheets, pajamas, clothes of attending nurses, doctors, etc.), should be oiled to bring about the maximum in dust control. The rational use of these measures will depend upon what proportion of infections is dust-borne.

ULTRAVIOLET IRRADIATION

The bactericidal property of sunlight has long been known, (68, 69). However, it is only in the past 25 years that quantitative studies on the effects of monochromatic ultraviolet radiation have been conducted systematically, (70). The early investigators used only the sun as their light source, and it was not until considerably later that artificial sources were used. Investigations at first were carried out with the entire radiation coming from the source; later crude filters such as Petri dish covers or window glass were used. Finally, carefully selected filters which isolated fairly narrow regions of the spectrum were employed. It was only after monochromatic radiation was used that the most effective regions of the spectrum were isolated. The wave length found to be most effective for bacteria is 2650 A., (71-74).

Mode of Action

Very little is known about the fundamental mechanism of the function on radiation on living cells. Bacteria show a maximum of sensitivity to ultraviolet radiation at 2650 A., (74), and this is

very close to the wave length which is most highly absorbed by nucleic acids.

Ultraviolet photographs taken with monochromatic radiation show clearly that 2600 A radiation is most highly absorbed by the nucleus and the chromatin material immediately surrounding the nucleus, (75). It seems reasonable to believe that ultraviolet radiation around 2600 A functions through the nucleic acid constituent of the cell.

In an attempt to obtain more intimate information about the mechanism of action of ultraviolet radiation in living cells, Hollaender investigated the effect of 2537 A on nucleic acid, (74). By irradiating water solutions of sodium thymonucleate he found he could depolymerize this substance without changing its chemical constitution, and believes that there is a similar reaction within the bacterial cell in response to radiation.

Limiting Factors in the Use of Ultraviolet Radiation

Direct irradiation of sufficient intensity to kill micro-organisms in air is also harmful to the eyes and exposed skin of human beings, particularly to conjunctivae which lack the protection offered by horny cells, (76). Exposure for less than

a minute may produce painful conjunctivitis after a latent period of several hours. However, no permanent eye injury has yet been reported in the literature of air disinfection. Much like sunburn, direct radiation on the skin may cause severe erythema and blisters after a latent period of a few hours, (77).

It is therefore necessary to irradiate the ceiling and upper air well above head levels. Lamps must be equipped with baffles that will confine the powerful rays to a region well above or below the normal line of vision. Control of air quality in the breathing zone is then effected by natural or forced circulation which displaces or dilutes circulation which displaces or dilutes contaminated air with irradiated upper air or lower layers, (78). It should be kept in mind that some walls, ceilings, and floors will reflect injurious radiations. Ultraviolet light meters are now available for measuring intensities down to the limits of human tolerance, (79).

The Council of Physical Therapy of the American Medical Association has tentatively recommended that the total ultraviolet intensity of wave length 2537 A (including reflection from ceilings, walls, and fixtures in addition to direct emanation

from lamps) falling on occupants be not more than 0.5 micro-watt per sq. cm. for exposures of 7 hours or less, and not more than 0.1 micro-watt per sq. cm. for exposures of 24 hours a day, (80, 81). Responsibility for protecting occupants in irradiated spaces falls largely on lamp manufacturers and installers, who should measure the energy distribution and output efficiency of their fixtures as installed. Periodic testing of energy output and cleaning of fixtures is essential if functional efficiency of installation is to be maintained.

Ultraviolet lamps used for air disinfection may produce ozone in objectionable concentrations, particularly when they are new. If the odor becomes distinctly perceptible the Council recommends increased ventilation.

The effectiveness of ultraviolet irradiation decreases rapidly with increasing relative humidities above 55 to 60 per cent, (82-82). The rays are more efficient against small particles, such as droplet nuclei, than large particles, such as dust and lint, in which micro-organisms may have a protective coating impermeable to the bactericidal rays, (85).

Clinical Application of Ultraviolet Irradiation

Wells and Fair, (86), were the first to apply ultraviolet irradiation to the disinfection of air. Since then many important contributions to the literature have been made. Irradiation has been undertaken in operating rooms, in pediatric and contagious disease wards, in schools, in military barracks, and in children's institutions. The most impressive results have been reported from operating rooms, (87, 88). The residual contamination of the air which remains even after the most rigid aseptic precautions can be greatly reduced by intensive irradiation. Reports indicate substantial reductions in the incidence of secondary infections of originally clean operative wounds. To achieve such results, with early installations it appeared to be necessary to take extreme precautions to protect the operating personnel, but improved designs have made such precautions unnecessary, (88).

Ultraviolet irradiation of the upper air and the use of light screens in front of cubicles and in entry ways to pediatric and contagious disease wards have been employed in a number of institutions. Rather dramatic results have been reported by a number of workers in carefully controlled experiments, (28, 32, 89). Negative results have been reported

by others, (90-92). It is difficult to evaluate these because of (1) inadequate information regarding the efficiency of the installations, (2) the lack of a sufficient number of controlled observations, and (3) the problem of distinguishing which infections were air-borne and which may have resulted from contact.

Irradiation of the upper air of school rooms in Swarthmore and Germantown, Pennsylvania, has been carried out continuously since 1937, (93-95). During the early part of this period, two epidemics of measles were apparently prevented among children in the primary grades whose rooms were irradiated, although large epidemics occurred among the less susceptible children in the secondary grades whose rooms were not irradiated. Beneficial effects in the reduction of the incidence of chicken pox have also been reported, although the procedure was less successful in controlling an epidemic of mumps which occurred in the early fall of 1941 when relative humidities were high. However these studies failed to show a decrease in the common cold rate where spread among the adults in the community plays so large a part in transmitting the disease to children as to swamp any beneficial result of schoolroom irradiation alone.

Irradiation of the upper air, of the corridors, and of the floors of the naval barracks at Camp Sampson, New York, was investigated during the winter of 1943-44, (96).

A self-contained unit comprising 22 two-story barracks was divided into four groups of approximately 1,250 men each. One group was subjected to radiation of high intensity, 234 watts of ultraviolet energy per dormitory of 112 men; and a second to low intensity, 121 watts per dormitory. Third and fourth groups served as controls. In addition to overhead lights, an ultraviolet lamp was installed under alternate bunks to irradiate the lower air and floor dusts. With a training period of 4 to 6 weeks, 15,000 men were observed in the two test groups and 15,000 in the control group between December 1943 and June 1944.

During this time, hospital admissions for respiratory infections were 25 per cent lower in the group of men exposed to high radiation intensity than in the control group. During the first 2½ months of the study, when illness rates were high, the difference in admissions averaged 35 per cent. On the other hand, there was no significant difference in hospital admissions from the low intensity group and its control.

One study of ultraviolet irradiation has been conducted in the restricted population of an institution for delinquent adolescents in Washington, D. C., (97). No reduction in the incidence of respiratory disease was demonstrable over a period of two years, but the total incidence rates were generally so low that a measurable effect could hardly have been anticipated.

Ultraviolet Irradiation Supplemented with Dust Control Measures

These experiements, (98), were also carried out at Camp Sampson using 22 barracks which housed a maximum of 5,280 men. Floors, blankets, mattress covers, and pillow slips in 15 barracks were treated with emulsified mineral oil. Seven of the "oiled" barracks were equipped with high-intensity irradiation, using ceiling, underbunk, and center-aisle lamps. The remaining 7 barracks served as untreated controls. Each control barrack was sandwiched between an oiled barrack and one which was treated with both oil and ultraviolet light.

Bacterial counts were 75 per cent lower in oiled than in unoiled barracks. Alpha and Beta hemolytic streptococci were greatly reduced in number

by oiling, and were practically eliminated from the air by combined action of oiling and irradiation. Most of the organisms were concentrated near the floor and decreased in numbers toward the ceiling.

In comparison with untreated control barracks, hospital admissions for upper respiratory infections from barracks in which ultraviolet irradiation was supplemented with oiling of floors and bed clothes were reduced about 25 per cent. Oiled barracks without irradiation showed a reduction of about 10 per cent.

GLYCOL VAPORS

The subject of air sterilization by means of germicidal mists and vapors is one which has been studied from time to time since Lister's original use of phenol sprays in rooms. Most of the bacterial agents which have been used for this purpose are toxic or irritating to the respiratory mucosa and hence are unsuitable for the sterilization of air breathed by human beings. During the influenza pandemic of 1918, Masterman, (99), found that spraying the air with dilute solutions of hypochlorites reduced the number of infected particles in the air and apparently lowered the incidence of influenza in crowded cotton mills, but his work apparently attracted little attention. The first indication of a renewed interest in this field was a paper by Douglas, Hill and Smith in 1928, (100), who were able to effect a marked dimunution or complete disappearance of colon bacilli suspended in air, by means of a very fine spray of electrolyzed sea-water, containing NaOCl and about one per cent available chlorine. The material appeared to be non-irritating in the amounts used, which were approximately one gram of the chemical solution in 2,000,000 cc. of air. This paper

also attracted little attention, and it was not until ten years later that the active development of the subject began.

In 1938 two publications appeared, one by Trillat, (101), on the properties of germicidal aerosols, and the other by Masterman, (99), on air sterilization by spraying or atomizing hypochlorite solutions. Trillat's earlier investigation, covering a period of many years, dealt with problems of droplet infection and the various properties of aerosols, and culminated in his discovery of the sterilizing properties of germicidal aerosols. As defined by Trillat, liquid aerosols consist of droplets 1-2 microns in diameter, dispersed in the air. He found that certain germicidal agents which killed bacteria in the test tube in dilutions not higher than 1-200 were capable of causing death of air-borne bacteria when dispersed in aerosol form in concentrations of one gram by weight of the chemical substance in 5,000,000 cc. of air. The theoretical basis postulated for the high bactericidal activity of such germicidal aerosols was briefly as follows: a very small quantity of the germicidal agent may be dispersed throughout a relatively large enclosed air space; yet, because each droplet contains the same concentration of the

effective chemical compound as does the parent solution, the bactericidal agent is enabled to act in high concentration on bacteria suspended in air. Trillat tested a number of common bactericidal agents and found that only two of them were satisfactory; namely, resorcinol and sodium hypochlorite. The others were either toxic, irritating or of a disagreeable odor or possessed little germicidal action. He states that resorcinol is the agent of choice because the odor of hypochlorite becomes disagreeable after a time.

Masterman's paper presents evidence for the germicidal effect of fine mists of sodium hypochlorite. He found that one gram of one per cent NaOCl atomized in as much as 40,000,000 cc. of air would produce sterilization. Masterman, (99, 102), believes that this marked bactericidal action is due to the HOCl gas liberated from the mist and is not an aerosol effect. The question as to the mode of action of germicidal mists will be discussed later.

During the following two years, two groups of workers in England, Pulvertaft and Walker, (103), and Twort, et al., (104), confirmed and extended Trillat's and Masterman's observations. Pulvertaft and Walker tested various substances for aerosol activity and recommended a solution of resorcinal in

glycerol and water as satisfactory. These workers also found that NaOCl in glycerol-water was highly effective and killed air-borne bacteria in a dilution of one gram of two per cent NaOCl to 6,000,000 cc. of air. Their test micro-organisms included pathogenic invaders of the respiratory tract as well as non-pathogens. Twort and associates carried out a very extensive investigation of the physical properties of aerosols, their droplet size and rate of evaporation, and the effect of various germicidal agents on a number of different micro-organisms under a variety of conditions. Their most effective aerosol contained 10 per cent hexylresorcinol and 0.05 per cent alkyl sulfate, "Lorol", in alkaline propylene glycol. They reported bactericidal effects on certain non-pathogenic micro-organisms with extraordinarily small amounts of this material e.g., one gram to 4,000,000,000 cc. of air.

Andrewes and co-workers, (105), published a brief confirmatory report on the use of bactericidal mists for air sterilization, and the additional finding that a few viruses, including that of influenza, are susceptible to the mist action as judged by the reduction of their infectivity for mice.

Twort and Baker, (106), have proposed another and quite different type of agent for air sterilization; namely, certain kinds of smokes. Incense smoke and smoke from ignited cardboard soaked with potassium nitrate were found to be highly effective. They report that one gram of the chemical substance dispersed in smoke form in 500,000,000 cc. of air causes destruction or 95 per cent of air-suspended bacteria within 15 minutes.

Robertson et al., (107), investigated the effectiveness of certain glycols in the sterilization of air. They found in their early work that the aerosol activity of certain highly bactericidal substances (e.g., the anti-bacterial synthetic detergents studied by Miller and Baker, (108), was greatly enhanced by employing a hygroscopic vehicle, such as propylene glycol, in place of water which had been used in the preliminary experiments. Subsequent tests with propylene glycol and other closely related glycols showed that they acted as effective bactericidal aerosols. They found propylene glycol to be odorless, tasteless and non-irritating, and of extremely low toxicity in mist and vapor form.

Although the English workers used glycols and glycerine as vehicles they apparently ascribed

little or no importance to these compounds beyond their usefulness as hygroscopic solvents for the germicidal substances, resorcinol and hexylresorcinol. The only reference to a possible independent action of the glycol is that made by Twort and co-workers, (104), who reported a single experiment in which solutions of propylene glycol in alcohol exerted a very high degree of bactericidal activity when dispersed in mist form. It seems probable, however, that germicidal action of this mixture was principally due to the alcohol, since alcohol vapor itself possesses marked germicidal properties.

Laboratory experiments, (109, 110), in a glass chamber of about 2 cu. ft. capacity, and in a room of 800 cu. ft., showed that concentrations of 1 gm. of propylene glycol vapor in 2,000 - 4,000 liters of air, or 1 gm. of triethylene glycol vapor in 100,000 - 200,000 liters of air produced almost immediate and complete sterilization of air into which streptococci, pneumococci, influenza virus, and other organisms had been sprayed. Tests with mouse-adapted influenza virus A on Swiss mice revealed that the glycol vapor protected mice completely against an amount of air-borne virus that killed all control animals.

Mode of Action

In approaching an understanding of the mechanism whereby germicidal mists produce their effect it is necessary to consider first the bactericidal potency of the active agent in solution and, second, the means by which contact between germicide and bacteria can occur. The bactericidal activity *in vitro* of the different chemical agents used for air sterilization varies over a wide range of effectiveness, (111). Depending on the manner in which the tests are carried out, and the particular micro-organism employed, resorcinol kills in dilutions of the order of magnitude of 1:25. Hexylresorcinol is considerably more potent as a bactericidal agent, killing in dilutions of about 1:15,000. Sodium hypochlorite is an effective germicide in dilutions of about 1:20,000. On the other hand, the glycols display a very low bactericidal action in the test tube. Certain organisms will grow abundantly in broth, containing as much as 5 to 15 per cent of the different glycols. When bacteria are suspended in 80 to 90 per cent propylene glycol, they are killed immediately. Ethylene and trimethylene glycols, and also glycerine, do not exhibit such marked activity, (112).

The means by which bactericidal mists produce a lethal concentration of the active agent in the immediate environment of the bacteria would seem to be limited to two possibilities: (a) direct contact between germicidal aerosol droplets and bacterial particles; (b) production of sufficient vapor or gas by evaporation from the germicidal droplets to permit rapid and abundant collision of gas molecules with the bacterial particles. Trillat, (101), Pulvertaft and Walker, (103), and Twort and his associates, (104), believe that germicidal mists exert their anti-bacterial action exclusively as aerosols. They state that the substances employed by them are ineffective in the gas phase. In fact, their investigations of different agents or mixtures for use as bactericidal aerosols have been directed toward developing a mist with a very slow rate of evaporation. Masterman, (102), on the other hand, considers that the activity of the germicidal mist he employed, namely NaOCl, is due to the liberation of HOCl gas.

Calculations of the maximum number of contacts possible between aerosol and bacterial droplets indicate that it would take between 2 and 200 hours for sterilization to occur if this were the mode of

action of the germicidal aerosol, (104, 112). Since complete sterilization of a heavily contaminated atmosphere has been found to take place in as short a time as five minutes by the English workers and within a matter of seconds by American workers, (111), the latter investigators have concluded that the germicidal substance must be present in the gas phase. Further tests carried out under conditions identical with those in which the aerosol was employed, showed that propylene glycol vapor was not only highly bactericidal but acted more effectively than did the aerosol of this substance, (112). When dispersed into the air as vapor, concentrations of 1 gram of propylene glycol in 10 million to 20 million cc. of air had a bactericidal effect. How the glycols produce the killing effect has not been clearly elucidated. Certain findings point to the mode of action; the glycol-killed bacteria remain morphologically intact and stain normally. Pneumococci for example not only retain their gram positiveness but also after as long as a year in propylene glycol show typical capsule swelling in the presence of specific anti-pneumococcus rabbit serum. Mice vaccinated with pneumococci killed by propylene glycol were found to be just as resistant to the injection of living micro-organisms as were mice similarly immunized with heat

killed pneumococci. While pneumococci suspended in propylene glycol retain their gram positiveness for long periods of time, removal from this medium results in a change to the gram nagative state followed by dissolution of the bacterial cell. These findings indicate that this glycol inhibits but does not destroy the autolytic enzyme system of the pneumococcus, (112). A study as to which of the enzyme systems essential to life of the cell are destroyed by the glycol has been initiated by Buck and Barron, (113). A most illuminating approach to this problem has been provided by the work of Lemon, (114), who found that propylene glycol denatures bacterial and other proteins in about the same concentration at which it produces bactericidal action in vitro.

Limiting Factors in Glycol Vapor Disinfection

Glycols are not chemical disinfectants in the ordinary sense, as has been pointed out. Their action in air apparently depends on some limiting action on the bacterial mechanism, and their potency is at a maximum in saturated concentrations. The degree of saturation, rather than absolute concentration, is the important factor. According to Robertson,

112), the ideal glycol concentration for air sterilization is one just below the saturation point with low rather than high temperatures and with relative humidities between 40 and 60 per cent. Glycol saturation increases progressively with rising temperature and humidity. Since it is difficult to control bactericidal glycol levels, particularly of triethylene glycol, a moderate fog must be maintained at all times which is likely to cause excessive condensation and produce undesirable psychological effects.

With propylene glycol, a concentration of 0.3 mg. per liter (67 per cent saturation) was found decidedly oppressive and the air felt humid and possessed a stale sweetish odor. Considerable condensation of glycol solution occurred on windows. Paints became sticky after several hours of exposure to this concentration. However, no toxic effects were observed in persons breathing the vapor for a period of 4 hours, (115).

Similar experiences have been recorded, (116), with propylene glycol. Concentrations of 0.2 mg. per liter or less resulted in heavy condensation and the men complained that the barracks were too warm and stuffy and had a bad odor. Some reported that their throats were sore and dry on awakening in

the morning. Overheating of barracks due to unusually mild weather is believed to have been responsible for some of these complaints.

Triethylene glycol has a lower vapor pressure than propylene glycol, and its saturation concentration and possible toxic effects are, therefore, less. In laboratory studies, (112), atmosphere saturated with pure triethylene glycol vapor produced no toxic effects on rats and monkeys exposed continuously for about one year. In field studies, (117), carried out during cold weather, patients readily adapted themselves to saturated concentrations with no harmful or irritating effects during the limited period of study.

When the temperature of the glycolized air is high, complaints may be high even after short exposures, because the glycol concentration required to approach saturation increases sharply with temperature. The indications are that glycolization in warm weather is undesirable and impractical unless the temperature is reduced by refrigeration.

Another practical drawback to the use of the triethylene glycol is its low volatility and the small range between bactericidal and fogging concentrations. These introduce difficulties in securing

even distribution and control of glycol concentrations in all parts of the room without inducing condensation. The use of room fans facilitates distribution but may cause uncomfortable drafts. Opening windows and doors seriously aggravates the distribution problem. An automatic controlling device recently described, (118), helps but does not entirely solve the problem.

Owing to excessive condensation of the vapor inside the ducts, distribution of glycol vapor through conventional duct ventilating or air conditioning systems is also troublesome, particularly in warm weather.

In vaporizing glycol for air disinfection, it is important to keep in mind that glycols disintegrate at boiling temperatures under normal atmospheric pressure to produce acrolein which is extremely irritating to the throat and lungs. The disintegration temperature of triethylene glycol is placed at 260 F., (119).

Tests with Glycol Vapors in Army Hospitals

Hamburger, Puck and Robertson, (117), carried out preliminary field tests at the Army Hospital at Chanute Field, Illinois. Triethylene

glycol vapor in concentrations near the saturation point (0.01 mg. per liter, mod. rate fog) reduced the number of air-borne beta-hemolytic streptococci by about 75 per cent in a ward housing patients convalescing from scarlet fever. In two German measles wards, triethylene glycol vapor lowered the number of air-borne hemolytic streptococci by 60 per cent. Streptococcal cross-infection is reported to have ceased following glycolization, but there were no control data to make sure of this finding.

Failure of glycol to produce rapid and complete sterilization of air in these wards, is ascribed to protective action of dried dusts and lint on which bacteria abound. (See section on dust control).

A combination of triethylene glycol vapor and dust control was tried out by the same authors, (65), in hospital wards at Camp Carson, Colorado. Floors were treated daily with a solution of 5 per cent urea, 3 per cent ninol, and 0.1 per cent roccal to hold down dust; bedding and clothing of the patients were treated with 2 per cent oil emulsion.

The combination of triethylene glycol vapor and oiling effected a reduction of 93 per cent in the number of air-borne hemolytic streptococci when the

wards were quiet, and 97 per cent during bed-making periods. Oiling of floors and bedclothes alone, without glycolization of air, reduced the streptococcal count by 86 per cent during bed-making but not at all during quiet periods.

Effect of Glycol Vapor on the Incidence of Air-Borne Infections

Preliminary experiments of Harris and Stokes, working at the Children's Seashore House in Atlantic City, New Jersey, have indicated a marked reduction of upper respiratory infection and of total bacterial count during periods of glycolization. The number of patients studied, however, was relatively small; most of the children were bedfast in a supine position; and there was a minimum of direct contact or droplet spread in the wards.

Bigg, Jennings, Olsen, (121), tried out triethylene glycol vapor in two similar barracks, each housing 320 men in four dormitories. With a training period of 6 weeks, three groups of 320 men each came under observation in four test dormitories in which the triethylene glycol concentration was maintained between 0.0025 and 0.004 mg. per liter. An equal number of men served as controls in four untreated

dormitories. Hospital admissions for "air-borne diseases" during the first and second training periods averaged about 12 per cent lower in the test than in the control group, and there was a marked reduction in the incidence of hemolytic streptococci in throat cultures. Data obtained during the third period were inconclusive, presumably owing to variables introduced by warm weather.

Less favorable results were obtained at the Lockheed Aircraft Plant, (98), where triethylene glycol vapor was tried out as a prophylactic measure against "colds". Although the male employees of the test group reported fewer colds than did those in the control group, no significant difference in colds was found in females of the two groups. The colds reported by both men and women of the experimental group were more severe than those reported in the control group. This is ascribed to individual differences of criteria used by examining nurses.

Essentially negative results were reported, (116), working with propylene glycol in Canadian Air Force Barracks. Concentrations of less than 0.1 mg. per liter showed little bactericidal action and had no effect on respiratory illness or on hemolytic streptococcus carrier rate. Concentrations greater

than 0.1 mg. per liter proved definitely bactericidal but were impracticable to maintain owing to excessive condensation on windows, walls, doors, despite the unusually mild weather prevailing during the period of the study.

DISCUSSION AND CONCLUSION

It has been established that diseases of respiratory origin are capable of spread, not only by direct contact with infected individuals, but also by means of bacteria and viruses and contaminated dust particles suspended in the air. The present methods of preventing the further spread of such infections have been presented and are summarized below.

It appears that the first step in controlling the spread of infection through physical environment is the suppression and removal of dust and lint particles. The oiling of floors and blankets and in hospital wards, of sheets and pillow cases, has been shown to be a practical, cheap and effective measure. It reduces the bacterial content of the air, and there is evidence that it reduces the risk of transmission of certain bacterial infections, particularly those due to hemolytic streptococci. A reduction in the risk from virus infections has not been demonstrated although some experimental work with influenza virus suggests this possibility. It is clear that dust suppression is a necessary adjunct to ultraviolet irradiation and glycol vaporization to accomplish the greatest results.

The use of mechanical barriers has proven effective in the prevention of cross infection in certain specialized cases, but is impractical for generalized application. Ventilation as practiced in the colder months of the year at present has been shown to be an inadequate method of diluting atmospheric contamination; however it serves its purpose by controlling variable factors which makes other means of air sanitation more efficient.

Ultraviolet irradiation has been shown to be a definite value in preventing secondary infections in operating rooms. It has shown striking results in the control of communicable diseases in contagious and pediatric wards. Irradiation of the upper air of school rooms in Swarthmore and Germantown, Pennsylvania, has controlled two epidemics of measles and showed beneficial results in an epidemic of chicken pox; a lesser degree of success is reported for the control of the common cold, where exposure to sources of infection outside the treated area is so prevalent. It has recently been demonstrated that better results can be obtained by a higher intensity irradiation than that used formerly. Precautions are necessary in the installation of ultraviolet lamps to prevent injury to room occupants.

Laboratory and controlled clinical experiments have shown that the glycol vapors are of definite value in the reduction of air-borne bacteria. While actual reduction of respiratory infections has not been as marked as with ultraviolet radiation, it should be pointed out that up to the present time there has been no truly satisfactory method developed for applying these vapors. The vapors have been developed to the point where they can be used without danger to room occupants and constitute an economical method of air sanitation.

Discussion

I do not wish to convey the idea that the only source of respiratory infections is via the air-borne route. Infective particles may pass directly from one individual to another in face-to-face contact. The handling of contaminated articles and hand-to-mouth infection is another source of infection.

There is no practical situation outside the experimental laboratory where completely controlled experiments can be carried out to determine the relative incidence of air-borne and contact infections of the respiratory nature. This inability to draw a dividing line between air-borne and contact infections has handicapped investigators in placing a true value on the procedures for air purification. In practical situations these methods have been applied to barracks, factories, schools, and business places, but have not been used in the other places of congregation that were a part of the daily routine of the individuals being investigated. Results of these experiments indicated some reduction of respiratory and allied infections, but failed to measure up to the reduction found in the more strictly controlled

hospital wards and experimental laboratories. This would indicate that advances in the future will be made when the methods of air sanitation are extended to include all confined areas where cross-infection is possible.

Another handicap experienced by present day investigators is the inability to cultivate and study viruses, particularly that of the common cold which initiates the majority of respiratory infections. When a practicle means is developed for the study of viruses the methods of air sanitation can be tested directly for their effectiveness.

It should be recognized that as a science, the field of air sanitation is still in its embryonic stages. It may well be that in the future other means of air sanitation may be developed along with improvements on the present methods. The basic concept of air-borne infection is now clearly established and the studies at the present are directed toward its complete control.

Conclusions

1. A source of respiratory and contagious diseases lies in the air in the form of bacteria and virus contamination.

2. Ventilation is a useful adjunct in the reduction of aerial contamination, but is inadequate when used alone.

3. The oiling of floors, blankets, and bedding is a very effective means of reducing dust-borne bacteria in enclosed spaces.

4. Ultraviolet radiation produces marked reduction in secondary infections of operative wounds, but becomes less effective as the irradiated individuals' contact with unprotected environment increases.

5. Germicidal vapors are also capable of reducing bacterial and virus contamination of the air. Greater progress will be made in this method when a satisfactory and practical method of application is developed.

6. In the author's opinion, the prevention of respiratory and other air-borne infections lies in the further development and widespread application of the methods listed above to the point where all enclosed spaces are adequately protected.

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a good paper.