Air Disinfection in Day Schools*

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THE prevalence of respiratory infection during the season of indoor congregation [1] suggests a natural relationship between ventilation and communicable disease. Reduction by radiant air disinfection, of surgical infection [2] and cross-infection between sick children continuously exposed in pediatric wards,[3] and continuous aggregations of infants in a nursery [4] and children in an orphanage [5] and dynamic spread of childhood contagion [6] through intermittent aggregations in classrooms of day schools [7] offers experimental evidence of the importance of sanitary ventilation in the control of respiratory disease. It may not now be premature in the interest of good design, to attempt a preliminary comparison of results from 6 years' study in one irradiated school with the results obtained under a different design during 3 years in two other schools.

Germantown Friends School

The educational standards which attracted pupils from a select class in a large urban population to the Germantown Friends School contributed much to the significance of the data. The social stability of this class insured unusual continuity of the pupil population from entering susceptibility to graduating immunity, giving cumulative significance to epidemiologic school experience. The dispersal of the pupils through a narrow social stratum of a wide population minimized simultaneous exposure to local epidemics outside the school which might confuse the school pattern. Intelligent coöperation of the staff and parents guaranteed the reliability of the intimate records essential to intensive analysis of the spread of contagion, and health records available for the previous 5 years provided a helpful background.

School arrangements were also well fitted to the needs of the study. Except for a corridor connecting the third floors of the two buildings, the four susceptible primary grades were separated from the four intermediate and four senior grades. Each grade was divided into two classes of approximately 20 pupils in similar classrooms of about 6,000 cu. ft. capacity, ventilated by windows. Irradiation of the upper region of each "home" room above the 7 ft. level, by two crossed "Safe-t-aire" quartz tubes in a shallow aluminum pan reflector, especially designed for the purpose by the Hanovia Chemical and Manufacturing Company, provided uniform air disinfection. Central fixtures were also hung in the nature and music rooms and in the library, but corridors, lunchroom, gymnasium, shop and restroom were equipped according to special

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needs. Correlation of sanitary and epidemiological indices of disinfection of standard " home " rooms then became the specific objective of the study.

SANITARY INDICES

Irradiation—The lethal rating of a tube was given as 1,000 milliwatts of 2,537 Å radiation. In a uniform parallel beam (as from the sun) radiation from two tubes could theoretically irradiate a cube of the same volume as a room to an intensity of 6.06 mw. per sq. ft.[8] Since not more than half the radiation in all directions can be realized from artificial sources in a room with nonreflecting walls, the theoretical irradiation from half the lethal rating is arbitrarily adopted as 100 per cent efficiency.[9] Irradiation efficiency is then derived from average intensity * (1.25 mw. per sq. ft.), yielding 42 per cent efficiency of irradiation.

Air Disinfection—It is possible by defining the lethal equivalent of an air change to express air disinfection in ventilation terms. The lethal rates of most pathogenic air-borne bacteria when exposed to ultra-violet radiation are similar enough to define the disinfection unit equivalent to one air change as the exposure required to reduce *Escherichia coli* atomized into dry air by 63.5 per cent—called a *lethe*. Thus it has been found that as uniformity of exposure is approached, a milliwatt foot of 2,537 Å radiation [9] will approach the sanitary equivalent of a cubic foot per minute of air displacement, and we may assume for practical purposes this arbitrary definition of a *foot lethe* as the unit of radiant disinfection of air. Efficiency of disinfection, however, falls with variable exposure to different intensities indicated by low irradiation efficiency, but air circulation tends to equalize exposure of air-borne organisms to variable intensities. The foot lethal equivalent of an air change per minute determined by bacteriological methods [10] at the Germantown Friends School, divided by the computed milliwatt feet, gave 63 per cent disinfection efficiency. This effective utilization of irradiation certifies to the propriety of correlating this sanitary index with epidemiologic indices.

* Milliwatt feet divided by room volume in cubic feet.
Milliwatt feet = the summed products of angular flux density and radiant distance in feet [9]

EPIDEMIOLOGIC INDICES

Secondary Class Incidence—An epidemiologic index of sanitary ventilation requires estimation of exposure, incidence, and susceptibility. Where outside exposure is eliminated by continuity of aggregation, and other modes of spread can be controlled, total incidence of respiratory disease may indicate air-borne infection. Uncertainty of diagnosis, multiplicity of exposure, and doubtful immunity, vitiate indices based upon colds among intermittent aggregations.[7] Childhood contagions, largely confined to a narrow age stratum, and therefore less subject to simultaneous class incidence from extramural exposure, provides the best index of air-borne infection in schools.[7] If we assume cases of measles, mumps, and chicken pox to be classroom infections when they appear within a proper incubation period after classroom exposure to pupils in an infective stage, the error will be small compared to difference needed to make contagious disease data significant. Though less determinate, this procedure is basically analgous to determining secondary attack rates in families.

Patterns—The occurrence of epidemic respiratory contagion among school children need not reflect upon the efficiency of sanitary barriers unless sanitary ventilation is generally practised in the community. Successful control of spread of contagion within the school will, on the other hand, alter

epidemic rates and proportionate incidence, and ultimately modify immunity patterns in a school population. Thus increased susceptibility of grades following irradiation of the primary school, together with lower rate of spread and proportion of class secondaries may provide a more reliable index of sanitary control than comparisons of incidence between small "controlled" groups, for exposure cannot be "controlled." Conversely, successful control will indicate the importance of an aggregation among community channels of contagion spread.

Results—During the first year (1937-1938), 89 children in four primary classes constituted a protected group, and the same number of similarly susceptible children in four corresponding classes constituted a control group. Seven introductions of mumps into each group resulted in 12 secondary cases in the control group and only 2 in the protected group.

The whole primary department was irradiated during the next session, when another epidemic of mumps, commencing on October 3, spread dynamically (27 cases) through the intermediate department (65 per cent susceptible), but flickered out in both the primary and senior departments. Failure of epidemic spread in the senior department might be explained by lower susceptibility (56 per cent), but more probably by irradiation of the more susceptible (74 per cent) primary department.

Chicken pox introduced 21 times into the primary department (average susceptibility 59.8 per cent) between December and the closing of schools (1939-1940), resulted in only 7 possibly secondary infections. An explosive outbreak in a particular class singled out to rehearse a school play in an unirradiated auditorium, however, exhibited a typical air-borne pattern. On 4 successive days this class was exposed to a missed case (sole secondary to a previous class exposure under the lights), diagnosed the evening before the play, and between the 14th and 20th day following the first day of exposure (May 8), 15 out of the 16 reportedly susceptible children came down in a static type of epidemic characterising intense common-source exposure.

SWARTHMORE STUDIES

The results of the first 3 years at the Germantown Friends School encouraged the extension of the demonstration to the small socially isolated college community of Swarthmore. The educational ideals of this community attracted an intellectually selected class of residents from Philadelphia, insuring in a public school system the epidemiologic advantages enjoyed in the private school at Germantown and similar epidemiologic opportunities to study the part the school played in community spread of a contagion. School cases embracing the whole childhood population became identical with community cases; so differentiation of outside and school exposure distinguished the part the school played in the community commerce in contagion.

The primary grades (kindergarten through the 6th grade) are accommodated in two schools, both merging into one high school of the 6 upper grades. The College Avenue Primary School is located on the same grounds as the High School, but the Rutgers Avenue School is about a mile away. This exposure of one-half of the primary population to upper grades constitutes an interesting variation between two otherwise equivalent epidemiologic and sanitary situations.

The modern school buildings were designed according to standard (Pennsylvania) specifications as to space, light, and ventilation. Mechanically ventilated classrooms of about 7,000 to 8,000 cu. ft. capacity, each accommo-

dating some 20 to 30 pupils, were equipped with four 30 watt fluorescent type of " Germicidal " tubes in high transmission glass, provided with fixtures by the General Electric Company. Corridors, lunchroom, gymnasium, and other places where children mingle, were not irradiated—an epidemiologic opportunity but a sanitary error.

Sanitary Indices—Two reflectors were installed on each end wall at 7 ft. levels, and not being specially designed for the purpose, directed the light beam upward at an angle of 60° from horizontal to avoid direct irradiation of the occupied zone. Only the remote angles between the end wall and ceiling were heavily irradiated, and ray lengths were limited to the distance between the light and the ceiling. Though the rated lethal radiation from the four tubes was tenfold that in the rooms at Germantown, the average irradiation in milliwatt feet per cubic foot (7.64) was only five times greater. The lower efficiency of irradiation (28 per cent as against 42 per cent) indicates a poorer distribution of irradiation, and a correspondingly low efficiency of disinfection (26 per cent as compared to 63 per cent at Germantown) yielded only two equivalent air changes per minute. The steep concentration gradients shown by tests made at different points in the room also indicated non-uniform exposure of the organisms.

MEASLES [7]

During the 8 months, October, 1940, to May, 1941, more than 25,000 cases of measles were reported in Philadelphia —the largest number on record. Though the total cases in the Germantown Friends School and also in the Swarthmore schools exceeded the number in any one of the previous 10 years, this was not due to cases in the protected primary classes, but in the upper unirradiated grades where more than twice the total of the previous 9 years occurred. Only 32 per cent of the school cases occurred in the irradiated classes, while 77 per cent occurred in these grades prior to irradiation. Since exposure outside the classrooms varies inversely with the proportion of school secondaries, the difference in irradiated and unirradiated rooms is even greater than these percentages indicate.

In the town of Swarthmore, hardly more than one-third (37.5 per cent) of the cases occurred at primary school ages, and nearly one-half (46.1 per cent) at high school age, but in Philadelphia as a whole, as in previous years, two-thirds of the cases occurred in primary school ages. In the district adjoining Swarthmore, the attack rate in three primary Nether Providence Schools was four times that in the corresponding high school, and in the grades corresponding to the irradiated grades of the Germantown Friends School, at the nearby William Penn Charter School, there were five times as many cases as in the upper grades.

Weekly attack rates among susceptibles in upper unirradiated classrooms were five times higher than in the irradiated primary classrooms. In the two primary schools sharing grounds with the upper schools, the attack rate was double that in the isolated Rutgers Avenue School at Swarthmore, though home secondaries showed no significant difference, and the small proportion of class secondaries also implicated upper school exposure rather than epidemic spread within their own classrooms. The curve of proportionate decline in the percentage of susceptible children in irradiated and unirradiated rooms during the course of this epidemic (Chart I) shows higher percentage susceptibility in the protected classes after the epidemic had passed than in the control classes before it commenced. The inflection point of this curve coming 13 days (incubation period of measles) after that for the unirradiated classes, like-

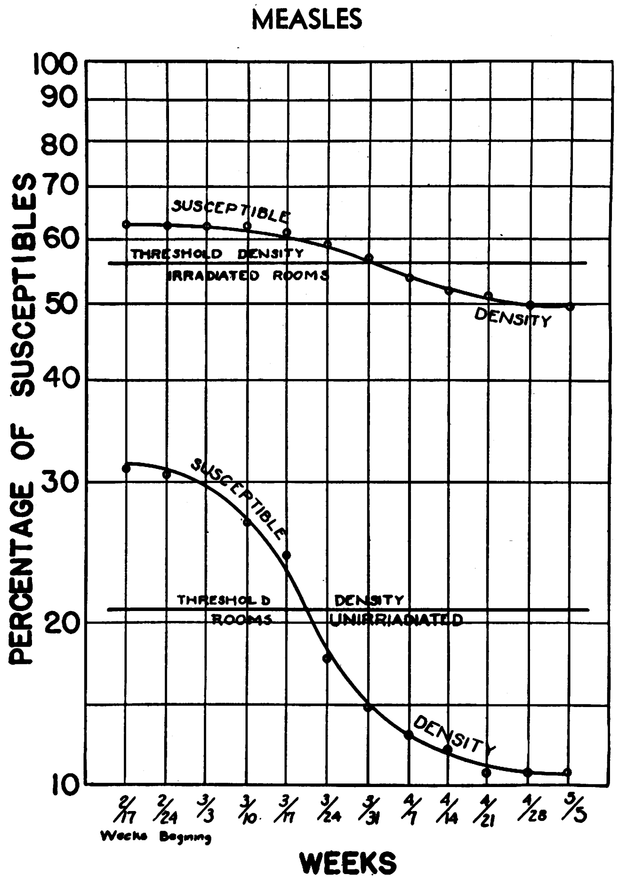

CHART I—Measles susceptibility in Germantown Friends School and Swarthmore Public Schools during 1941 epidemic (primary classrooms irradiated). Threshold density of susceptibles indicated at point of inflection in accordance with McKendrick's theory.

wise indicates secondary spread from the unirradiated school rather than dynamic spread within the primary irradiated classrooms.

The swift course of the epidemic through the schools swept out susceptibility before secondary spread in the community could become established, and so accounts for the similarity in pattern at the Germantown Friends School and in Swarthmore. Occasional class secondaries in some of the irradiated Swarthmore classrooms were overlooked, since the lights were not operated from a central switch as at Germantown, but responsibility rested on each teacher for her room, and more than once the principal was called out after sundown to attend to a "peculiar violet light" in his school.

MUMPS[6]

The dynamic pattern of spread of mumps through the community of Swarthmore during the succeeding year accentuated epidemiologic and sanitary complications in an experimental study of air-borne infection among human aggregations. A case of mumps, exposing the 3rd grade of the College Avenue School on September 29 and 30, detonated an explosive accumulation of

susceptible material. On the second and third generations, synchronous epidemic waves were initiated in the 1st and 2nd grades, respectively. Waves of decreasing amplitude then fanned out on an ever-widening front through the entire population of Swarthmore during the remainder of the season.

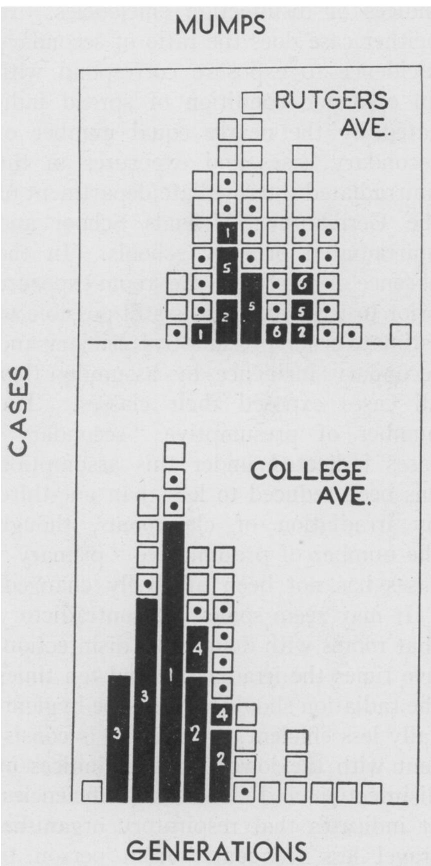

CHART II—Mumps in Swarthmore Primary Schools, 1941–1942. Cases plotted against generation periods. First introduction September 30. Each bar represents one generation period beginning October 7, 25, November 10, 27, December 14, January 1, 19, February 6, 24, March 14, April 1, 19, May 9. Black bars indicate class secondaries defined by cases occurring from 13th to 22nd day after class exposure on day of onset or previous day. White numbers on black bar represent the grade. White squares represent extra class infections. Black dots indicate home secondaries.

The localization of epidemic classroom spread (indicated in black on Chart II), to classes exposed during the fall, contrasts with the generalized endemic smouldering through the community after classroom spread ceased with the onset of cold weather. Thus the secondary class incidence at the College Avenue School, exposed earlier in the season, was more than double that in the more susceptible and more heavily exposed Rutgers Avenue School. In three primary classes first attacked, 32 out of 42 cases could have been secondary to 23 classroom exposures, but only 15 of 73 cases in 11 remaining primary grades of comparable susceptibility could have been secondary to 30 class exposures. Similarly, 31 of 51 cases in the two primary schools could have been infected by 18 class exposures between September 30 and November 19, yet 53 class exposures between November 18 and April 7 could account for no more than 16 of the 64 cases infected after November 18, and probably some of these were extra-class infections. Some factor favorable to epidemic spread of mumps during mild, moist, fall weather appeared to be under control during the cold winter weather.

Epidemic spread of mumps through these irradiated classrooms in the fall, if air-borne, presents a sanitary complication. Direct experimental evidence that mumps virus can be spread through the air, or destroyed by ultra-violet lights, is indeed lacking, and the epidemic behavior of mumps is notoriously erratic. But epidemiologic evidence indicates that "the infective agent of mumps is transmitted by the air"[11] epidemically as well as endemically by salivary communism,[12] and epidemic spread in irradiated classrooms seemed in previous winters to be controlled, and ceased this year with onset of cold weather. An air-borne pattern between the season of abundant window ventilation and the season of dry indoor air

could be explained if the viricidal efficiency of the irradiation is decreased at high humidity.[13] Between September 30 and November 19, weather reports indicate that on 16 days indoor relative humidity exceeded 70 per cent; on 19 days 60 per cent, and 27 days 50 per cent, accountable for a loss of more than half of the bactericidal efficiency in dry indoor air during cold weather when classroom spread was checked. The problem, however, is too serious to be dismissed without further exhaustive laboratory and field investigation.

During the winter, the school now plays a more important rôle in spreading contagion among high school ages than among the primary school children in the town of Swarthmore, and the College Avenue School similarly plays a more important rôle in the spread of contagion among primary school children than the Rutgers Avenue School. Except for minor episodes unattributable to design, but which do emphasize the importance of vigilant servicing, the last year has been uneventful.

Design

A truly quantitative specific secondary attack rate would require correction for time and intensity of exposure, multiple infections, and susceptibles exposed. Under epidemic conditions where rapidly increasing exposure corresponds with a large decrease in susceptibility, the correction would be greater than under sporadic conditions of spread. In fact, the necessary condition of epidemic spread, a higher specific secondary incidence than specific exposure, would normally be unobserved, for indicated secondary incidence ordinarily approaches indicated exposure. Actual differences in rate of spread would therefore exceed differences in the indicated ratio of secondary incidence to exposure.

During the period of dry indoor air, about one in every four exposures of irradiated classrooms to measles, mumps or chicken pox was followed by one or more secondary cases, both at the Germantown Friends School and in the Swarthmore primary schools. A third more cases per outbreak at the latter indicates that failures, though no more frequent, were more serious—epidemiologic confirmation of the sanitary indices of disinfection efficiencies. In neither case does the ratio of secondary incidence to exposure correspond with an epidemic condition of spread indicated by the nearly equal number of secondary cases and exposures in the unirradiated intermediate department of the Germantown Friends School and unirradiated primary schools. In the absence of records of classroom exposure prior to irradiation, it is still possible to estimate crude presumptive primary and secondary incidence by assuming that all cases exposed their classes. The number of presumptive "secondary" cases indicated under this assumption has been reduced to less than one-third by irradiation of classrooms, though the number of presumptive "primary" cases has not been markedly changed.

It may seem somewhat contradictory that rooms with double the disinfection, five times the irradiation, and ten times the radiation should prove to be hygienically less efficient, though this is consistent with the lower sanitary indices of disinfection and irradiation efficiencies. It indicates that respiratory organisms travel less frequently from person to person through lethal zones. Bacteriological tests showed that rotation of the reflectors to throw a horizontal beam across the room increased irradiation more than threefold and disinfection more than tenfold. That an even greater hygienic efficiency can be expected has been indicated by the superior epidemiologic indices within rooms with one-half the disinfection and one-fifth the irradiation but with higher disinfection and irradiation efficiencies.

SUMMARY AND CONCLUSION

1. Epidemic spread of childhood contagion in irradiated classrooms during winter months appears to have been checked for 6 years at the Germantown Friends School and for 3 years in two primary schools at Swarthmore. Measles, mumps, and chicken pox prevailed during the same period in unirradiated classrooms in these schools and in nearby primary schools.

2. Epidemic spread of mumps in irradiated classrooms (of one of these schools) exposed during the fall was checked with the onset of cold weather.

3. Failure of the lights to control the epidemic spread of mumps during the moist, mild autumn weather suggests that the viricidal activity of ultra-violet light decreases with humidity. When respiratory infection is normally most prevalent during cold weather and indoor air is dryest, irradiation was efficient.

4. The importance of the classroom in the epidemic spread of childhood contagion through the community of Swarthmore was revealed by radiant disinfection of the air of the primary schools.

5. The design which yields the highest average intensity per unit of ultra-violet light radiated into a room (i.e., highest efficiency of irradiation) will generally accomplish the most disinfection per unit of intensity (i.e., highest efficiency of disinfection), and prove hygienically more effective per unit of disinfection (i.e., highest hygienic efficiency). An installation with several times the radiation per cu. ft. performed less consistently, according to epidemiologic indices, than one with higher efficiencies of irradiation and disinfection.

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