Airborne Infection

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TRANSMISSION AND CONTROL

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TO

William Firth Wells

FOREWORD

Our understanding of certain noxious contents of the air we breathe and their effects on the health and survival of man and lowlier animals has been acquired slowly and unsteadily. In retrospect, it is interesting to read accounts of some of the early attempts to discover the means of transmission of infections which even then were assumed to be inhalational. Villemin in the eighteen-sixties suspected the respiratory discharges of sick animals to be the vehicle carrying glanders to the healthy, but neither he nor others could prove that the disease was directly airborne. Thenceforth, a favorite tool for studying the problem was tuberculosis, not only because it was the leading cause of human deaths, but also because its easily recognized anatomic features indicated the probability that it was acquired by inhalation. But a good deal of frustration hindered the attempts to demonstrate just how this might occur. Villemin in 1869 observed that the air expired by consumptives did not seem to transmit the disease; as evidence he cited the immunity of physicians and others who were in daily contact with these sick people. During the next twenty-five years, most experiments failed to demonstrate direct airborne transmission (due to the faulty, although ingenious, methods employed), and opinion prevailed that the dust from dried pulverized sputum and contaminated articles such as clothing was the main vehicle. True, contamination might result from droplets falling out of moist spray expelled by the coughing consumptive as shown by Flügge, but quietly expired air was found, as Straus and Dubreuilh expressed it, to be "bacteriologically pure." The dust theory then held sway and became the basic premise behind hygienic measures such as antispitting laws and the disinfection of habitats vacated by the sick. The existence of the "droplet nucleus," the means of its creation, and its movement in the air were still unknown.

Reading the first chapter of this book—a nicely connected and intriguing sketch of the evolution of our knowledge of airborne infection—stirs one's wonder over the ignorance that pervaded the thinking and practices of our ancestors. At the same time, it illustrates how surges of progress come about through individuals who are able to integrate accumulated facts into new conceptions of truth. One of these, established and simply expressed by W. F. Wells earlier in this century, is that ". . . most droplets atomized into air evaporate almost instantly, leaving disease germs drifting like cigarette smoke in droplet nuclei." It followed that the drift of these floating nuclei obeys physical laws, not only in ambient air, but also in that which traverses the respiratory passages of living beings. The delivery of an infectious droplet nucleus to the surface of a vulnerable pulmonary alveolus is governed by the same forces that deliver an inanimate particle such as industrial dust. As Drinker and Hatch express it, ". . . the finest particles become a part of the air itself." These are the decisive events so far as the inception of certain diseases is concerned; in some respects this concept of infection takes precedence over that which stresses the size of the infecting dose. Without this understanding, methods of prevention are crude and often ineffective.

The infectious droplet nucleus, possibly pathogenic, responds also to other laws. Some of these relate to the environment, e.g., the calculable risk of school children acquiring measles from an infectious case in a room of a certain size with a certain rate of ventilation. Some relate to intrinsic properties of the respiratory passages exemplified so well by the role of an inhaled tubercle bacillus: if caught in the sticky mucous stream moving over the surfaces of the nasal or bronchial membranes, it is likely to be carried away harmless; whereas, if it drifts with the air into an alveolus, the chances are better for its implantation, proliferation in situ, and pathogenic effectiveness. Such circumstances of transmission, insofar as they can be verified, are preliminaries to the exploration of more obscure areas, e.g., why measles may be fatal or "abortive" and highly immunizing; why laborers develop such varying degrees of silicosis after approximately similar exposures to siliceous dust; why the single tuberculous lesion arising from the inhalation of a single droplet nucleus remains localized and heals in many individuals but progresses swiftly in others. Obviously there is a vast continuum of intrinsic and external factors and events that determines such happenings.

In this book, Riley and O'Grady have undertaken with remarkable success to extend and refine the application of physical and biological principles to the transmission of airborne infection. The material is well organized, and they maintain a certain continuity with the contributions of others, particularly Wells. (Riley is a disciple and associate of Wells.) Also in original and ingenious ways they have taken some of the known peculiarities of specific infectious diseases—epidemiologic, pathologic, and clinical—and used these as tools for investigation and mathematical formulation. Their work with the transmission of tubercle bacilli in hospital wards is unique and highly significant. Some of their conclusions are exact and some recommendations are readily practicable. Some inferences are qualified by a consideration of the numerous influences that may modify the mechanisms and effects of airborne infections. The points of view reflect to a great extent the varied, thorough, and productive experience of Riley, the senior author, in the fields of respiratory physiology and clinical medicine. His breadth of view enables him with good balance to identify and relate many of the factors that influence the occurrence and course of inhalational infections and to express the meaning of these in terms of prevention and control.

The authors indicate the rationale of specific preventive measures in dealing with certain identifiable situations such as staphylococcal infections in the operating room. They recognize the practical difficulties of preventing the transmission of tuberculous infections in homes and institutions but define specific steps which may be taken and the principles which will guide future progress. Likewise, they apply similar principles to viral infections and others. They leave no uncertainty about the effects of coughing, sneezing, and other violent or abrupt respiratory acts in contaminating the air.

The soundness of their approach to the investigation of natural and artificial processes, the precision of their methodology, the reasonableness of their interpretations, and the clarity and conciseness of their expressions make this work a source of valuable information and a thoroughly scientific guide for those who are interested in and concerned with the numerous and vital implications of airborne infections.

J. BURNS AMBERSON, M.D.

PREFACE

This book concerns the natural transmission of respiratory infection between humans. Airborne spread of infection between individuals is first considered: how organisms are discharged into the air, how they survive there, and how they reach a new host. Different mechanisms of transmission are related to differences in the physical behavior of infectious particles in air. This forms the basis of a discussion of the spread of infection between groups of individuals, first within single enclosed atmospheres and later under the complex conditions of community life. Certain fundamental characteristics of airborne epidemics are developed from a consideration of the aerodynamic behavior of infectious particles in air.

Concepts will be presented that challenge the accepted beliefs of the last half century. These ideas are largely attributable to William Firth Wells, to whom this book is dedicated. The authors have had a unique opportunity to assimilate and interpret Wells' ways of thinking through close association and apprenticeship. Riley worked under Wells as a medical student at Harvard in the early 1930's; this was when Wells was pondering the implications of the differences in aerodynamic behavior between dust and droplet nuclei. Twenty years later Wells and Riley began a second working association at Johns Hopkins; by this time Wells, with the help of his wife, Dr. Mildred Weeks Wells, and others, had established the basic tenets of the droplet nucleus theory and had published his classic book entitled *Airborne Contagion and Air Hygiene.*

The existence in human habitations of droplet nuclei containing pathogenic organisms had not yet been proved, however, Wells was of the opinion that such proof could be obtained by sampling large quantities of air from a tuberculosis ward. Thus began a program of research on airborne tuberculosis at the Veterans Administration Hospital in Baltimore. This work brought O'Grady from England in 1958, but before his arrival Wells suffered the collapse of a spinal vertebra and was admitted as a chronic patient to the hospital where his work on airborne tuberculosis was going forward. O'Grady assumed direct responsibility for the research and wisely included in his daily routine an hour's tutorial with Wells. The project on airborne tuberculosis successfully demonstrated the presence of infectious droplet nuclei in the air and fulfilled Wells' predictions with uncanny precision.

The plan of this book includes a review of the history of ideas on airborne infection, followed by an analysis of the distinguishing characteristics and epidemiologic implications of airborne transmission by different types of particles. Selected studies in which control measures have been tested are evaluated. As each different aspect of the subject is developed, sections on dust, respiratory droplets, and droplet nuclei are carried along in parallel so that the behavior of these particles can be contrasted.

Airborne infection impinges on many disciplines, including medicine, public health, nursing, sanitary engineering, hospital administration, and school administration. The authors hope this book will be of interest not only to people working in these fields but also to many others as well, since all have a personal stake in understanding the stubborn fact of epidemic respiratory contagion.

In recognizing our indebtedness to those who supported our work, there is one man whose quiet influence, largely behind the scenes, was decisive. Dr. John B. Barnwell, as chief of the Tu-

berculosis Service and later as director of research and education for the Veterans Administration, initiated and nurtured the tuberculosis study at the Veterans Administration Hospital in Baltimore. At no time did he lose faith in those of us who were responsible for carrying out the research.

Mrs. Cretyl C. Mills, Wells' assistant of many years' standing, gave dedicated service throughout the program in Baltimore. Drs. Walenty Nyka, Ross L. McLean, Patrick B. Storey, Louise U. Sultan, and others on the medical, laboratory, nursing, housekeeping, and engineering staffs of the Veterans Administration Hospital provided indispensable cooperation and help. Dr. Canby Robinson, who was executive director of the Maryland Tuberculosis Association in the early days of our work in Baltimore, gave vigorous support when we needed it most, and the Association continued to provide money to supplement the categorical support from the Veterans Administration.

The authors are grateful to Drs. James E. Perkins and Robert M. Albrecht for providing detailed data on the Cato-Meridian and Mexico school epidemics of 1945–46, and to Drs. D. D. Reid and A. S. Fairbairn for detailed epidemiologic data from the study of primary schools in the Southall district of Greater London. Dr. Helen Abbey, of the Department of Biostatistics, The Johns Hopkins School of Hygiene and Public Health, gave much-needed advice and encouragement in connection with the material on epidemiology and control. All the quotations in the first chapter of this book were taken by kind permission from Professor C. E. A. Winslow's book *Conquest of Epidemic Disease* (Princeton University Press, 1943), with the exception of the quotation from Professor Bulloch ("Pulmonary Tuberculosis" in *A System of Medicine*, edited by Allbutt and Rolleston. Macmillan & Co., Ltd., London, 1912, pp. 301–2) and from Henle ("On Miasmata and Contagia," translated by George Rosen in *Bulletin of the History of Medicine*, Oct., 1938. The Johns Hopkins Press).

R. L. R.
F. O'G.

CONTENTS

CHAPTER 1

History of Airborne Infection

In earliest history, there were writers who held that certain diseases were transferred by the air. But there also existed so many possible explanations for the origin of disease in demonology of one form or another, that there is doubt that the contagiousness of disease was generally accepted. In the middle of the fourteenth century, epidemic plague, the Black Death, appeared in Constantinople and ravaged through Europe with unspeakable ferocity. It has been variously estimated that between one-quarter and three-quarters of the population of Europe perished. In his fascinating *Conquest of Epidemic Disease,* Winslow tells us that this calamity, which "marked the nearest approach to a definite break in the continuity of history that has ever occurred," produced almost universal conversion to the doctrine of communicability of disease. There was little doubt left too that the plague must have spread as Galen (A.D. 131–201 or 210) had taught: "When many sicken and die at once, we must look to a single common cause, the air we breathe."

Miasmatic theory

After the Black Death, epidemic disease was generally visualized in the terms of Albertus Magnus (A.D. 350) as "pestilential winds and corruption of the air." There was general agreement with Galen's belief that this arose from "either a multitude of dead bodies which have not been burned, as happens commonly in war; or an exhalation from swamps or stagnant waters in the summertime." Besides this notion of *miasmata* (as they came to be called) which arose outside the body and pervaded the atmosphere, it was also believed that disease spread through the air from the sick to the well. The Medical Faculty of Paris wrote, ". . . for the corrupted and poisoned air breathed out by those sick infects those present."

Nature of atmospheric corruption

At this time, it was held that pestilential corruption was a change in the air itself. Apparently there was wide acceptance of the concept embodied in de Machaud's graphic description of air during an epidemic as "no longer fresh and pure, but dirty and vile, black and obscure." This belief, however, was frequently not clearly distinguished from the alternative explanation of Fracastorius (1483–1553) that pestilence consisted of something added to the air rather than a change in the air itself. In a happy choice, Fracastorius compared the spread of contagion to the diffusion of smoke throughout a room. Even so, he did not regard the air itself as unimportant. He attributed the special predilection of Britain for the "English sweating disease" to some special local quality of the air. Although he recognized syphilis as essentially a venereal disease, he maintained that the severe epidemic in the sixteenth century was due to a "general corruption of the air" and attributed the tendency of the disease to become milder and more chronic to the disappearance of the peculiar atmospheric condition that had prevailed at its onset.

This important idea of contagion as something added to air modified in its behavior by atmospheric conditions was restated at the end of the seventeenth century by Sydenham (1624–89), who wrote: "I much doubt if the disposition of the air tho' it be pestilential is of itself able to produce the *plague;* but the plague, being always in someplace or other, it is conveyed by pestilential particles or the coming of an infected person from someplace when it rages into an uninfected one, and is not epidemic there, unless the constitution of the air favors it."

Nature of pestilential particles

The full-grown germ theory of disease can easily be seen in (or into) the writings of Fracastorius. In *Contagion* he says, "The original germs which have adhered to the neighboring humors with which they are analogous, generate and propagate other germs precisely like themselves, and these in turn propagate others, until the whole mass and bulk of humors is infected by them." However, Winslow warns us, as does Garrison, of the dangers of judging apparently clairvoyant statements by ancient writers in the light of modern knowledge instead of in relation to their own writing and their own times. From his general studies of Fracastorius' views, Winslow insists that Fracastorius did not really see his "germs" as living organisms but as ferments, and he awards the credit for the first clear enunciation of the doctrine that living organisms are responsible for disease to Kircher (1598–1680), the much maligned Jesuit, who published his *Scrutinium Pestis* in 1658.

Wherever it may be held to begin, the doctrine gained increasing numbers of adherents, and in 1840 Henle (1809–85) gathered up the evidence in its favor in his *On Miasmata and Contagia.* He concludes "that the matter of the contagions is not only organic, but also animate, indeed endowed with individual life, and that it stands in the relation of a parasitic organism to the diseased body." He also plainly states, "The contagium of the miasmatic contagious diseases is a matter which may float in the air."