Annu. Rev. Publ. Health 1993. 14:635–48

TEMPLES OF THE FUTURE: An Historical Overview of the Laboratory's Role in Public Health Practice[1]

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KEY WORDS: public health laboratory, laboratory history, bacteriology, sanitation, state laboratory

ANTECEDENTS OF THE PUBLIC HEALTH LABORATORY

Public health practice predates the development of the public health laboratory. But, with the birth of modern laboratory science, especially microbiology and serology, disease prevention and control activities developed a more rational scientific basis and, hence, more effective outcomes. However, before the public health laboratory could exist, two prerequisites were necessary: a firm knowledge base that supported laboratory practice as a routine component of scientific inquiry, and a stable and administratively sound organization devoted to public health, into which the laboratory could be integrated. Both elements were lacking in America's early years. Several American cities established boards of health in the late eighteenth and early nineteenth centuries (26); however, these boards tended to be poorly organized and often lay dormant until "an epidemic knocked at the gates of the city" (25).

Urbanization and rapid population growth, both consequences of industrialization, created health problems that, unlike epidemics, were not cyclical in nature. The persistently negative health consequences of poor housing, overcrowding, and inadequate sanitation were difficult to ignore and raised public health issues to a level that demanded permanent action. In the years following the American Civil War, improved methods in the collection of statistics, which showed alarming rates of morbidity and mortality in large cities, coalesced public opinion in support of sanitary reform, thus paving the way for legislative changes (15). Beginning with New York City in 1866, many larger American cities implemented improved public health laws that permitted a "stable administrative foundation" for public health activities by creating independent boards of health composed of physicians and sanitarians (36). In 1869, the Massachusetts legislature passed a bill to create a state board of health (26). As Rosen indicates, this change "from a haphazard to an efficient administration" made it easier "to incorporate new scientific knowledge into public health practice" (36).

Other municipal and state governments followed the examples of New York City and Massachusetts. By 1890, 292 of 345 (85%) American cities with populations in excess of 10,000 reported that they had municipal boards of health—the majority of which met regularly and had physician members (3). In 1870, California created a state health department and was soon joined by Minnesota and Virginia in 1872 and by Michigan in 1873 (36). By 1900, "all but eight of the states had state boards of health, and by 1907 this was accomplished for all states" (48).

With the development of an adequate infrastructure, the stage was set for the institutional birth of the public health laboratory. But, a stable, permanent public health department was not the only ingredient required for its debut. Because the laboratory is the place where scientific methods are applied to solve problems, its birth was delayed until science and technology had reached a level of development that permitted the practical application of this knowledge.

Like most human knowledge, laboratory science did not arise de novo. It evolved over time, and its precursors are evident throughout history. Today, when we think of a public health laboratory, we envision a place where specimens, often derived from the human body, are tested for various analytes or microorganisms. However, the practice of studying material from the human body to learn more about disease is probably as old as human consciousness. Urine, no doubt because of its accessibility, was examined by physicians throughout antiquity (8). But, because of an inadequate knowledge base, these ancient observations were often explained by incorrect theoretical constructs. Nevertheless, these early examinations did establish the practice of searching for clues, within human excretions and discharges, to discover the cause or course of an illness.

The adoption of the scientific method, i.e. posing a hypothesis to explain a phenomenon and testing the veracity of that hypothesis through the systematic collection of data, did much to advance the knowledge base and pave the way for laboratory investigation as an integral component of disease prevention and treatment activities. Medical historians often cite William Harvey's work in elucidating the circulation of blood as one of the major milestones in the use of the scientific method to answer a medical question (46).

As new discoveries were added to the scientific knowledge base, laboratory investigation slowly moved from the realm of the alchemist to the scientist and eventually became recognized as an essential component in the process of scientific problem solving. When Wilhelm von Humboldt founded the University of Berlin in 1810, he foresaw the necessity of linking the academic institution to laboratories, where students could receive practical instruction (37). In 1826, Justus von Liebig, a pioneer in metabolic physiology, persuaded the Hessian government to build and support a chemistry laboratory at the University of Giessen. And, in 1839, the Prussian government constructed an institute of physiology for Johann E. Purkinje—the man who described the purkinje cells of the cerebellar cortex (37). According to Rosen, these events signaled the transition from "the situation in which laboratories had existed as private studies in which scientists did their work to that where the research laboratory was accepted as an integral element in the university and, more specifically, of the medical school" (37).

The appearance of research laboratories as institutional components of centers of higher education marked the acceptance of laboratory study as a legitimate and necessary tool in scientific inquiry. Soon, the European concept that "a thorougly equipped laboratory for the scientific investigation of clinical problems should be an integral part of a teaching hospital" was adopted in America (37), often popularized by Americans who had studied in European laboratories (35). Training in scientific laboratory methods become an accepted part of the academic curriculum, and subsequent generations of graduates ultimately helped move the laboratory from a strictly experimental realm into routine clinical and public health practice.

BIRTH OF THE PUBLIC HEALTH LABORATORY

In America, even before the germ theory became widely accepted, scientists began to use laboratory investigations in their studies of hygiene and sanitation. In 1870, the Massachusetts State Board of Health invited William Ripley Nichols "to investigate the sanitary conditions of water supplies by laboratory methods" (57). However, the public health laboratory truly came into being with the incontrovertible proof of the germ theory.

In the late 1850s, Louis Pasteur's seminal work on fermentation disproved the theory of spontaneous generation and brought science to the brink of accepting the germ theory (36). However, it was not until 1876 that Robert Koch proved, for the first time, that a specific microorganism, *Bacillus* *anthracis*, was the definite cause of a specific disease, anthrax (41). Before this indisputable proof of the germ theory, epidemic outbreaks of infectious disease were explained by one of three schools of throught: the miasmatic theory, the strict contagionist theory, or the contingent contagionist theory (36).

Proponents of the miasmatic theory believed that disease resulted from the inhalation of putrid air, tainted by decaying organic matter. The contagionists believed that epidemics were caused by "an animated particle invisible to the naked eye" (20). The contingent contagionist theory represented an amalgam of the other two; supporters of this view believed that infectious diseases were caused by contagia that acted "in conjunction with other elements such as the state of the atmosphere, condition of the soil, or social factors" (36). By the mid-1800s, it was the miasmatic theory that predominated in explaining epidemics of infectious disease (36).

With Koch's discovery in 1876, the theory of miasma was all but discarded. In rapid succession, the causative organisms for leprosy (1880), typhoid fever (1880), tuberculosis (1882), cholera (1883), and diphtheria (1883) were discovered (36). Equally impressive was Pasteur's work in the early 1880s in the field of immunization. Working with chicken cholera, Pasteur demonstrated that hens inoculated with attenuated organisms could subsequently withstand a challenge of virulent organisms without becoming ill (36).

As America approached the end of the nineteenth century, the appearance of laboratories within institutions and organizations concerned with public health and hygiene reflected the dramatic effect of these discoveries on the world of science. In 1887, Joseph Kinyoun established one of the first American research laboratories of bacteriology at the Marine Hospital in Stapleton, Staten Island; in 1892, the laboratory was moved to Washington, DC, where nearly 40 years later it would become the National Institutes of Health (37). Under the guidance of Charles V. Chapin, a municipal public health laboratory was established in Providence, Rhode Island, in 1888 (48). That same year, Michigan opened a hygienic laboratory at Ann Arbor (57).

According to Rosen (36), the primary purpose of these early public health laboratories was to perform microbiological analyses of water and food. In Providence, the bacteriology laboratory was under the immediate supervision of Gardner T. Swarts, who "purchased the equipment for the laboratory and ran it largely at his own expense for several years" (9). Exemplifying the work of these early laboratories was Swarts' 1888 analysis of household water filters. He detected typhoid bacilli in several of these filters, thus proving that they were "not only useless but actually dangerous because of their tendency in heated rooms to act as incubators for germs" (9). The bacteriology laboratory in Providence continued to perform routine bacteriologic testing of commercial water, spring water, ice, and water filters for several years (9). Diagnostic testing of human specimens did not routinely occur in these early public health laboratories until several years later, after the practice had been introduced by the New York City Health Department (3, 36, 50).

In 1892, in response to the threat that a European cholera epidemic might spread to the eastern seaboard, the New York City Health Department established a division of bacteriology and disinfection (16, 36). Herman Michael Biggs, a physician who taught bacteriology at Bellevue Hospital, was recruited to take charge of this newly established division and its associated laboratory (47). Shortly thereafter, Biggs recruited William H. Park to work in the laboratory on the problem of diphtheria (36).

Diphtheria, long a major cause of childhood mortality, had come under intense study using the new scientific techniques pioneered by the early microbiologists. Soon after Klebs described the causative organism responsible for diphtheria in 1883 (23), Loeffler successfully cultivated it and reproduced its characteristic pseudomembrane by swabbing the mucous membranes of various animals with pure cultures of the bacillus (29). Beginning in 1888, Roux & Yersin (40) confirmed Loeffler's findings and demonstrated the exotoxin of *Corynebacterium diphtheriae*, by showing that bacillus-free culture filtrates would kill guinea pigs. Their work paved the way for von Behring. Working with Kitasato at the Hygienic Institute at the University of Berlin, he discovered diphtheria antitoxin (2), which was later shown by Roux and Martin to be beneficial in the treatment of human diphtheria (39).

In 1893, these findings were put to practical use by Biggs and Park. By culturing throat swabs for the presence of *Corynebacterium diphtheriae*, Park demonstrated that, at one New York City hospital, many persons diagnosed with diphtheria did not actually have the disease and that "placing these patients in contact with the real disease endangered their lives" (50). In his 1893 annual report to Biggs, Park presented the results of "bacteriological examination of 5611 cases of suspected diphtheria" (34) and noted that the bacillus could be recovered from the throats of convalescents, as well as from healthy persons who were in contact with infected individuals (47).

To encourage the use of the diagnostic diphtheria tests, the New York City Health Department offered the tests free of charge to the medical community; "a doctor could pick up a 'culture outfit' left by the health department at a local pharmacy, inoculate and return it, and receive the laboratory verdict by mail within 24 hours" (50). In the year following its introduction of diphtheria diagnostic services, New York City began to aid physicians in treating the disease. While traveling in Europe in 1894, Biggs "heard Roux and von Behring describe the effects of antitoxin in diphtheria" and cabled Park "to start production of antitoxin at once" (47). Park's laboratory became the first in America to make the antitoxin, which was sold in drugstores and "made available to physicians for free for patients in hardship" (50).

Other laboratories quickly followed New York's example. Massachusetts organized a laboratory to produce diphtheria antitoxin in 1894. And, early in 1895, a laboratory for the diagnosis and control of diphtheria was established in Philadelphia (36). Chapin's laboratory in Providence began culturing throat swabs for *Corynebacterium diphtheria* in January 1895 (12). Soon, "almost every state and practically all large cities in the United States had established a diagnostic bacteriological laboratory" (36). These laboratory-supported diagnostic and therapeutic efforts paid off in significant reductions in diphtheria mortality. Spink cites that New York City's 1894 death rates from diphtheria and croup were 105 per 100,000, but that by 1905 this rate had decreased to 38 per 100,000 (49).

Expansion of the public health laboratory's diagnostic ability had a direct and significant impact on public health practice. Culture methods permitted the discovery of previously unrecognized cases of infection in asymptomatic persons. Proof that carriers did exist eventually led to a reexamination of the age-old practice of isolation, i.e. separating diseased persons from the nondiseased population to prevent further spread of illness. In his seminal work, *The Sources and Modes of Infection,* Chapin (12) advised that "the effectiveness of isolation varies inversely as the number of missed cases and carriers" and that when large numbers of unrecognized carriers remained in the population, the isolation of persons with symptomatic illness would have little overall benefit.

Laboratory science's contribution to the study of epidemics of infectious disease permitted more rational and focused interventions to prevent and control them. By 1894, when the New York City Health Department laboratory began examining sputum for *Mycobacterium tuberculosis* (57), tuberculosis (TB) had moved from being a "constitutional, hereditary disease related in some vague way to deleterious environmental conditions" (36) to a communicable infection caused by a specific microbe. Public health departments began to use the information provided by the laboratory to shape TB control efforts by developing public education campaigns that stressed the importance of personal hygiene in preventing the spread of infection (3). The laboratory's ability to confirm clinical diagnoses also bolstered both surveillance and reporting practices, although not without some opposition, especially from the medical community who believed that these health department activities were encroaching upon the traditional role of the physician in treatment and diagnosis (17, 38, 50). In general, however, the functions of assessment, policy development, and assurance, which are now recognized as core activities of public health agencies at all levels of government (14), were significantly strengthened as a result of information provided by the burgeoning public health laboratory.

EARLY YEARS OF THE PUBLIC HEALTH LABORATORY

In many respects, the annals of the early years of the public health laboratory are indistinguishable from the history of bacteriology. In 1897, when Henry B. Horlbeck addressed the twenty-fifth Annual Meeting of the American Public Health Association, he opined that "bacteriology is now a part and parcel of our science. It is one of the foundation stones of all progress in the opening of our knowledge of sanitary science" (52).

The new science of bacteriology added a dimension to public health activities that had been previously lacking, such that the prevention of illness became more than minimizing filth in the environment. The ability to visualize, isolate, and culture the causative agents of disease proved a powerful boon to prevention and control activities. In rapid succession, scientists built upon the findings of their colleagues, and soon the impact of these early discoveries spread into other disciplines. Gruber & Durham's (21) discovery that sera from patients with typhoid fever would agglutinate with typhoid bacillus led to the application of testing patient sera with bacteria of known type to diagnose or confirm infectious diseases (55). In 1901, Bordet & Gengou (15) demonstrated that bacteriolysis by immune serum required a heat-labile serum component, which is today known as complement; their complement-fixation reaction served as the basis for diagnostic tests for many infectious diseases, including the Wassermann test for syphilis (54). It is no wonder that laboratories, the facilities where microbes were studied so that their secrets might be revealed, were so effustively described by Pasteur (4):

> Take interest, I implore you, in those sacred dwellings which are designated by the expressive term: Laboratories. Demand that they be multiplied; that they be adorned. These are the temples of the future. . . . Temples of well being and happiness. There it is that humanity grows greater, stronger, better.

Winslow's 1914 survey of state health department laboratories provides an excellent overview of the activities of the early public health laboratory (57). Among his other achievements, Winslow was a founding editor of the *Journal of Bacteriology* and served as the Chairman of the Committee on Administrative Practice for the American Public Health Association (47). In 1914, as part of his American Public Health Association activities, he surveyed secretaries of state departments of health and asked for information about the variety of work performed in their laboratories. Although his questionnaire did not attempt to quantify testing volume, it did document a remarkable complexity of services, considering the relatively young age of the public health laboratory at the time of his survey.

Table 1 summarizes Winslow's findings. Of 48 states, 47 responded to the survey. New Mexico, which did not have a state health department at the time, established one in 1919 (10). Almost all of the laboratories surveyed performed diagnostic tests for diphtheria, typhoid fever, and tuberculosis. A majority performed diagnostic tests for malaria, rabies, gonorrhea, glanders *(Malleomyces mallei)*, and syphilis. Other activities reported with a high

Table 1 Activities of state health department laboratories in 1914 (57)

Number of states performing diagnostic tests for	
Diphtheria	45/47 (96%)
Typhoid fever	45/47 (96%)
Tuberculosis	44/47 (94%)
Malaria	41/47 (87%)
Rabies	37/47 (79%)
Gonorrhea	36/47 (77%)
Glanders *(Malleomyces mallei)*	30/47 (64%)
Syphilis	27/47 (57%)
Cancer	19/47 (40%)
Number of states performing tests on water supply	
Bacteriological tests	44/47 (94%)
Chemical tests	36/47 (77%)
Number of states performing tests on milk	
Bacteriological tests	30/47 (64%)
Chemical tests	26/47 (55%)
Number of states performing tests on food/drugs	
Bacteriological tests	24/47 (51%)
Chemical tests	20/47 (42%)
Number of states manufacturing antitoxin for	
Diphtheria	5/47 (11%)
Tetanus	1/47 (2%)
Number of states manufacturing "vaccines" for	
Typhoid	19/47 (40%)
Rabies	7/47 (15%)
Tuberculosis	3/47 (6%)
Smallpox	1/47 (2%)
Number of states reporting research activities	20/47 (42%)

frequency included examination of water, milk, and food drugs; research; and manufacture of "vaccine" for typhoid.

While Winslow was conducting his survey, Chapin, at the request of the Council on Health and Public Instruction of the American Medical Association, was conducting a comprehensive study of the activities of state health departments. His findings on the scope of state health department laboratory activities are essentially identical to Winslow's. Unlike Winslow's survey, however, Chapin sought quantitative data on testing volume, which demonstrated that tests for diphtheria, tuberculosis, typhoid fever, and malaria were among the most commonly performed (13). Chapin also documented that fecal examination for intestinal parasites, especially hookworm, was performed by 18 of the 48 state laboratories (13). Perhaps the most important contribution of his report, from a laboratory perspective, was his evaluation of the role of the laboratory in public health programs, for it provides additional documentation of the speed with which laboratory services had become an integrated and indispensable component of the public health system (13):

> The diagnostic laboratory is the most essential part of the machinery for the control of communicable diseases. Without it municipality and state can do nothing. It has been well said that 'the laboratory is the handmaid of epidemiology.' The laboratory has a threefold function. It discovers cases of communicable diseases. It keeps the physician acquainted with scientific methods of diagnosis. It teaches that the mild, atypical case is more common that the typical case of the textbooks.

DEVELOPMENT OF THE MODERN PUBLIC HEALTH LABORATORY

Tracking the evolution of the public health laboratory from its early years to the present day reveals the continued influence of two major variables: science and public policy. Throughout the twentieth century, advances in scientific technology have been manifested in new and improved tests for disease surveillance and diagnosis within the public health laboratory. Public policy decisions, especially those with funding ramifications, have also had a major impact on shaping the configuration of public health laboratories and in refining their role in the overall public health system. Both of these influences are evident in the results of a 1940 survey conducted by Mountin and Flook.

To provide the Public Health Service with "a general inclusive picture of health work at the state level," Mountin & Flook (31–33) surveyed the 48 states; the District of Columbia; and the territories of Alaska, Hawaii, Puerto Rico, and the Virgin Islands. They collected information on the scope of public health work at the state level and on which state agencies were involved in providing services, state health expenditures, and staffing patterns.

Regarding laboratory services, Mountin & Flook (32) identified three major reasons why public health laboratories were maintained by the state:

> First, they make available to physicians, hospitals, and public health personnel diagnostic facilities which would otherwise be unavailable. Second, certain biologicals to be distributed for preventive or therapeutic purposes are prepared therein. Third, the personnel of such laboratories act in a supervisory capacity with regard to practices and procedures of private laboratories.

Mountin & Flook (32) found that most laboratory services provided by the state supported the control of communicable disease programs and that "serologic tests for syphilis represent approximately two thirds of the entire diagnostic laboratory work of state health departments for all communicable diseases." Laboratory testing in support of noncommunicable disease control was less common. Chemical and bacteriologic testing of drinking water samples, milk, foods, and drugs were performed by most of the laboratories surveyed.

One of the major differences between Mountin & Flook's findings and those of Chapin and Winslow, who had surveyed essentially the same target audience 26 years earlier, was the large increase in publicly supported testing for syphilis. This development was the result of both scientific advances and changes in public policy.

In 1905, Schaudinn & Hofmann (43) identified the causative organism of syphilis by examining serum obtained from a genital lesion. In the following year, Landsteiner (27) described the use of dark field microscopy for detecting the presence of *Treponema pallidum*. However, von Wassermann's (54) modification of the complement-fixation reaction of Bordet & Gengou produced the first specific blood test for syphilis. And, in 1909, Ehrlich, working with Hata, discovered Salvarsan, the first effective treatment for syphilis (6).

With the discovery of a laboratory test to diagnose syphilis and an effective treatment to halt the course of infection and render the patient noninfectious, public health practitioners were provided with two essential ingredients for prevention and control programs. But, despite the public health benefit heralded by these advances, this new technology was slow to move into public health practice. According to Brandt (6), "as late as 1912, few physicians had the necessary laboratory and technical facilities to conduct these tests." When Winslow surveyed state health department laboratories in 1914, more than half reported offering tests for syphilis, but he believed "that in a number of instances only a microscopic examination for spirochaetes is relied upon" (57). However, Chapins's 1914 survey documented that only one third of state health department laboratories were actually performing Wasserman tests on human sera (13).

Several factors impeded the development of public health programs for the control of syphilis, and thereby the full-scale implementation of syphilis testing in the public health laboratory. Brandt (6), Duffy (17), and Starr (50) all cite the sentiment expressed by organized medicine that public health efforts to diagnose and treat syphilis were unwelcomed forays into medical practice. According to Brandt, opposing moral values about sexuality and sexually transmitted diseases (STDs) also contributed to the delay in broad-based public support for syphilis control programs.

Although the exigencies of World War I induced the federal government to take a more proactive interest in the control of STDs, including syphilis (16), it was not until the passage of the Social Security Act of 1935 that the federal government "established a permanent machinery for distributing Federal funds for health purposes and recognized special needs in allocating these funds" (16). Title VI of the Act was administered by the US Public Health Service and authorized grants-in-aid to the states for strengthening state and local health departments (56). A significant portion of Title VI monies were used by states to develop STD control programs, including "diagnostic facilities, clinics, and epidemiological programs" (7). The signing of the National Venereal Disease Control Act on May 24, 1938, brought even more resources to bear on this important public health problem, such that the number of laboratory tests performed to detect syphilis "increased 300 percent between 1936 and 1940" (7). The influence of these changes in public policy, especially in terms of funding initiatives, is evident in the large numbers of serologic tests for syphilis documented by Mountin & Flook's survey (32).

Advances in the scientific knowledge base and changes in public policy continue to exert their influence on the public health laboratory. In the Association of State and Territorial Public Health Laboratory Directors 1989 Annual Report, which summarizes the services offered by public health laboratories for that year, the largest number of tests is reported in the category of newborn screening—40% of nearly 36 million (1). This category of testing was not present on either of the two earlier surveys discussed, because the scientific knowledge needed to understand and ultimately diagnose these disorders was not yet available. Phenylketonuria (PKU), one of the first metabolic disorders proven to be a cause of mental deficiency, was not discovered until 1934 (19). And, an effective neonatal screening test for PKU, which facilitated mass newborn screening programs, was not developed until the early 1960s (22, 51).

Just as advances in technology will continue to shape the future of the public health laboratory, so too will policy issues. One of the more significant issues currently facing policy makers relates to the overall distribution of laboratory services in this country. When the American College of Surgeons surveyed hospitals in the early decades of the twentieth century, they found that "many institutions did not yet possess laboratories" (45). Yet, by 1957, more than 90% of all US hospitals maintained clinical laboratories (28). This increase in national laboratory capacity means that the performance of tests that support public health surveillance, prevention, and control efforts may not be limited exclusively to public health laboratory settings (18).

Expansion of the availability of laboratory services has raised policy issues about duplication of effort, thus forcing many to consider the questions of privatization of public health laboratory services (24, 30). Some have suggested that public health laboratories should concentrate on assuring the quality of testing, rather than on duplicating tests that are available elsewhere (42, 44).

THE FUTURE OF THE PUBLIC HEALTH LABORATORY

Reviewing the history of the public health laboratory helps us not only to understand its contribution to public health practice, but also to anticipate how it will continue to evolve in the future, along lines discussed in the accompanying article by Dowdle (14a). This historical overview has demonstrated that technologic advances in testing for diseases of public health significance have ultimately been incorporated into the repertoire of public health laboratories.

More than anything else, this overview reminds us that public health laboratory practice is not static. As our knowledge base increases, our understanding of how to prevent and control disease also expands. Changes in program direction will be mirrored by changes in the services provided by the public health laboratory. Newer, more sophisticated laboratory techniques will result in early diagnosis, earlier intervention, and more complete surveillance. Perhaps Pasteur's description of laboratories as "temples of well being and happiness" was not so extravagant after all.

Acknowledgements

The author wishes to acknowledge the secretarial assistance of Eleanor Herren and Lynn Clemons.

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