Pathology and Laboratory Medicine Support for the American Expeditionary Forces by the US Army Medical Corps During World War I

James R. Wright Jr, MD, PhD; Leland B. Baskin, MD

• *Context.*—**Historical research on pathology and laboratory medicine services in World War I has been limited. In the Spanish American War, these efforts were primarily focused on tropical diseases. World War I problems that could be addressed by pathology and laboratory medicine were strikingly different because of the new field of clinical pathology. Geographic differences, changing war tactics, and trench warfare created new issues.**

Objectives.—**To describe the scope of pathology and laboratory medicine services in World War I and the value these services brought to the war effort.**

Methods.—**Available primary and secondary sources related to American Expeditionary Forces' laboratory services were analyzed and contrasted with the British and German approaches.**

Results.—**The United States entered the war in April 1917. Colonel Joseph Siler, MD, a career medical officer, was the director, and Colonel Louis B. Wilson, MD, head of pathology at the Mayo Clinic, was appointed assistant director of the US Army Medical Corps Division of Laboratories and Infectious Disease, based in Dijon, France. During the next year, they organized 300 efficient laboratories to support the American Expeditionary Forces. Autopsies were performed to better understand treatment of battlefield injuries, effects of chemical warfare agents, and the influenza pandemic; autopsies also generated teaching specimens for the US Army Medical Museum. Bacteriology services focused on communicable diseases. Laboratory testing for social diseases was very aggressive. Significant advances in blood transfusion techniques, which allowed brief blood storage, occurred during the war but were not primarily overseen by laboratory services.**

Conclusions.—**Both Siler and Wilson received Distinguished Service Medals. Wilson's vision for military pathology services helped transform American civilian laboratory services in the 1920s.**

(*Arch Pathol Lab Med.* 2015;139:1161–1172; doi: 10.5858/arpa.2014-0528-HP)

In early American wars, pathology-related services were overseen by the US Army Medical Museum (Washington, DC), which was established in its initial form in 1862 with a circular sent from the Surgeon General's office telling medical officers to send it "all specimens of morbid anatomy, surgical or medical, which may be regarded as valuable… in the study of military medicine or surgery."[1–3,4(p121)] In the American Civil War, although "hygiene" was a strong focus, the field of bacteriology was not yet well-established and clinical pathology (ie, laboratory tests) did not yet exist. By the end of the war, the US Army Medical Museum, under the direction of Joseph Woodward, MD,[5] had collected 7630 specimens that could be instructive in the study of camp fevers, diarrheas, gunshot/battle wounds, gangrene, typhoid fever, and parasitic diseases.[1–4] John Shaw Billings, MD, the librarian for the US Army Medical Museum, who established the Surgeon General's Index (the predecessor to the *Index Medicus* and PubMed [US National Library of Medicine]) and who served as curator of the museum from 1883 to 1893, promoted the museum for teaching and research in public health, pathologic anatomy, and physical anthropology. Walter Reed, MD, was appointed curator of the museum in 1893 by incoming Surgeon General George Miller Sternberg, MD, a bacteriologist. Sternberg established the US Army Medical School at the museum and broadened the museum's scope to include bacteriologic and chemical study. At that time, there were 29 486 specimens, and the scope of the collection included specimens from civilian hospitals and animal experimentation.[1–4]

By the Spanish-American War (1898), bacteriology as a science was well-established and considerable efforts were made to use laboratory science to control tropical diseases. In this campaign, deaths attributed to infection outnumbered deaths from battle wounds by a 7:1 ratio. Typhoid fever was the major cause of mortality, but yellow fever,

Accepted for publication December 3, 2014.

From the Department of Pathology & Laboratory Medicine, University of Calgary/Alberta Health Services, Calgary, Alberta, Canada.

The authors have no relevant financial interest in the products or companies described in this article.

Presented at the Great War's Shadow: New Perspectives on the First World War conference; September 27, 2014; Lake Louise, Alberta, Canada.

Reprints: James R. Wright Jr, MD, PhD, Department of Pathology & Laboratory Medicine, University of Calgary/Alberta Health Services, and Calgary Laboratory Services Diagnostic and Scientific Centre 9, 3535 Research Rd NW, Calgary, Alberta, Canada T2L 2K8 (e-mail: jim.wright@cls.ab.ca).

malaria, and other maladies also adversely affected troop readiness and the war effort. The Typhoid Commission of the US Army Medical Museum, led by Walter Reed, MD, studied typhoid fever in more than 100 army camps, greatly improved understanding of the disease, and generated ways to minimize its effects on troops. By 1909, based on interactions with William Boog Leishman, MB, CM, LLD, of London, the laboratories of the US Army Medical Museum began producing a typhoid vaccine, and vaccination of troops was compulsory; in combination, the museum's efforts resulted in 800-fold decrease in the incidence of typhoid fever. Reed and his colleagues also led the American efforts to study yellow fever and its transmission (ie, proving the mosquito theory of Cuban physician Carlos Finlay, MD). The US Army Medical Museum, through its efforts to understand tropical disease, had a profound effect on American troop readiness.[1–4]

The United States entered World War I (WWI) in April 1917. Differing geography and weather, changing technology, changing war tactics, trench warfare, and similar changes created new issues that could be addressed by pathology and laboratory medicine.

MATERIALS AND METHODS

To describe the scope of pathology and laboratory medicine services in World War I and the value those services brought to the war effort, available primary and secondary sources related to the laboratory services of the American Expeditionary Forces (AEF) were analyzed and contrasted with the British approach, which was fairly similar, and the German approach, which was radically different based on fundamental differences in the philosophies of leading German pathologists.

RESULTS AND COMMENT

According to Major General Joseph Blumberg, MD, in his Ward Burdick Award address[6] at the annual meeting of the American Society for Clinical Pathology in 1969, in which he reviewed the contributions of the US Army Medical Department to the field of clinical pathology:

> The Division of Laboratories and Infectious Diseases, established during World War I, determined the standardization of equipment and trained personnel for chemistry, pathology, and bacteriology laboratories; investigation of infectious diseases was pursued and typhoid vaccine made. Thus, for the first time in a field army, thoughts evolved around the application of clinical pathology to the patient and the prevention of disease. An Army Expeditionary Forces' section of the Division of Laboratories and Infectious Diseases was established at Dijon, France, under the direction of Col. Joseph Siler (MD), Medical Corps; this move allowed for the first time, complete control of laboratory services and mobile laboratories and the supplies for the latter, with resulting improved diagnosis and treatment and research. Col. Siler was assisted in the collection of tissue specimens, bacteria, animal parasites, and other items of medical interest by issuance of Circular Number 42 by Chief Surgeon of the A.E.F., Brigadier General Merriette Ireland (MD); these items he sent to the Army Medical Museum for "medical education and research or which may be of historic interest."[p300]

Although clearly the overall service provided was outstanding, there were significant bureaucracy and organizational structural issues to be overcome from the beginning. According to Mary C. Gillett, PhD, a former senior historian at US Army Center of Military History who authored the definitive 4-volume history of the Army Medical Department covering the years from 1775 to 1941, even "the official history of the Medical Department in World War I is contradictory"[7(p237)] about the origins of the Division of Laboratories and Infectious Disease and its place on the overall organizational structure of the chief surgeon's office, noting that initially it fell under "the Professional Services Divisions" but was "loosely connected with the Sanitation Division."[7(p237)] Before the creation of the division in October 1917, there had been a loose arrangement that "the head of Army Laboratory No. 1, set up at Neufchâteau, France, served as the chief surgeon's advisor concerning laboratories."[7(p237)] By early 1918, Siler's (Figure 1) division had 2 sections: laboratories and infectious disease. Later that year, it acquired 4 additional sections, including office and records; the Central Medical Laboratory at Dijon, France; food and nutrition and water supplies. According to Gillett[7]:

> As time passed, the work of the various sections was, in turn, subdivided, until an organization of considerable complexity and some confusion emerged. The division was permitted to operate with considerable independence.[p238]

Nevertheless, although the quality of services was apparently good, the stature of laboratory services continued to plummet in the chief surgeon's organizational chart. According to Gillett,[7] "In the spring of 1918, when the professional services were reorganized, the Division of Laboratories, now downgraded to a section of the Sanitation Division, was no longer among them"[p238] (ie, professional services). Ironically, this soon gave them further autonomy because they moved to Dijon, France, and, therefore, had actual physical separation from the chief surgeon's office in Neufchâteau, France (and later Tours, France). Congestion of telephone and telegraph lines, censorship, poor mail service, and other communication issues necessitated further autonomy. Perhaps, functional autonomy, secondary to the high degree of disorder resulting from excessive bureaucracy, was one key to success!

Perhaps not surprisingly, the uncertain status of laboratory physicians in the military was not dissimilar to their uncertain status in contemporary American civilian life. The early 20th Century saw an exponential increase in available laboratory tests,[8–10] and most of these were too complex to be performed readily by the clinician treating the patient. This created a niche for laboratory physicians to provide laboratory services, and in large American cities, there were 2 potential models competing for this work: hospital-based laboratories, which were smaller and less efficient, and large commercial laboratories, advertising low prices in medical journals, such as the *Journal of the American Medical Association*.[11] Therefore, in the 1910s, laboratory services had quickly "devolved" into a commodity, and the physicians providing these services were under considerable economic pressure and held positions of low status (considered "manipulators of test tubes") in the medical hierarchy.[11] Further complicating matters, in more than one-half of the states, state public health laboratories would provide some types of testing for free.[12] This chaos soon caused the formation of the American Society for Clinical Pathology in 1922, as well as collaboration with the

Figure 1. *Colonel Joseph Siler, MD, Medical Corps, director of the Laboratory Division of the American Expeditionary Forces [image in the public domain].*

Figure 2. *Colonel Louis B. Wilson, MD, assistant director of the Laboratory Division of the American Expeditionary Forces [image in the public domain].*

American College of Surgeons (ACS), which resulted in increased income and status for clinical pathologists.[11] The excellent pathology and other laboratory services provided to AEF surgeons helped tip the balance toward hospital-based laboratories almost immediately after WWI (see below). Ironically, the problem of where to put laboratory services in North American hospital organizational charts still persists, and laboratory medicine is sometimes lumped with "support services," such as food, laundry, and janitorial services, rather than other medical professional services (J.R.W. and L.B.B., unpublished data, December 2014).

World War I was the first major foreign war in which clinical pathology had an important role.[6] New tests in the clinical pathologist's armamentarium included the Wassermann complement fixation test for syphilis and the Widal agglutination test for typhoid fever, two of the most important communicable diseases affecting troop readiness. Other new clinical pathology tests included agglutination tests for diseases other than typhoid, bacteriologic cultures and examinations for parasites, measurements of hemoglobin and its derivatives, measurements of iron and hematocrit, blood morphology, blood cell counts with differential counts, blood and serum specific gravity tests, microscopic examination of crystals in urine and sputum, fecal fat measurements, gastric and fecal chemistries, and tests for urine glucose, urine urea, ammonia, creatinine, uric acid, total nitrogen, phosphorus, chloride, total sulfate, among others.[8–10]

Louis B. Wilson, MD (Figure 2), assistant director of the laboratory division of the AEF, had considerable breadth of expertise in both anatomic and clinical pathology. Wilson was on leave from his position as director of laboratories at the Mayo Clinic (Rochester, Minnesota), and, before that, he had worked as a bacteriologist at the Minnesota Department of Health (Minneapolis).[13] Wilson published multiple papers about his experience in the AEF and nicely describes pathologic service provision, breaking it into 4 periods, each with distinctive needs[14]:

Period 1.—This period began with the "landing of troops, June 10, 1917, to November 30, 1917, about which date a large number of cases of pneumonia developed."

Period 2.—This period was "from December 1, 1917, to May 31, 1918, when the hospitals of the A.E.F. began to be

concerned most actively with wounded soldiers following the heavy German offensive of May 28."

Period 3.—This period was "from June 1, 1918, to November 30, 1918, the period of serious epidemics and of greatest battle activity, during which time the laboratory was concerned largely with cases of enteric disease, influenza, and with recently wounded patients."

Period 4.—This was the "period of demobilization from December 1, 1918, to May 15, 1919."[p692]

According to Wilson[14]:

> The first period...was one of tentative organization in which the laboratory staffs were for the most part doing the clinical pathology incident to ordinary illness and accidents in a small body of troops...in training. The Wassermann service was begun in September, 1917. In the few laboratories then operating (4 camp hospitals, 8 base hospitals and 2 section laboratories) a small but important autopsy service was begun. Very meager data concerning the technical laboratory work of this period are available since no monthly reports were made.
>
> In the second period...laboratories in twelve more camp hospitals, three evacuation hospitals, ten more base hospitals and the Central Medical Department Laboratory, began to function, and the organization...was perfected, thus greatly increasing the facilities for all types of technical work. Early in this period epidemics of pneumonia, diphtheria, scarlet fever, and meningitis taxed these facilities to their full capacity for routine clinical and bacteriologic examinations. At the end of this period the system of monthly laboratory reports was begun, but the available information for most of the period is quite incomplete.
>
> The beginning of the third period was marked by the German offensive, May 28, 1918, in the Chateau Thierry district, which brought large numbers of American wounded into the hospitals. The Medical Department, on the laboratory side as well as on the administrative, clinical and surgical sides, was then still greatly undermanned. So great was the need for medical attention that in many instances all laboratory officers were diverted from laboratory work to the more direct care of the wounded. At no period from this time on until the signing of the armistice were there half enough laboratory officers.... However, by working without regard to fatigue or the day's length, as did their fellows in the medical and surgical divisions, they succeeded, besides helping out the other divisions, in organizing and developing their laboratories, in doing most of the absolutely essential clinico-pathologic routine work, and in meeting emergencies such as making large numbers of bacteriologic examinations and autopsies incident to battle casualties and epidemics of enteric diseases, influenza, diphtheria, meningitis, etc. This was accomplished...with equipment so inadequate as to have been considered utterly impossible under peace conditions. If the amount and character of work done during this third period is studied and the meager personnel and equipment is considered, only astonishment is elicited at what was accomplished. By November 1st the total number of laboratories in operation had risen to nearly 300.... This third period...will forever stand as a monument to the ability of the American laboratory man to get results regardless of conditions. The available information concerning the technical work for this period is fairly good....
>
> The signing of the armistice marked the beginning of the fourth period of the laboratory service and, regrettably in some respects, the period of its dissolution. Many laboratory officers in civil life, unlike their fellows in clinical medicine and surgery, had not been enjoying large incomes and had left their families inadequately provided for.... Many laboratory officers requested leave to return with their hospital organizations, a request which could not well be refused.... At the same time typhoid fever made its appearance in a number of organizations, rendering necessary extensive bacteriologic examinations. Troops in training areas were being very thoroughly examined for venereal diseases, and the concentration of troops at embarkation camps and base ports resulted in potential danger-points which demanded a very great increase of laboratory service. Thus, as a result on the one hand of decreased personnel and on the other of increased service demanded, much of the technical service of the laboratory division, even in this final period, was done under considerable stress. Fortunately, however, early in this period the arrival and distribution of laboratory supplies had been greatly expedited, which, coupled with the transfer of material from organizations being demobilized, greatly improved the physical conditions under which the work was done.[14(p692–693)]

One issue raised repeatedly in the Wilson[14] article relates to appropriate use of laboratory tests, especially in periods 3 and 4. Wilson noted[14]:

> The amount of clinico-pathologic work done in hospital which is properly manned and equipped depends very largely upon the hospital clinicians. Not all hospitals in the A.E.F. were manned by such officers well trained in the selection of cases in which clinico-pathologic examinations might be of assistance, nor were they all sufficiently trained in interpreting the results once they were obtained. In some instances serious diagnostic errors were made which might have been prevented by even a urinalysis; in others the laboratory was called upon to make large numbers of difficult examinations in the search for the specific cause of a disease which was scarcely even suggested by the symptoms.[p695]

Wilson noted excessive use of some bacteriologic testing and a certain laxness in the way specimens were obtained and transported, perhaps affecting specimen integrity. In discussing the very low tubercle bacilli positivity rate in sputum samples (in the range of 1 in 100), Wilson[14] states: "Specimens which the laboratory officer knows are not intelligently selected or collected are apt to be superficially examined, thus rendering negative reports of little value."[p697]

Wilson was not allowed to report incidence of infectious disease because that fell under the purview of the Special Reports of the Section of Infectious Disease. Instead, "the number of 'positive' examinations in certain diseases was given merely to aid the reviewer in determining whether the clinician was under-using or over-using the laborato-

ry."[14(p694)] Wilson's approach must represent one of the earliest uses of a "physician report card."

Wilson, coming from the Mayo Clinic where he had created a strong tradition in surgical pathology in which all specimens were examined,[11,15–18] was frustrated that this was not the case in the AEF. In some of his laboratories, Wilson noted[14]:

> The routine examination of material from surgical operations by pathologists was an established practice, particularly after December, 1918. In many hospitals, however, this was neglected. This arose from 2 conditions: First, in civil life many surgeons had not previously learned the importance of the review of operative material by a pathologist for obtaining information which might be of value in the subsequent treatment of other cases or in the treatment of the same case; and second, during times of great battle activity the operating-room attendants were too busy even to transfer the specimen and necessary data to the laboratory. Commanding officers of hospital organizations should realize the importance of having operative material reviewed by a competent pathologist as a routine procedure, and not just occasionally on request of the surgeon.[(p699)]

However, the reader should remember that this was not even routine in American civilian hospitals until required by the ACS for hospital accreditation in 1926.[11]

Wilson also oversaw the autopsy service.[19,20] He noted variable autopsy rates in each of the 4 periods and noted that at the beginning of the third period, there were 72 hospitals and laboratories, but "less than fifteen pathologists capable of making post-mortems and intelligently interpreting the results." Wilson concluded that "this condition was due in part to the long neglect of autopsies in many civil institutions in the United States, with the inevitable reduction in number of pathologists, and in part to the overshadowing status of bacteriology in military laboratories."[19(p292)] During period 1, less than 25% of hospital deaths were followed by autopsies, but this increased to 57% in May 1918, after Circular No. 17 was issued by the chief surgeon's office on April 2 stating that "autopsies are authorized in all cases of officers and soldiers and should be performed whenever possible."[19(p292)] Wilson noted[19]:

> [T]he need of a routine autopsy service, amounting in fact to professional inspection of the diagnostic and therapeutic measures of medical and surgical officers, became rapidly apparent during the summer of 1918. Surgeons were called upon to diagnose and treat, with little time for study or reflection, many gunshot wounds the like of which they had had little or no previous experience. Even those who were well grounded in the general principles of surgery were forced to make decisions and institute treatment thereon without sufficient basis or study. As a result, there were errors in diagnosis and errors in treatment. The worst of these could be determined only by the pathologist. In like manner, attending medical officers, that is, in cases of war gas poisoning and especially in the widespread epidemic of influenza and pneumonia, were brought face to face with conditions with which they were totally unfamiliar, and were frequently forced to make diagnoses and institute treatment with a very meager knowledge of the facts. Here autopsies were of tremendous importance.... [In] the fourth period, numerous isolated epidemics of typhoid fever in vaccinated troops began to appear, the conditions were in many instances so obscure that the clinicians failed to make the diagnoses, the pathologist being the first to recognize the true nature of the disease when the patient came to the autopsy table.[(p293)]

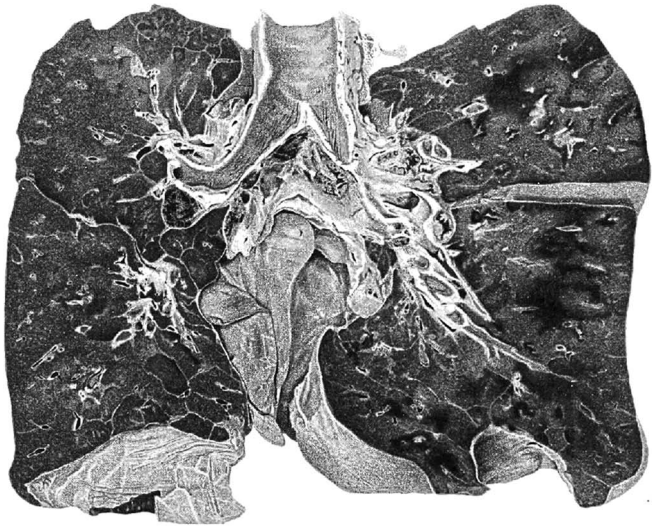
Wilson's assessment related to errors in diagnosis and errors in treatment reinforced the importance of military autopsies, just as the Richard Cabot, MD[21,22] classic studies, less than a decade earlier, had shown a very significant clinical diagnostic error rate in civilian medical and surgical care at Massachusetts General Hospital (Boston). In the AEF, the need was likely even greater because clinicians were sometimes dealing with even greater uncertainty, were having to do so much more urgently, and were likely not as skilled as Massachusetts General Hospital attending physicians.

Because of Wilson's assessment, Colonel Siler requested 10 additional "competent pathologists" from the United States and, when these arrived, the autopsy service was better staffed. The importance of autopsies was stressed by inspectors from Siler's office, and the autopsy rate peaked at 92% of all deaths in hospitals with laboratories attached in both August and September of 1918. In October, 3896 autopsies were performed, with the absolute increase because of both influenza deaths and Argonne (France) offensive casualties; this represented 85% of all deaths in hospitals with laboratories attached. Wilson's assessment was that the general quality of the autopsies was "very high" because these usually resulted in "obtaining data for the immediate information of the attending physician and surgeon."[19(p294)]

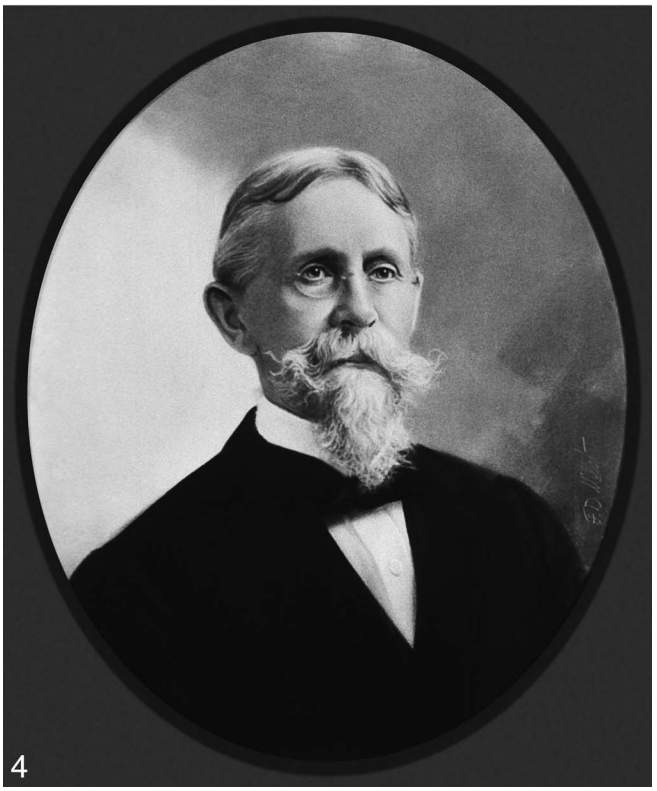
Wilson noted one glaring deficiency in the service. Bodies of soldiers killed in battle (ie, those who did not live long enough to make it to a hospital) were not examined. He felt this was a huge lost opportunity to observe and compare the relative effectiveness of various types of weapons and protective armor, such as helmets. He recognized this would not require actual autopsies but that "such information could be readily obtained during battle activity by temporarily attaching competent medical officers to burial parties."[19(p297)] Wilson notes that this field of postmortem examination "was entered by but one pathologist in the A.E.F."[19(p296)]; although Wilson does not name this individual, one might surmise it was him because he later published several papers on ballistics.[23,24]

More than 10 years after the end of the war, Wilson, citing his war experience, was still vocal about the lack of adequate autopsy training and expertise in civilian and military surgeons and pathologists and made a proposal to rectify the problem.[25]

How was Louis B. Wilson, a famous Mayo Clinic pathologist and not a career military medical officer, appointed assistant director of the Division of Laboratories and Infectious Diseases and posted in France? The answer is... very indirectly. In January of 1918, the Surgeon General sought authorization from the commanding general of the AEF to send a US Army Medical Museum unit to France, and Colonel Wilson was selected as its director. Initially, he was sent to England to study British collections and then to France for duty. Because the collection of pathologic material would be dependent on pathologists making postmortem examinations, Wilson's museum and medical



3 DIFFUSE, HEMORRHAGIC PNEUMONIA.
Streptococcus hemolyticus infection following influenza. Beginning consolidation.
Accession 2696, Army Medical Museum. Colored photograph.



4

Figure 3. *US Army Medical Museum color illustration of a lung removed at autopsy from a patient with influenza dying of pneumonia; color plate 1 in:* The Medical Department of the United States Army in the World War. Vol. XII: Pathology of the Acute Respiratory Diseases, and of Gas Gangrene following War Wounds. *Washington, DC: US Government Printing Office, 1929.*[27]

Figure 4. *Daniel Smith Lamb, MD, Army Medical Museum, Washington, DC [image in the public domain].*

art collection service was placed under the direction of the Division of Laboratories.[26] Wilson needed to improve the autopsy service to achieve his initial primary mission of collecting pathologic materials to be shipped to the US Army Medical Museum in Washington, DC. Likely, Colonel Siler simply recognized that Wilson's many talents could be better used as assistant director, Division of Laboratories, and that he could handle his primary museum director position through multitasking. In the chaotic organizational structure that Gillett describes surrounding laboratory services, who would even notice that Wilson's primary role had changed as long as he was sending specimens to Washington, DC. After all, we could not even find evidence that the Division of Laboratories and Infectious Diseases ever even bothered to change its name when it was "downgraded to a section of the Sanitation Division" in the spring of 1918. Apparently, Colonel Siler and Colonel Wilson simply ignored this demotion and went on with their "divisional business" as usual.

In Wilson's role as museum director, he was responsible for "collecting all those things which may be used for medical education and research or which may be of historical interest" including "pathological specimens, bacteria, animal parasites, missiles, armor, instruments, apparatus, casts, models, paintings, drawings, diagrams, charts, statistical tables, cinema films, photographs, radiographs, lantern slides or other things pertaining to the preservation of the health and the prevention and treatment of the diseases of the United States soldiers or to the history of the Medical Department of the Army."[26(p166)] Wilson's initial problem, other than an inadequate autopsy service, was that he had not been assigned any artists or photographers experienced in medical illustration from the US Army Medical Museum in Washington, DC, and there was a general order in place that precluded the use of cameras in the AEF except by members of the Signal Corps. After considerable correspondence, Wilson finally succeeded in getting the general order amended to give "the Medical Department authority to make 'technical photographs of surgical and pathological interest'" on May 25, 1918,[26(p166)] and he was able to acquire 8 appropriately trained artists who were assigned to him in France on September 14, 1918. However, because of "the order previously issued forbidding the taking of photographs, almost no hospitals were equipped with cameras or other photographic apparatus."[26(p166)] Wilson resorted to "French sources" for both photographic supplies and fixative solutions other than formalin, which would better preserve natural colors.

On July 27, 1918, Wilsons' efforts were helped by Circular No. 42, issued by Surgeon General Ireland outlining the need to collect museum material for medical education and research and indicating that "it is the duty of each medical officer in the AEF to direct to proper channels all such desirable material coming to his notice."[26(p167)] The circular provided considerable details on the scope of what was to be collected and how to accomplish this. Wilson's pathologists collected more than 6000 pathologic specimens, which were preserved and shipped to the Army Medical Museum; most of these related to war wounds, gas poisoning, influenza, and typhoid infection in vaccinated men. His artists and photographers also generated numerous wax models, drawings, paintings, and photographs of technical subjects. Figure 3 shows a "product" of the museum service, a color illustration of the gross appearance of a lung removed at autopsy from an influenza patient dying of pneumonia.[27] In addition to contributions from the AEF, many other specimens originated from domestic military training camp sources.[7]

The AEF and domestic specimens were received in Washington, DC, by Daniel Smith Lamb, MD (Figure 4), who served at the US Army Medical Museum from 1865 to

1920. Lamb had enlisted as a private in the Union Army at the beginning of the Civil War and served in military hospitals until he was transferred to the US Army Medical Museum; he graduated from Georgetown University, Washington, DC, with an MD in 1867 and served as an assistant surgeon from 1868 to 1892 and was then was appointed pathologist in 1892. From 1873, he also served as professor at Howard Medical School, Washington, DC, and was chair of anatomy from 1877 until his retirement in 1923; in these roles, he made important contributions to educating black physicians.[28] According to Major George Callender, MD, speaking on behalf of the surgeon general, "from 1883 until the World War in 1917, Doctor Lamb was the real head of the Army Medical Museum, the pathologist and except in name, the curator of its collections to which he contributed more specimens than any other whoever has or ever will so contribute."[28(p62)]

Finally, the first of Wilson's war papers was a bit of an anomaly for a pathologist; it was written in the fall of 1917, before he went to Europe. Wilson[29] wrote a scholarly review on trench foot, describing the history, predisposing factors, immediate causes, symptoms, diagnosis, pathologic anatomy, animal models, treatment, prognosis, and prevention; in that article, he noted that most wars are "wars of movement" but that this war is largely "a war of position" and that "it has been fought largely in water-soaked trenches, almost or quite freezing cold in winter, by men with bandaged legs and with little freedom of movement" and he anticipated that "the prospects are that the highest percentage (of troops affected) will be among our own men—the newest comers in France—unless vigorous preventive measures are taken at once."[29(p203)]

Pathology Services Supporting the German and the British War Efforts

Wilson's papers provide good insight into the scope of pathology services provided to the AEF. How did these compare with those provided by British pathologists, whose civilian practice bore considerable similarities to that of American pathologists,[30] and those provided by German pathologists, whose practice was very different?[31,32] A study comparing British and German pathology in WWI by German medical historian Cay-Rüdiger Prüll, PhD, provides some excellent insights.[31] Prüll[31] correctly notes that the British and Germans had "very different traditions in Pathology."[(p131)] The German tradition in pathology was still very heavily influenced by Rudolf Virchow, MD, the father of cellular pathology, and was almost entirely based on autopsy pathology; furthermore, it had evolved separately from the practice of clinical medicine. By the late 19th and early 20th centuries, anatomic pathologists and bacteriologists in Germany were having a "turf war,"[33] in that the preeminence of anatomic pathology established in the mid-19th Century was being challenged by "'the bacteriologists' claim to have found the cause of a number of diseases by discovering various types of bacteria."[31(p131)] Therefore, German pathologists in the period following 1900 "emphasized the significance of the human constitution and the 'inner' causes of disease."[31(p132),32] Ludwig Aschoff, MD, head of the pathological institute at the University of Freiburg, Frieburg, Germany, forged the German approach to pathology in WWI, and there were 2 primary foci: (1) practical routine work (ie, "conducting autopsies on a routine basis to ascertain cause of death and to draw up mortality statistics"),[31(p133)] and (2) research on "constitutional pathology," as this was a "once in a lifetime opportunity to perform autopsies on such a great number of individuals in their best years of youth and manhood, some of whom had no previous illnesses of note, their deaths having set in rapidly following gunshot wounds."[31(p133)] In other words, "the focal point of pathology was no longer the sick individual but rather the comportment of the healthy organism of the able-bodied male and how it adapted to the war situation."[31(p134)] For this reason, autopsies were to be performed on all soldiers who were killed; this is in stark contrast to the British focus on clinical pathology directed at helping live patients,[34] as in the AEF. The British pathology services took a rather minimalistic approach to autopsies, whereas the AEF pathology services strongly supported performing autopsies, but for the practical reason of focusing on where medical/surgical treatment had failed so that the clinicians could learn from their mistakes. As emphasized above, AEF soldiers who died in combat and did not reach a hospital alive were not autopsied and were not even considered when calculating and reporting their official autopsy rates. Clearly, the American and British approaches were more practical, whereas German pathologists used the war as an opportunity to conduct theoretical research. British pathology was overseen by Colonel Sir William Boog Leishman, MB, FRS,[34] the famous tropical medicine specialist who had helped Walter Reed develop a typhoid vaccine a decade earlier, whose interest was "not so much to gain knowledge by working on the deceased but, rather, to provide direct assistance in the treatment of the living."[31(p135)]

Even after the war, German pathologists continued to do constitutional pathology research on dead soldiers;[31,32] for instance, in studies published in 1921, the authors concluded that dead soldiers with too many lymphocytes in their thymus ("status thymicolymphaticus") "represent an inferior human race… [who] often succumb to the hazards of daily life whereas the majority of people withstand them without a problem" and that their deaths could be attributed to "the inappropriate reaction of a mentally and physically inferior person to a momentary hazard."[31(p140)] Clearly, it was a slippery slope in the interwar years from the "science" of constitutional pathology to Aryan racial superiority, eugenics, and the rise of Nazism in postwar Germany.[32]

American, British, and German pathologists all performed autopsies for the collection of materials for their national pathology museums and for exhibition, but these efforts were greatest within the German Army. Samuel J.M.M. Alberti, PhD,[35] has recently published a fascinating review of the British efforts entitled "The 'Regiment of Skeletons': A First World War Medical Collection" coinciding with the 100th anniversary of the start of WWI.[35] The French Army also had a pathologic museum at Val-de-Grâce military hospital in Paris, France.[36,37] Consent for autopsies in the AEF was not dependent on family permission, and consent was provided through military policy[1,19]; therefore, there was no need to resort to "covert autopsy" techniques that had been developed by contemporary North American pathologists to procure teaching specimens for civilian pathology museums.[38]

Another major difference from the Americans and the British is that German pathologists did little bacteriology, a field in Germany that was overseen by hygienists. According to Prüll, "neither before nor during the First World War, did German pathologists get a foothold in this field, thus they

could not participate in the successes of the hygienists."[31(p143)]

The Great Influenza Pandemic of 1918–1919

The Great Influenza Pandemic of 1918–1919 had considerable effect on the war effort in the final year of the war because it upset every aspect of the war machinery from the generation and shipping of supplies from home to the actual fighting on the front. It is generally recognized that the pandemic hit in 3 different waves. The first was a mild form that erupted in the late spring and the summer of 1918, the second was an outbreak of a severe influenza in the fall of 1918, and the third occurred in the spring of 1919.

Pathologic changes related to influenza were often difficult to separate from those associated with secondary pneumonias. Much effort was expended trying to determine the causative organism, and there was much focus on *Bacillus influenzae* initially described by German bacteriologist Richard Pfeiffer, FRS, in 1892. There was considerable controversy as to whether this organism was the cause or simply one of many secondary invaders.[39] Many pathologists and bacteriologists agreed that this organism was not consistently present but the Pfeiffer's bacillus "believers" simply claimed that it was difficult to culture and then impugned its critics for their poor technical expertise.[39] This was a huge controversy and not only of academic interest but also, because of prior success making antityphoid fever vaccines, bacteriologists were attempting to determine what organism or combination of organisms should be used to make a protective influenza vaccine.[39–41] A few investigators suspected a "filter passing" organism, which proved to be the case when the influenza virus was discovered in 1933.

Influenza decimated army camps both domestic and abroad. One graphic article[42] describes the second wave of the epidemic as it hit Camp Sherman in Chillicothe, Ohio; in the period from September 24, 1918, to October 11, 1918, there were 7618 admissions for influenza or pneumonia and 842 soldier deaths, including 125 deaths on a single day. The "purple plague," as they called it, was characterized by "a purplish, reddish, grayish, ashen color of the face—chiefly around the lips, but sometimes over other parts of the body or the entire body. The fluids from the respiratory tract were brilliant pink or red. Hemorrhage was everywhere. Every sheet, towel, pillowcase, gown whether on a patient, doctor, nurse or orderly was purplish red."[42(p594)]

Possibly one of the best autopsy studies published shortly after the pandemic had subsided was that of pathologist Sydney W. Patterson, MD, DSc, director of the Walter and Eliza Hall Institute of Medical Research in Pathology and Medicine in Melbourne, Australia.[43] Major Patterson was based in Rouen, France, during the first and second waves of the epidemic. Patterson[43] noted that frothy, sanguineous fluid generally exuded from the mouth and nostrils and that:

> . . .the most striking feature was the general engorgement and water-logged condition of the lungs. Except in the grey consolidated patches, there was profuse exudation of frothy, sanguinous fluid from the cut surface. In extricating the lungs, especially when pleural adhesions were present, frothy blood-stained fluid was expressed from the bronchi and poured out of the mouth.
>
> Microscopically, it was seen that the capillaries of the pleura, of the alveolar walls, and of the walls of the bronchi were greatly engorged and were frequently ruptured, with the result that extravasation of red corpuscles had taken place. The walls of the larger vessels appeared to be normal and contained no fibrin.
>
> The alveoli were full of a homogeneous, coagulated, albuminous exudate, often containing red blood corpuscles, and in the more affected parts leucocytes and endothelial cells. To this primary inflammatory, slimy oedema and congestion were added the following types of broncho pneumonic involvement: (i) The Peri-Bronchial Type. . .., (ii) The Usual Broncho-Pneumonic Type. . .., (iii) Purulent Bronchitis. . .., [and] (iv) Acute Emphysema. . .. In all cases the bronchi contained frothy, bloodstained fluid. The mucous membrane was congested. In many cases this congestion was intense and extended up to and involved the epiglottis, being accompanied at times by sub-mucous haemorrhages. In cases of longer standing erosion and ulceration of the vocal cords had occurred.[43]

Outside the respiratory tract, common changes included right heart dilatation, engorged liver with small subcapsular areas of yellow degeneration (fatty change), friable and sometimes hemorrhagic adrenals, pale edematous kidneys, and interstitial hemorrhages/hyaline degenerative changes in the lower part of the rectus abdominis muscle (Zenker degeneration).[43]

In 1929, the surgeon general's office and the US Government Printing Office published their massive book *The Medical Department of the United States Army in the World War*. Vol. XII. *Pathology of the Acute Respiratory Diseases, and of Gas Gangrene following War Wounds*.[27]; it was 583 pages with 312 figures (including 25 color plates) (see Figure 3). The first section by Major George R. Callender, MD (Figure 5), was on the pathology of the influenza pandemic (406 pages), and the second section by Major James F. Coupal, MD (Figure 6), was on pathology of gas gangrene following war wounds (159 pages); there was also a brief appendix describing staining and photography methodologies. Callender's section contained 5 chapters; interestingly, there is a 180-page chapter on influenza statistics and pathology for "camps in the United States" and only a 9-page chapter for "in the American Expeditionary Forces." This ratio of "coverage" gives credence to Dr Gillett's assessment (see below) that collecting influenza specimens overseas in the midst of the war effort was not very efficient. There were also chapters on "pathological anatomy" of the respiratory tract (192 pages), on "lesions in organs outside of the respiratory tract" (11 pages), and on "bacteriology" (7 pages). The general findings are consistent with those previously published by Patterson.

Sources are not entirely consistent on the overall effectiveness of archiving influenza tissue and other samples from the AEF hospitals for the Medical Museum. According to Gillett,[7] "Most physicians were too busy caring for the living to be concerned about preserving tissues from the dead, and in the near panic and disorder of the stricken camps the hospital staffs were in no position to obtain them in a manner best calculated to preserve them for shipment." In fact, she claims that "most of the really good specimens of 'influenza lungs' received by the museum had to be obtained by a trained nonmedical member of the museum staff who was sent to Camp Wheeler [Macon, Georgia], and almost all were acquired by museum staff members sent out

Figure 5. *Major George R. Callender, MD, Medical Corps, Army Medical Museum [image in the public domain].*

Figure 6. *Major James F. Coupal, MD, Medical Corps, Army Medical Museum [image in the public domain].*

specifically for the purpose."[7(p168)] Nevertheless, the US Army Medical Museum's overall collection thrived, even though only slightly more than 10% of specimens came from Wilson's AEF team. According to the centennial history of the Armed Forces Institute of Pathology; "During and just after the First World War, the collections of the Museum more than doubled, rising from fewer than 48,000 to more than 100,000 specimens."[1]

Chemical Warfare

The use of chemical warfare is usually dated as beginning on April 22, 1915, at the Second Battle of Ypres (Ypres, Belgium) when German troops, under the direction of Professor Fritz Haber, PhD, of the Kaiser Wilhelm Institute (Dahlem-Berlin, Germany) (1918 Nobel Laureate in chemistry and "father of chemical weapons"), used chlorine gas against the French.[44] However, contrary to popular belief, chemical warfare was introduced not by Germany, but by the French who fired ethyl bromoacetate tear gas grenades at Germans in August 1914.[45] Both sides enlisted the help of prominent chemists to develop chemical weapons. Up to 41 distinct chemical species in 5 different categories (ie, sternutating [respiratory irritant], lacrimatory [tearing], pulmonary [choking], vesicant [blister], and systemic [blood] agents) were used on battlefields between 1914 and 1918, although most of the damage was limited to chlorine, phosgene, and sulfur mustard.[45] Accounting for more than 1 million casualties with a 7% fatality rate in WWI, these were responsible for only about 2% of all deaths in WWI but almost one-half of all casualties and more than 30% of all those hospitalized.[45,46]

Phosgene and chlorine gas (carbonyl dichloride [CCl_2O]) are pulmonary agents. Phosgene, the most lethal gas used in WWI, was heavier than air and accumulated in low-lying areas, such as trenches; its toxicity was insidious with initial exposure being asymptomatic but often followed by death within 24 to 72 hours of inhalation. It is estimated that phosgene killed more than 85% of soldiers exposed to it and more than 80% of all chemical agent fatalities were attributed to it.[45] Although chlorine gas was initially considered to be only incapacitating by irritating the eyes and throat resulting in coughing, choking, chest tightness, and lacrimation, it proved to be much more lethal than expected.[46] Chlorine gas also directly burns the laryngeal, tracheal, and bronchial epithelium causing desquamation. Both chlorine and phosgene damage the bronchiolar epithelium causing patchy emphysema, partial atelectasis, and massive pulmonary edema.

By the time the United States entered the war, gas masks had been developed, which, if worn as prescribed, protected against these choking agents. To overcome this countermeasure, in July 1917, Germany introduced the vesicant or blistering agent, sulfur mustard (1-chloro-2-[(2-chloroethyl)sulfanyl]ethane) [$C_4H_8Cl_2S$]), which did not require inhalation to be effective. It was quickly adopted by the Allies as well. This stable oily liquid with low volatility (nb, its name was derived from its yellow brown color and its mustard, garlic or horseradish odor) was dispersed as an aerosol, and, as a liquid, it remained in the local

environment for days continuing to expose victims. Sulfur mustard, because of its high lipid solubility, was rapidly absorbed into the skin, but because it took several hours for blisters to develop, soldiers could receive extensive exposure without realizing it. Exposure to more than 50% of the body surface was fatal, but most fatalities were related to its pulmonary complications. Mustard caused thousands of casualties, including 27 000 Americans, in the short time it was in used, although it was fatal to only about 1% of those exposed. Mustard's low production cost, ease of manufacturing, high toxicity, persistence, and lack of effective protection and treatment made it a game changer and earned it the nickname *King of the War Gases*.[45]

As modern pathologists reviewing AEF autopsy studies on WWI chemical warfare victims, the data are both confusing and imprecise. First, those performing the autopsies often had limited information about the type or types of gas, length of exposure, and manner of application (ie, whether by inhalation or contact). Second, other factors made interpretation difficult. In many instances, soldiers were also injured by their proximity to the "explosion" of the shell that gassed them or they had already been injured by another projectile or its shrapnel at the time they were gassed. All these injuries tended to lead to wound infections followed by secondary pneumonias. Furthermore, many of the mustard casualties occurred during the influenza pandemic of October to November 1918, which made interpretation of pulmonary findings nearly impossible.[47] In one American study[47] of 107 autopsies, 4 were attributed specifically to "suffocant gases," 2 others were probably due to phosgene, and the remainder were believed to be due to vesicant gases (mustard). Two other reports[48,49] detailed the autopsy findings from 62 cases of fatal exposure to mustard and occasionally other chemicals. Thirty-seven were reported by George W. Covey, MD, and Moses Barron, MD,[48] while the remaining 25 were reported by James F. Coupal, MD[49] (Figure 6). At least 11 different pathologists performed the autopsies in these 2 series, including several who went on to distinguished careers in pathology, such as Russell Wilder, MD; Howard H. Parmar, MD, and Alwin Max Pappenheimer Jr, MD. Most cases believed to be strictly mustard exposure had significant respiratory findings, such as tracheobronchitis and bronchopneumonia, with varying amounts of external injuries. In only 3 of 37 cases reported by Covey and Barron[48] were the primary fatal findings related to external mustard burns. Instead, they observed that "the respiratory tract is attacked from the tip of the epiglottis to the terminal bronchioles and air vesicles. The effects seen here are due (1) to the intense irritation and escharotics action of the gas, and (2) to secondary infection, which promptly occurs."(p808) Many of the cases had gross and microscopic similarities to diphtheria. The histologic findings varied considerably depending on the intensity and length of exposure and the clinical time course.[48] Unfortunately, similarities in the pulmonary histology between influenza and mustard were noted, and so, the pandemic likely confounded many of these autopsy studies. Experimental studies performed on animals helped generate a better understanding of the pathophysiology of chemical warfare.[47]

Pathology of the skin lesions produced by sulfur mustard was studied by Aldred Scott Warthin, MD, and Carl V. Weller, MD, of the University of Michigan (Ann Arbor, Michigan).[50] They described specific gross stages of injury following mustard contact with the epidermis: erythema, edema, vesicle formation, pustule, collapse, eschar formation, sloughing separation of crust, and scarring. They noted, microscopically, consistent inflammatory, and destructive changes focused around hair follicles and glands with sloughing occurring by the 19th day, followed by a long period of congestion and pigmentation.[50]

Blood Transfusion

Indirect transfusion of citrated, nutrient-enhanced blood, acclaimed as the most important advance of the war,[51,52] was in widespread use by the Allies by Armistice Day in 1918. In the AEF, blood for transfusion was not only citrated but was often tested for blood group and for blood-borne pathogens, primarily because of the efforts of Oswald Hope (Robby) Robertson, MD, "creator of the World's first blood bank in World War I in Belgium and France."[51] Many of the important discoveries allowing these advances were made by pathologists and/or medical/scientific staff working in pathology departments, mostly in the United States.[51–53] According to the Hedley-Whyte and Milamed[51] scholarly review, "by 1918, each base-hospital and casualty clearing station hospital was transfusing about 50 to 100 pints of blood to an average of 50 wounded each day on the Western front."(p131) However, we find little evidence that supporting transfusion medicine, per se, became part of the routine work of clinical pathologists in WWI, except for the testing of donors for blood transmissible diseases, including syphilis and malaria.[51–54]

SUMMARY

Clearly, despite bureaucratic hurdles, the "Division" of Laboratories and Infectious Diseases was highly efficient and provided a wide array of essential services for which both Colonel Siler and Colonel Wilson were awarded Distinguished Service Medals, presented by the President of the United States after authorization by Congress, "for exceptionally meritorious and distinguished services to the Government of the United States, in a duty of great responsibility" during WWI.[55,56] Siler's medal was for having:

> …been in charge of the Laboratory Service of the American Expeditionary Forces. Because of his untiring zeal and high professional attainments, he has been able to render invaluable service in the prevention of the spread of infectious disease among our troops. Under his able instructions, medical officers were sent out equipped to handle the new medical and surgical problems of war in a manner not believed possible before the present war.[55]

Wilson's citation read in part "by reason of his exceptional organizing and executive ability he organized most efficiently a pathologic service throughout the A.E.F. that was of inestimable value to the medical and surgical services."[15(p149)]

Finally, these excellent military laboratory services helped remodel and transform civilian laboratory medicine in the United States in the decade immediately after the War.[57,58] Wilson's vision of close teamwork between pathologists and clinicians and his demonstration that pathology services can rapidly address direct patient care issues supported the concept of hospital-based pathologists as opposed to commercial laboratories. Medical sociologist William Rothstein, PhD, has noted[48]:

> The thousands of physicians recruited to serve in the army during World War I found army medicine to be far superior to civilian medicine. Many of these physicians probably first encountered laboratory medicine at this time, and surgeons especially must have learned much from the experience. These physicians brought back to civilian life new ideas about the role of pathology.[p979]

As alluded to earlier, the ACS implemented new minimum standards for hospitals, which explicitly required pathologic examination of surgical specimens in 1926.[11] Their earlier attempt at minimum standards in 1917, a 1-page document addressing all issues important to hospital accreditation, made only brief mention of laboratory services. However, the 18-page 1926 minimum standard briefly outlined scope of practice and required "that the clinical laboratory shall be under the direction of a graduate in medicine, especially trained in clinical pathology."[11(p320)] Not surprisingly, Louis B. Wilson, MD, had a direct role here as well. Starting in 1922, Wilson served on a 5-member ACS standardization of clinical laboratories committee (sadly described to ACS Fellows as "a committee of eminent laboratory technicians") tasked with laboratory design for the new minimum standards.[59(p14)] Although the 1926 minimum standards did not set a minimum acceptable hospital autopsy rate, autopsy rates were soon equated as a direct measure of "hospital quality," and hospitals with high autopsy rates took great pride in this accomplishment. Throughout history, medical advances often occur because of war; in WWI, the same can be said for laboratory medicine.

We thank Renee E. Ziemer, BA (Mayo Historical Unit, Rochester, Minnesota), Thomas Kryton, BFA, Sherry Mount, and Docs for Docs (Calgary, Alberta, Canada) for assistance in finding historical materials.

References

1. Henry RS. *The Armed Forces Institute of Pathology: Its First Century 1862–1962*. Washington, DC: Office of the Surgeon General, Department of the Army; 1964; quote, p 191.
2. Lamb DS. *A History of the United States Army Medical Museum, 1862–1917* [electronic reproduction]. [Sl]: HathiTrust Digital Library; 2010. MiAaHDL.
3. Stone P. *Legacy of Excellence: The Armed Forces Institute of Pathology: 1862–2011*. Fort Detrick, Frederick, MD and Fort Sam, Houston, TX: Borden Institute of the US Army Medical Department; 2011.
4. Nelson AM, Sledzik PS, Mullick FG. The Army Medical Museum/Armed Forces Institute of Pathology and Emerging Infections: from camp fevers and diarrhea during the American Civil War in the 1860s to global molecular epidemiology and pathology in the 1990s. *Arch Pathol Lab Med*. 1996;120(2):129–133.
5. Rapkiewicz AV, Hawk A, Noe A, Berman DM. Surgical pathology in the era of the Civil War: the remarkable life and accomplishments of Joseph Janvier Woodward. *Arch Pathol Lab Med*. 2005;129(10):1313–1316.
6. Bloomberg JM. Contributions by the United States Army Medical Department to clinical pathology—past, present, and future (Ward Burdick Award Address). *Am J Clin Pathol*. 1970;53(3):295–303.
7. Gillett MC. *The Army Medical Department, 1917–1941*. Washington, DC: US Army Center of Military History; 2009.
8. Berger D. A brief history of medical diagnosis and the birth of the clinical laboratory, part 1—ancient times through the 19th century. *MLO Med Lab Obs*. 1999;31(7):28–30,32,34–40.
9. Berger D. A brief history of medical diagnosis and the birth of the clinical laboratory, part 2—laboratory science and professional certification in the 20th century. *MLO Med Lab Obs*. 1999;31(8):32–34,36,38.
10. Wood FC. *Chemical and Microscopical Diagnosis: With 188 Illustrations in the Text and 9 Colored Plates*. New York, NY: D Appleton & Co; 1905.
11. Wright JR Jr. The development of the frozen section technique, the evolution of surgical biopsy, and the origins of surgical pathology (William Osler Medal Essay). *Bull Hist Med*. 1985;59(3):295–326.
12. Wright JR Jr. The 1917 New York biopsy controversy: a question of surgical incision and the promotion of metastases. *Bull Hist Med*. 1988;62(4):546–562.
13. Wilson LB. In: *Physicians of the Mayo Clinic and the Mayo Foundation*. Vol 4. Minneapolis, MN: University of Minnesota Press; 1937:1485–1491.
14. Wilson LB. The pathologic service of the American Expeditionary Force. *Mil Surg*. 1919;xlv(6):692–705.
15. Woolner LB. Surgical pathology at the Mayo Clinic. In: Rosai J, ed. *Guiding the Surgeon's Hand: The History of American Surgical Pathology*. Washington, DC: Armed Forces Institute of Pathology; 1997:145–179.
16. Wold LE. *Mayo Clinic Pathology: The First Hundred Years*. Rochester, MN: Mayo Foundation; 2005.
17. Wright JR Jr. Albert C. Broders' paradigm shifts involving the prognostication and definition of cancer. *Arch Pathol Lab Med*. 2012;136(11):1437–1446.
18. Wright JR Jr. The Prince Edward Island—Mayo Clinic connection: Malcolm B. Dockerty and Lewis B Woolner. *Arch Pathol Lab Med*. 2014;138(3):420–427.
19. Wilson LB. The autopsy service of the American Expeditionary Forces. *Trans Assoc Am Physicians*. 1919;34(6):291–297.
20. Wilson LB. The autopsy service of the American Expeditionary Force. *Med Rec*. 1919;xcvi(12):527.
21. Cabot RC. A study of mistaken diagnoses based upon the analysis of 1000 autopsies and a comparison with the clinical findings. *JAMA*. 1910;55(16):1343–1350.
22. Cabot RC. Diagnostic pitfalls identified during a study of three thousand autopsies. *JAMA*. 1912;LIX(26):2295–2298.
23. Wilson LB. Dispersion of bullet energy in relation to wound effects. *Mil Surg*. 1921;xlix(3):241–251.
24. Wilson LB. Firearms and projectiles: their bearing on wound production. In: Weed FW, McAfee L, eds. *The Medical Department of the United States Army in the World War*. Vol XI. Washington, DC: US Government Printing Office; 1927:9–56. *Part 1: Surgery*.
25. Wilson LB. The graduate study of morbid anatomy by the military surgeon. *Mil Surg*. 1930;lxvi(5):613–620.
26. Wilson LB. Museum and art service of the American Expeditionary Forces. *Mil Surg*. 1920;xlvi(2):165–172.
27. Callender GR, Coupal JF. *The Medical Department of the Unites States Army in the World War*. Vol. XII. Washington, DC: US Government Printing Office; 1929. *Pathology of the Acute Respiratory Diseases, and of Gas Gangrene following War Wounds*.
28. Cobb WM. Daniel Smith Lamb, MD, 1843–1929. *J Natl Med Assoc*. 1958;50(1):62–65.
29. Wilson LB. Trench foot: a review of the literature of the etiology and the pathology. *Bull Int Assoc Med Mus*. 1918;vii(May):202–223.
30. Foster WD. *A Short History of Clinical Pathology*. Edinburgh, Scotland: E&S Livingstone; 1961.
31. Prüll CR. Pathology at war 1914–1918: Germany and Britain in comparison. *Clio Med* 1999;55:131–161; quotes, pp 131–135,140,143.
32. Prüll CR. Holism and German pathology (1914–1933). In: Lawrence C, Weisz G, eds. *Greater Than the Parts: Holism in Biomedicine, 1920–1950*. New York, NY: Oxford; 1998:46–67.
33. Gradmann C. *Laboratory Disease: Robert Koch's Medical Bacteriology*. Baltimore, MD: Johns Hopkins University Press; 2009.
34. McPherson WG, Leishman WB, Cummins SL, eds. *History of the Great War Based on Official Documents: Medical Services; Pathology*. London, England: His Majesty's Stationary Office; 1923.
35. Alberti SJMM. The "regiment of skeletons": a First World War medical collection [published online ahead of print June 18, 2014]. *Soc Hist Med*. 2014. doi:10.1093/shm/hku038.
36. Wikipedia Foundation. Val-de-Grâce. http://en.wikipedia.org/wiki/Val-de-Gr%C3%A2ce. Accessed August 18, 2014.
37. Hassenforder M. Justin Godart (1871–1956), organizer of the Val-de-Grâce Military Hospital Museum [in French]. *Rev Corps Sante Mil*. 1957;13(2):228–232.
38. Wright JR Jr. Sins of our fathers: two of *The Four Doctors* and their roles in the development of techniques to permit covert autopsies. *Arch Pathol Lab Med*. 2009;133(12):1969–1974.
39. Bresalier M. Fighting flu: military pathology, vaccines, and the conflicted identity of the 1918–19 pandemic in Britain. *J Sci Hist Med Allied Sci*. 2013;68(1):87–128.
40. Eyler J. The state of science, microbiology, and vaccines circa 1918. *Pub Health Rep*. 2010;125(suppl 3):27–36.
41. Eyler J. The fog of research: influenza vaccine trials during the 1918–19 pandemic. *J Hist Med Allied Sci*. 2009;64(4):401–428.
42. McCord CP. The purple death: Some things remembered about the influenza epidemic of 1918 at one army camp. *J Occup Med*. 1966;8(11):593–598.
43. Patterson SW. The Pathology of influenza in France. *Med J Aust*. 1920;1(10):207–210.
44. Fitzgerald GJ. Chemical warfare and medical response during World War I. *Am J Public Health*. 2008;98(4):611–625.
45. Hilmas CJ, Smart JK, Hill BA. History of chemical warfare. In: Tuorinsky, SD, ed. *Medical Aspects of Chemical Warfare*. Falls Church, VA: Office of the Surgeon General; 2008:9–76. *US Army Medical Department AMEDD Center & School*.
46. Hill BA. History of the medical management of chemical casualties. In: Tuorinsky, SD, ed. *Medical Aspects of Chemical Warfare*. Falls Church, VA: Office of the Surgeon General; 2008:77–114. *US Army Medical Department AMEDD Center & School*.
47. Miller MG; WWI The Medical Front. the medical aspect of gas warfare. http://www.vlib.us/medical/gaswar/gasindex.htm. Accessed November 18, 2014.
48. Covey GW, Barron M. Pathology of (mustard?) gas inhalation. *Am J Med Sci*. 1919;157(6):808–826.
49. Fatal exposure to mustard gas, WWI: the detailed autopsy protocols of 25 cases, with microscopic examination of tissues. http://www.vlib.us/medical/gaswar/mustrdpm.htm. Accessed November 18, 2014.

50. Warthin AS, Weller CV. The pathology of skin lesions produced by mustard gas (dichlorethylsulphide). *J Lab Clin Med*. 1918;3(May):447–449.
51. Hedley-Whyte J, Milamed DR. Blood and war. *Ulster Med J*. 2010;79(3):125–134.
52. Stansbury LG, Hess JR. Blood transfusion in World War I: the roles of Lawrence Bruce Robertson and Oswald Hope Robertson in the "most important medical advance of the war." *Transfus Med Rev*. 2009;23(3):232–236.
53. Wright JR Jr. Blood transfusion and blood banking. In: Andrea AJ, Nadis F, eds. *Era 8: Crisis and Achievement, 1900–1945*. Santa Barbara, CA: ABC-CLIO; 2011:711–713. *ABC-CLIO World History Encyclopedia*. Vol 18.
54. Nelson MG. Thomas Houston and the founding of clinical pathology at the Royal Victoria Hospital, Belfast. *Ulster Med J*. 1994;63(2):223–234.
55. Military Times. Hall of Valor—Joseph F. Siler. http://projects.militarytimes.com/citations-medals-awards/recipient.php?recipientid=18167. Accessed November 12, 2014.
56. OCLC WorldCat. Wilson, Louis B.: [the Distinguished-Service Medal]. http://www.worldcat.org/title/wilson-louis-b-the-distinguished-service-medal/oclc/699484908. Accessed November 12, 2014.
57. German WM. *Doctors Anonymous: The Story of Laboratory Medicine*. New York, NY: Duell Sloan & Pierce; 1941.
58. Rothstein WG. Pathology: The evolution of a specialty in American medicine. *Med Care*. 1979;17(10):975–988.
59. Standardization of clinical laboratories. *Bull Am Coll Surg*. 1924;8:14.