Experimental Sciences in Surgery: 
Harvey Cushing's Work 
at the Turn of the Twentieth Century

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At the turn of the twentieth century, experimental medical sciences influenced on clinical medicine. The process was not simple, as medical historians have been divided in their opinions of whether the relationship between basic science and clinical medicine was one of cooperation, or conflicts. Since the emergence of experimental sciences as the basis of scientific medicine in the late nineteenth and early twentieth centuries, experimental science and clinical medicine have been interdependent in America. The historical relationships were complicated. Historians of medicine, reflecting the complex relationship between medical science and practice, are divided in their opinions. Some scholars have focused on tension and conflicts in the relationship. Other historians have studied the relationship as a cooperative, and necessary one.1) Taking Harvey Cushing(1869-1939),2) the founder of neurosurgery in America, as an

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example, I examine the relationship between clinical medicine and experimental science in early twentieth-century America, employing secondary literature review, analysis of primary material, and archival research.

In the early-twentieth-century America Cushing developed himself as a neurosurgeon, at the favorable academic and institutional environment at Johns Hopkins Hospital. Especially after his European trip in 1900–1901, Cushing became a surgeon–physiologist. Training himself as a neurosurgeon from 1896 to 1905, Cushing established neurosurgery as a specialty from 1905 to 1912, by devising effective neurosurgical treatment, publishing a textbook and papers, and training residents. In 1901 when he first operated on a pituitary patient at the Johns Hopkins Hospital, Cushing got interested in the pituitary gland. From 1908 to 1912, he studied the normal function, abnormal conditions, and surgical treatment of the pituitary at the Hunterian laboratory, and at the bedside. In 1912 Cushing presented the results of ten years work as a monograph, *The Pituitary Body and Its Disorders*, which established him as an expert in the field. As one of the new group of clinical investigators who worked in universities and teaching hospitals and benefited from the laboratory sciences, Cushing developed new medical knowledge from interaction among surgery, experimental science, and bedside observation in his early work on neurosurgery.

1. Cultivating Scientific Attitudes Toward Surgery: The First Anesthesia Records

At Harvard in the early 1890s, Cushing began to develop his scientific attitudes toward surgery. As a third-year medical student, he was called upon to anesthetize an old man suffering from strangulated hernia. Untrained in how to administer ether, Cushing became very nervous. There were no formal instructions on ether anesthesia. Physicians tended...
to use a large amount of ether to anesthetize patients quickly and sufficiently long for the operation. After anesthetizing the patient with considerable difficulty due to vomitus, Cushing wheeled him into the amphitheater. As soon as the operation started, the patient died. Nevertheless, the operation went on. Cushing recalled:

I stood aside, burning with chagrin and remorse. No one paid the slightest attention to me, though I supposed that I had killed the patient. The operation was completed in spite of the episode, as a demonstration to the class. I slunk out of the hospital, walked the streets of North Boston the rest of the afternoon, and in the evening went to the surgeon's house to ask if there was any possible way I could atone for the calamity to the man’s family before I left the Medical School and went into some other business. 

To his astonishment, the surgeon told Cushing that he had had nothing to do with the death of the patient, who had been vomiting all night anyway as a result of a strangulated hernia. Those kinds of thing happened frequently. He advised Cushing to forget about it and go on with medical school. Never forgetting the incident, Cushing continued medical school with more passionate devotion to his work than ever.

The death of the patient exerted a deep impact on Cushing’s thoughts about surgery and anesthesia. He felt keenly the need for physiological monitoring of patients during surgical operations. In 1895, when he became a Junior House Pupil at the Massachusetts General Hospital, Cushing with his classmate Amory Codman began to keep ether charts. During an operation, they recorded on a chart the patient's temperature, respiration rate, pulse rate, and other noticeable changes such as vomiting, together with an evaluation of the patient’s condition. The chart demonstrated clearly at a glance the changing condition of the patient through the course of an operation. Codman and Cushing kept such records for a series of operations. They were the first anesthesia

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3) Cushing MSS, Boston. Some Harvey Cushing correspondence, and ether charts are in the Francis A. Countway Library of Medicine, Boston.
4) More than fifty ether charts which Cushing and Codman recorded in 1895–1896 are
records, marking the beginning of patient monitoring during surgical operations. The practice reduced mortality during and after operations, and improved patient care. 5)

2. Development as a Surgeon at the Johns Hopkins Hospital

When Cushing went to Baltimore in 1896 to work as a surgical resident under William Stewart Halsted at the Johns Hopkins Hospital, Halsted entrusted Cushing with most of the operations, including major surgeries, so that Cushing experienced a variety of surgical cases. Cushing also learned how Halsted combined experimental studies with clinical practice to solve surgical problems. 6)

At Johns Hopkins, Cushing found a spirit quite different from that of Harvard. The new and vigorous university stimulated young doctors to carry out research along various lines. William Henry Welch and other professors taught the latest knowledge of bacteriology and pathology developed in Germany, and directed experimental studies in the laboratory. Exposed to such an exciting intellectual milieu, Cushing tried to learn the new bacteriology and pathology, studying specimens and performing experiments at the laboratory until late at night.

In 1898, Cushing began to publish papers on surgery. From the beginning, he revealed in his papers an unusual ability to integrate clinical experience and scientific reasoning with a wide literature review and innovative surgical procedures. In May 1897, at a meeting of the Johns Hopkins Hospital Medical Society, Cushing presented his first paper on two neurological patients, suffering from spinal lesions caused by gunshot wounds. It was published the following year. 7)

kept as Cushing MSS., Boston, at the Francis A. Countway Library of Medicine, Harvard University.


In 1898, Cushing demonstrated that typhoid fever might result in gallstones.\(^7\) In 1890 Welch had shown the presence of typhoid bacilli at the center of gallstones, and had produced clumpings of the bacilli in the gall bladder experimentally, after intravenous injection of the bacilli into rabbits. Accompanied by a review of the literature, Cushing described six patients who had suffered typhoid cholecystitis with subsequent gallstones. Several months after contracting typhoid fever, the patients had begun to suffer acute attacks of gallstone colic. After an exploratory laparotomy, Cushing examined the gall bladder, revealing stones, clumps of typhoid bacilli, and inflammation of the gall bladder. He explained how typhoid fever caused gallstones. The typhoid bacillus invaded the gall bladder, continued to live long there, and became clumped in the bile. The clumps acted as nuclei for the deposit of bile salts, thus forming gallstones. This paper drew wide attention from the medical community and was reviewed in several medical journals.\(^9\) Cushing’s clear exposition of the cases, and the significance of the pathophysiology of post-typhoidal cholelithiasis (gallstone), gave the paper a broad appeal among physicians.

In 1898 Cushing reported seven cases of operative injury to the thoracic duct including a case of his own in which he had sutured the wound.\(^10\) Frequently the constant leakage of chyle made a wound of the thoracic duct fatal, producing chylous ascites, chylothorax, and chyluria, or chylous diarrhea. Surgeons considered it beyond surgical treatment and thought its treatment should be purely symptomatic. Summarizing the

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9) The paper was reviewed at least in nine medical journals including an editorial of Journal of the American Medical Association 1898:30: 1415–1416.

consequences of division or obstruction of the thoracic duct from experimental and pathological data, Cushing concluded that accidental wounds of the thoracic duct could be repaired surgically, and suggested operative methods to treat such injuries.

One of Cushing’s most important papers in his resident years was on typhoid fever. Typhoid fever was then a common infectious disease, characterized by high fever, inflammation and ulceration of Peyer's patches in the small intestine, enlargement of the spleen and mesenteric glands, and catarrhal inflammation of the intestinal mucous membrane. Twenty to thirty percent of typhoid fever patients died of intestinal perforation and ensuing peritonitis. Once the small intestine was perforated, 95 to 100 percent of patients died. Physicians, barely capable of diagnosing intestinal perforations in typhoid fever, could not treat them.

Cushing maintained that patients with an impending intestinal perforation could be saved by early diagnosis and surgical measures. He described four typhoid fever patients with intestinal perforation. One patient, a nine-year-old boy with typhoid fever, was crying out from acute abdominal colic when Cushing first saw him. He vomited, and had a weak pulse at a rate of 165 per minute. There was general tenderness of the abdomen, cyanosis, and leukocytosis. Recognizing an impending perforation of the small intestine, Cushing performed a laparotomy, resecting a segment of the small intestine, suturing the intestines, and irrigating the peritoneal cavity with saline solution. The patient recovered well. After one week, he began to have colic again. Despite the seriously ill condition of the patient, Cushing performed two more operations to close intestinal perforations. Slowly but completely, the patient recovered.

In spite of early operation, two out of four of Cushing's patients died of streptococcal peritonitis caused by perforation. One patient, found on

operation not to have perforation, recovered from typhoid fever. Early diagnosis was crucial to save the patient. Cushing described in detail the early symptoms of perforation. They included acute onset of increased abdominal pain, usually on the right side, with slight tenderness and rigidity, irregular vomiting, chill and sudden fall of core temperature, weak pulse, and leukocytosis. Repeatedly, Cushing emphasized the need for early operation upon patients with impending intestinal perforation. "When the diagnosis is made," said he, "operation is indicated, whatever the condition of the patient." 

Cushing's pioneering surgical treatments of intestinal perforation in typhoid fever were an important contribution to general surgery. By describing the early symptoms and signs of impending intestinal perforation in typhoid fever, he helped physicians to diagnose such imminent events. His principles of early diagnosis and early operation would increase the survival rate of patients with typhoid fever. The results from Cushing's surgical treatment of imminent intestinal perforation in typhoid fever were incomparably better than those of medical treatment. In the discussion of the paper, William Osler said: "Dr. Cushing is to be congratulated upon his excellent results. Certainly to save one case in three of perforation is much more than we can do on the medical side, for they all die with us." 

The next year Osler wrote to Cushing to ask him for a reprint of the paper, saying "your paper on Typhoidal Perforation is tip-top." In 1901, Cushing's paper on intestinal perforation in typhoid fever was translated into French.

During his residency, Cushing also devised a method of local anesthesia for operations on patients with various diseases that prevented them from taking general anesthesia. Without knowledge of Halsted's early work

14) John F. Fulton, op. cit. p. 149.
16) Harvey Cushing. Cocaine anaesthesia in the treatment of certain cases of hernia and in
on local anesthesia, Cushing thought he was the first to administer local anesthesia at the Johns Hopkins Hospital.

In 1898 when Cushing saw a twenty-eight-year-old man who had suffered for ten years from chronic jejunal fistula, Cushing made observations through the fistula on the bacteriology of the jejunal contents under various conditions. With sterilized food and antiseptic solutions, he was able to render the contents of the jejunum free of microorganisms. After a forty-eight-hour's precaution to guard against intrusion of bacteria, Cushing succeeded in closing the fistula by resection and end-to-end anastomosis.

3. The Bacteriological Years : 1898-1900

In 1898, Cushing became so interested in bacteriology that he thought once of becoming a bacteriologist. Halsted urged his residents to perform their own bacteriological studies, and Welch helped them to carry out experiments. Studying bacteriology in earnest, Cushing treated his patients on bacteriological principles and used bacteriological methods. In 1898, after operating on two patients with acute general peritonitis, he was able to present convincing evidence as to whether gonococcus could cause peritonitis. Medical scientists knew that the gonococcus could cause salpingitis, and pelvic peritonitis. However for lack of evidence, they could not decide whether the gonococcus might also cause general peritonitis, independently of infection with other microorganisms.

In 1898 a twenty-five-year-old woman came to the hospital, complaining of lower abdominal pain, and showing tenderness of the abdomen, leukocytosis, and high fever. The patient's history and physical examinations revealed nothing specific as to the cause of her peritonitis.

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At laparotomy, performed to find the source of infection, Cushing first searched the appendix, but it was normal. Exploring the whole abdominal viscera and cavity, he found both salpinxes inflamed and filled with pus. Bacteriological examination of the pus during the operation showed abundance of gonococcus. From the peritoneum, and the serosa of the abdominal viscera, Cushing made smears and cultures for bacteriological examination. After removing both uterine tubes, he irrigated the abdominal cavity with saline solution. The patient recovered fully. She told Cushing that she had been exposed to infection for five years, and had recently been re-infected, a few days before her menstrual period.

In the same year, Cushing operated upon an eighteen-year-old girl for peritonitis. Before the operation he did not anticipate gonococcal infection. The patient insisted that her pain was located in the epigastric region, and on pelvic examination denied any tenderness in the area. Only during the operation, after bacteriological examination of pus from the uterine tubes, did Cushing diagnose it as gonococcal infection. Hugh H. Young reported the results of bacteriological examinations of specimens taken from various parts of the abdominal cavity of the two patients. Smears and cultures from the peritoneal cavity revealed the gonococcus without the presence of other organisms. After complete recovery, the patient told Cushing that she had been exposed frequently to infection for a year, and had been exposed again several days before her last menstruation. Three days after menstruation, she began to suffer acute abdominal pain, vomiting, leucorrhrea, and fever, with cessation of menstruation.

From the case records, and the results of bacteriological examination, Cushing concluded that the gonococcus could cause general peritonitis without infection by other microorganisms. Under ordinary circumstances, ascending gonococcal peritonitis was confined to the pelvic cavity. In the puerperal state, or during menstruation, gonococcal infections of the genital organs might extend to the whole abdominal cavity, causing a generalized peritonitis. Through systemic bacteriological examination of the whole abdominal cavity during the operation, Cushing was able to demonstrate that the gonococcus could cause a generalized peritonitis.

In 1899, in his spare time between operations and at night in the
laboratory. Cushing studied the bacilli of hog cholera, or *Bacillus enteritidis* (Gartner type), comparing it with other pathogenic microorganisms of the gastro-intestinal system.\(^{19}\) To determine the characteristics of *Bacillus enteritidis*, Cushing made cultures of eleven enteric bacilli, cultured them in different media, and injected the cultured bacilli into rabbits. He found that *Bacillus enteritidis* had characteristics intermediate between those of the typhoid and colon groups. In 1900 Cushing published his bacteriological studies with photographs to show the various reactions of the eleven enteric bacilli. It was a purely bacteriological paper.

In 1900, Cushing published another bacteriological paper on experiments that he performed with Louis E. Livingood on intestinal microorganisms.\(^{20}\) The series of experiments had begun with a clinical observation of a patient. In the fall of 1897 a young man who had received a gunshot wound in the abdomen came to the hospital twenty-seven hours after the injury. The accident had occurred several hours after a meal, and the patient had not taken any food since. In an exploratory laparotomy, Cushing found four large intestinal perforations in the upper part of the jejunum. In spite of the leakage of jejunal contents for a long time, he found no evidence of peritonitis during the operation or in post-operative cultures from the abdominal cavity. Cushing sutured the perforated jejunum, and the patient recovered from the operation. This case led Cushing to review hospital records of all patients with gunshot wounds in

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19) Harvey Cushing. A comparative study of some members of a pathogenic group of bacilli of the hog cholera or bac. enteritidis (Gartner type), intermediate between the typhoid and colon groups. With the report of a case resembling typhoid, in which there occurred a post-febrile osteomyelitis due to such an intermediate bacillus. Johns Hopkins Hospital Bulletin 1900;11: 156-170.

20) Louis E. Livingood (1868-1898), an associate in the Pathology Department of the Johns Hopkins Hospital, worked on intestinal flora with Cushing during the spring of 1898. In July 1898, on his way to Havana for a vacation, Livingood died in the disaster of the French ship La Bourgogne. After Livingood’s death, Cushing finished the study by himself, and published it with Livingood’s name. Livingood’s preceptor, William Henry Welch, was pleased when he saw Livingood’s name on the paper. Harvey Cushing and Louis E. Livingood. Experimental and surgical notes upon the bacteriology of the upper portion of the alimentary canal, with observations on the establishment there of an amicrobic state as a preliminary to operative procedures on the stomach and small intestine. Johns Hopkins Hospital Report 1900:9: 543-591.
the abdomen. To his surprise, he found that patients with wounds of the upper portion of the alimentary canal (stomach, duodenum, and upper parts of the jejunum) alone recovered from the wounds. All of the patients with a gunshot wound in the lower parts of the intestine (the ileum, the caecum, and the large intestines) developed generalized peritonitis. From that time, whenever possible, Cushing made routine bacteriological examinations of the digestive canal of patients on the operating table.

Through clinical observation, and experiments, Cushing tried to establish the various kinds and numbers of intestinal microorganisms in various parts of the digestive system at different periods of digestion. In the pre-antibiotic era, peritonitis occurred frequently after abdominal surgery, for surgeons might easily inoculate microorganisms from the intestine into the peritoneal cavity. To reduce post-operative infections in abdominal surgery, a surgeon needed to know the nature and pathogenicity of the local bacterial flora in the part on which he was going to operate, and to try to reduce the number of pathogenic microorganisms by adequate preparations. Nevertheless, the medical literature seldom dealt with the subject. Cushing decided to carry out research on the question.

After opening the abdomen of a healthy dog, which had not been fed for twenty-four hours, Cushing took specimens for cultures successively at eleven points distributed along the alimentary canal from the stomach to the rectum. Bacteriological examinations revealed that the upper part of the alimentary canal contained scarcely any microorganisms, while the lower part possessed an abundant bacterial flora. In order to observe the effects of diet upon intestinal microorganisms, Cushing repeated the experiment in thirty-five dogs under various conditions: at various intervals: after feeding freely without dietary precaution, after feeding sterile liquid food, or without feeding any food. In diverse conditions of diet and periods of digestion, the upper part of the canal constantly had fewer microorganisms than the lower part. Cushing found that pathological microorganisms in the alimentary canal came mostly from food. The feeding of sterile liquid food prevented the rich growth of pathological organisms in agar plates. After fasting, the duodenum became free of microorganisms.
Clinical studies verified that the upper portion of the alimentary canal could become free of microorganisms after fasting. In a patient who ate freely without dietary precaution before an operation, bacteriological studies of the alimentary canal showed a large number of pathogenic microorganisms. Even in pathological conditions, dietary restriction to sterilized food greatly reduced the possibility of subsequent peritonitis. From his experimental and clinical observations, Cushing offered suggestions as to how to make the upper alimentary canal aseptic for surgical operations. They included cleansing the teeth and mouth with an antiseptic solution before and after feeding, providing the patient with sterilized liquid food, and washing out the stomach morning and evening, if microorganisms were found during bacteriological test of the stomach. Before an operation, food was prohibited for ten hours.

Cushing’s paper on the bacteriology of the alimentary canal was valuable both practically and scientifically. It suggested strongly that the upper alimentary canal should be made aseptic before operations on the stomach and small intestine. To Cushing, Welch commented: "Your paper is of very great value and I confess that I had not realized how thorough a study you had made of the bacterial flora of the intestine under varying conditions. Your observations are certainly of great practical importance, as well as of scientific interest." 21)

In June 1900 Cushing completed four years of training under Halsted, first as Assistant Resident and then Resident Surgeon at the Johns Hopkins Hospital. His bacteriological studies ended, and he departed for Europe.

4. Acquiring a Physiological Mind : Training in European Physiological Laboratories at 1900-1901

After four strenuous years at Johns Hopkins, Cushing had an opportunity to rest and to observe scientific medicine as it was developed in Europe. In spite of his extensive surgical experience and eighteen published papers, Cushing’s perspectives had so far been confined to

American medicine. Welch, Osler, and Halsted, all of whom had studied in Europe and had been deeply influenced by German medical science, encouraged him to go to Europe for study.

Cushing spent fourteen months in Europe in surgical and physiological studies. The academic trip proved to be one of the most fruitful in his career, making him appreciate physiological studies as an important part of surgical training and research. A few years later, writing of the value of physiological investigations, he recalled: "Its desirability was impressed upon me by the more recent experience of working for a few semesters in physiological laboratories abroad, during which time, it seems to me, I acquired more of real value for my surgical work than in my previous six years service as a hospital intern."\(^{22}\)

At London in July 1900, Cushing visited Victor Horsley, a pioneer of neurosurgery in Europe. After observing Horsley’s operation for trigeminal neuralgia, Cushing was disappointed with Horsley’s surgical skill. As a pupil of Halsted, a master of surgical skill and aseptic technique, Cushing found operations in British hospitals hardly satisfactory. After visiting French hospitals for three months, Cushing went to Berne to work with the prominent Swiss surgeon Theodor Kocher. He found Kocher much like Halsted in his careful, painstaking work, and meticulous surgical technique. Deeply impressed by Kocher’s operations, Cushing understood why Halsted had valued German surgery so highly. Observing the exact technique, complete hemostasis, and clean surgical field, Cushing thought that Kocher’s surgery outdid even that of the Johns Hopkins Hospital. He spent much time observing Kocher’s operations, making notes of techniques that he wanted to introduce at Johns Hopkins, including methods of draping the head for operations on the head and neck.

Kocher also provided Cushing with an opportunity to perform neurophysiological experiments. He gave Cushing four propositions concerning the relationship between arterial blood pressure and intracranial pressure during episodes of compression of the brain.\(^{23}\) With

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the help of the German physiologist Hugo Kronecker, Cushing performed experiments on animals at a well-equipped laboratory called the Hallerianum, named for the Swiss physiologist Albrecht von Haller (1708-1777). He invented a method to observe blood vessels of the brain directly, by making a small window in the skull of an animal. Through this opening he was able to see the effects of increasing intracranial pressure. The German physiologist Leon Asher who worked with Cushing at the same laboratory recalled:

I well remember with what cleverness, using simple but effective methods, he [Cushing] managed to apply pressures of varied intensity to the dog’s brain. He got up on a high ladder to fix a pulley on the ceiling of the room in the Hallerianum. It served to draw up by a rope the pressure bottle, which he used to raise brain pressure. He was a most assiduous worker and untiring in his efforts to master the physiological technique new to him at that time. 24)

With continuous records of the animal’s respiration and blood pressure, Cushing discovered that as the intracranial pressure rose, the arterial blood pressure increased correspondingly, maintaining a higher level than that of the intracranial pressure. Having established the relationship clearly, he wrote several papers based upon the experimental work carried out during his European sojourn. 25)

In addition to the experiments on cerebral compression, Kronecker assigned Cushing to study nerve-muscle physiology, involving the perfusion of frogs. Through the perfusion experiments, Cushing acquired a broad knowledge of the physiology of body fluids, muscles, and nerves. He demonstrated that a pure sodium chloride solution deprived frog muscle of its excitability in response to nerve stimuli. Small amounts of calcium chloride and potassium needed to be added to keep the muscle functioning normally.26)

In July 1901, Cushing spent a month at Liverpool in England with the British neurophysiologist Charles Sherrington. Using primates, such as the chimpanzee, orang-utang, and gorilla, they stimulated the cerebral cortex with electrodes to localize its functions. With extraordinary surgical skill, Cushing helped Sherrington by trephining the skulls of the primates. Sherrington's experiments in 1901 established the localization of function in the motor cortex and were of great significance in the history of physiology. Cushing was thus able to be there to participate in one of the most important experiments in neurophysiology. Sherrington was grateful for Cushing's surgical assistance as well as for his excellent drawings of the cortex of the gorilla, which Sherrington later used in his paper.27)

Through his laboratory work at Berne and Liverpool, Cushing acquired a physiological approach to the solution of problems relating to normal and pathological conditions of the human body, using animal experiments. His laboratory work with Kocher, Kronecker, and Sherrington exerted a lasting impact on his way of thinking and on his career. He became familiar with physiological techniques and reasoning. Through the experiments with Sherrington on brain physiology, Cushing became deeply interested in neurophysiology, and neurosurgery. The European trip played a pivotal role in his decision to become a neurosurgeon. After returning to Baltimore, he began to concentrate his attention on

Medical Sciences 1903;125: 1017–1044.


neurosurgical patients. His studies at Berne on the relationship between increased intracranial pressure and blood pressure elucidated fundamental phenomena in neurophysiology. They served later as a theoretical basis for decompressive surgery. The European trip convinced Cushing that surgical education should be based upon animal experiments. He made a long-lasting contribution to surgical education by the establishment at Johns Hopkins of a laboratory for experimental medicine. The European trip transformed Cushing into a surgeon-physiologist.

5. Introduction of Blood Pressure Monitoring to America

As a result of the European trip, Cushing also made an important contribution to general surgery in America. In May 1901 at the Ospidale di San Matteo at Pavia, Cushing found that Riva-Rocci's blood pressure device was in routine daily use throughout the hospital. Promptly grasping the importance of the device for medical practice, Cushing sketched it, and brought a model of the inflatable armlet to Baltimore in August 1901. He began to use the apparatus at the bedside in the Johns Hopkins Hospital, and paid special attention to its use to monitor blood pressure during surgical operations.

Up to that time, surgeons had depended upon palpation to check the condition of the heart in critical operations. Codman and Cushing's anesthesia charts of 1895 had not spread widely. Before its publication, Codman showed a paper that he had written on the anesthesia charts to John Collins Warren, professor of surgery at Harvard. Warren opposed publication of the paper, because he said it was "too frank for the good of the hospital." It revealed frequently careless administration of anesthesia and operations at the Massachusetts General Hospital.28) Although Cushing and Codman began the first anesthesia charts in 1895, the Massachusetts General Hospital did not begin to keep anesthesia records until 1915.29) At the Massachusetts General Hospital, surgery remained a matter of the surgeon's manipulative skill and ability to detect

and deal with any changes in the physiological state of the patient during an operation. In December 1901, at a meeting in Cleveland, Cushing talked about the Riva-Rocci apparatus to George W. Crile, professor of surgery at Western Reserve University. Listening to their conversation, William T. Councilman, professor of pathology at Harvard became interested in the apparatus, and invited both Cushing and Crile to present papers on blood pressure.

At Boston in January 1903, Crile read a paper on methods for the control of blood pressure, while Cushing demonstrated various apparatuses for measuring blood pressure, and discussed the clinical value of blood pressure observations.\(^{30}\) Well aware of the conservatism of older surgeons and medical practitioners, Cushing began with historical examples of the slow introduction of two instruments—the thermometer and the watch—to medical practice. Although both instruments dated back to Galilei Galileo in the early seventeenth century, their use at the bedside was established only in the nineteenth century. Simple as they were, the thermometer and the watch to check temperature and pulse rate played a vital role in revealing the condition of the patient. Cushing pointed out that medical practitioners had always adopted instruments with considerable reluctance, believing that the use of instruments might blunt the powers of observation developed by their predecessors. Prophetically, he said: "I earnestly believe that the time is not far distant when routine observations on blood pressure ... will be taken in our hospitals in correspondence with the present thermic and pulse-rate observations."\(^{31}\) Persuasively and systematically, Cushing explained the value of blood pressure observations in diagnosis and treatment, both in the clinic and the operating room. Patients might show either hypotension or hypertension. Shock might occur from mechanical, toxic, or nervous origins. If a physician checked the blood pressure of the patient regularly, he could recognize too-low, or too-high blood pressures. The therapeutic value of blood pressure monitoring was even more apparent.

\(^{30}\) The paper was published as Harvey Cushing. On routine determinations of arterial tension in operating room and clinic. The Boston Medical and Surgical Journal 1903:148: 250–256.

\(^{31}\) Ibid., p. 252.
The physician could intervene in shock, either by giving fluid, or administering such medicines as digitalis, or adrenaline, as he monitored the effects of the medicine by checking the blood pressure. When a physician performed minor operative procedures at the bedside such as aspiration of fluid from the body cavities, he could prevent occasional accompanying accidents such as shock by simultaneous recording of the blood pressure. Cushing explained how blood pressure monitoring could play a vital role in the prevention of surgical shock, which occurred frequently from various causes. During operations, surgeons frequently faced such situations as extensive hemorrhage, or injury to nerves and tissues, any of which might cause a serious fall in the blood pressure, resulting in surgical shock. By monitoring blood pressure at regular intervals, the surgeon could check whether the operative procedures were causing the patient’s condition to deteriorate, and could thereby prevent dangerous situations.

In operations on the central nervous system, Cushing found blood pressure monitoring of the greatest value. From his experiments at Berne, he knew that blood pressure was related closely to intracranial pressure. During operations upon the brain, the surgeon might have to compress or elevate parts of the brain, causing increased intracranial pressure, or impose direct compression on the cardiovascular center in the medulla. Continuous observation of blood pressure gave the neurosurgeon timely warning whether he was carrying out the procedures safely. In neurosurgical operations, Cushing found that it was most satisfactory to have an anesthesiologist monitor blood pressure, and, in critical operations, to listen to the heart sounds by a stethoscope applied continuously to the patient’s chest.

To Cushing, the introduction of the blood pressure device at the bedside meant far more than adding a new instrument to the medical armament. He maintained that clinicians should apply the methods and principles of physiology to the solution of clinical problems. Adoption of the blood pressure apparatus could be one way to do so. While in the late nineteenth century physicians had become more involved in bacteriology, and pathology, they had gradually withdrawn their interest from experimental physiology. Of the medical student, Cushing noted:
"there is little if anything said or done in most schools during his period of bedside instruction to point out the physiological effects of processes of disease, much less to stimulate him with any personal keenness for the pursuit of knowledge along the physiological highway."32) By the introduction of instrumental methods to measure the blood pressure of the patient more precisely, students could keep their mind alive to the principles of the circulation, and connect what they learned in the physiological laboratory to clinical experience.

Cushing's paper on the importance of routine examinations of blood pressure arouse widespread interest. A month later, in February 1903, the Surgical Department of the Harvard Medical School appointed a committee "to determine, so far as the opportunities in this community will allow, the extent to which blood pressure observations in surgical cases may be of value from a clinical point of view."33) The Committee sent a letter to surgeons at the Massachusetts General, Boston City, and Children's Hospitals, asking their help in estimating the value of the blood pressure apparatus. After receiving the instrument and instructions for its use, surgeons employed it at the bedside and in the operating room, and reported their observations to the Committee. In March 1904 the Committee published the results of the survey.34) Thirty-four surgeons, including many prominent surgeons in Boston, responded to the request. After presenting dozens of blood pressure charts, the Committee drew several conclusions concerning the usefulness of blood pressure observations. In cases of surgical shock, the blood pressure observations contributed little to diagnosis, since they only confirmed what the surgeon already knew from physical examination. The report continued: "In hemorrhage the condition of the patient, as estimated by the pulse, respiration, temperature and general appearance, seemed to be more valuable than the blood pressure observations."35) The report discussed the value of blood pressure observations at three different stages of

32) Ibid., p. 255.
33) Harvey Cushing Papers, Microfilm Reel 127.
35) Ibid., p. 39.
surgical treatment: before the operation, during the operation, and during post-operative care of the patient. In all cases, the results were negative or inconclusive. "The adoption of blood-pressure observations in surgical patients," it concluded, "does not at present appear to be necessary as a routine measure." 

Disappointed at the report, Cushing wrote a line at the bottom of his own reprint of the invitation letter of the Committee in February 1903: "And they did not approve ...." Underneath the line, Cushing added verses from Oliver Wendell Holmes' "Stethoscope Song."

"Now, such as hate new-fangled toys
Began to look extremely glum:
They said that rattles were made for boys,
And vowed that his buzzing was all a hum."

— The Stethoscope Song. O.W.H.

Despite the report of the committee, physicians and surgeons throughout the country began to adopt the routine examination of blood pressure. In 1902 Cushing published another paper on blood pressure. In 1903, George Crile's monograph on the observation of blood pressure during surgical operations persuaded the medical world to begin to use the apparatus at the bedside and in the operating room. Of the Committee's report, the Moseley Professor of Surgery at Harvard, Francis D. Moore wrote long afterward: "This epic report was followed within months by the widespread adoption of the practice, and, of course, the members of the Committee never forgot the episode."

36) Ibid., p. 41.
37) Harvey Cushing Papers, Microfilm Reel 127.
6. The Hunterian Laboratory and Cushing’s Surgical Education

In fall of 1901, when Cushing returned to Baltimore as Associate in Surgery, he began an elective course on experimental surgery on a small scale at the Johns Hopkins Medical School. Since 1895, William Halsted had conducted a course in experimental surgery for third-year medical students. Cushing developed this course into a model for surgical education in American medical schools. During the first four years, he used the northeast room on the ground floor of the anatomical building for the operative course. It soon became popular, with many more applicants than could be accepted.

To meet the demand, Cushing made a formal request to the university trustees for an inexpensive new building. He expected a favorable response, but the financial losses that the university had suffered in the Baltimore fire of February 1904 prevented the trustees from acting. With the help of friends, Cushing raised $5,000 and returned to the trustees to make a second appeal. He wanted first a temporary one-room barrack to cost $1,000 for construction and $4,000 for equipment and operation. The university turned down the request on the ground that the money was inadequate to construct a building in conformity with the other buildings of the Medical School. When Cushing learned why his request was rejected, he made another appeal together with the professor of pathology, W. G. MacCallum, who similarly needed facilities for experimental researches. The two men requested a simple building to serve as a center both for experimental studies and to house the animals used for research by the whole school. This time, the medical students supported the request, and the entire class signed up for the elective course in operative surgery. Finally, the university accepted the appeal, and erected the building at cost of $15,000.

The building was divided into two equal parts: one for experimental surgery, the other for experimental pathology. The ground floor was used to receive and distribute animals for investigation, or for classwork in the various departments of the medical school. The second floor contained rooms for teaching and research. Cushing and his colleagues discussed
how the building should be named. Cushing proposed to call it the Magendie Laboratory, but the antivivisectionists then active in Baltimore regarded Francois Magendie with intense anathema. William Henry Welch, therefore, suggested the use of John Hunter's name instead. Hence, the new building was called the Hunterian Laboratory of Experimental Medicine.

After the establishment of the Hunterian Laboratory in 1905, Cushing made the course in operative surgery an important part of the regular medical curriculum.\(^{41}\) He intended that the laboratory should serve both for the training of medical students in surgery, and for experimental research in surgery and pathology.\(^{42}\) At the laboratory, Cushing continued the course in experimental surgery for third-year medical students. He believed firmly that both physician and surgeon should have a broad knowledge of medicine and surgery, and that surgical skill should be acquired by training in actual operations.

The course in experimental surgery was a rigorous one, running on Fridays from eleven o'clock in the morning till evening. The twenty students in the course were divided into four groups. Within each group, the members played various roles, serving in turn as non-operating physician, surgical operator, the operator's first assistant, operator's second assistant, and anesthetist. The students taking the role of physician selected cases from William Stewart Halsted's surgical cases, after the instructor told them the subjects of the next exercise. The topics included laminectomies, craniotomies, surgery of the blood-vessels, interscapulothoracic amputation, and the various kinds of intestinal suture used in appendectomy, pyloroplasty, cholecystectomy, resection of the caecum, and lateral and 'end-to-end' entero-enterostomy.\(^{43}\) After

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\(^{43}\) John F. Fulton. op. cit. p. 219.
presenting the history of the patient under consideration, the physician answered questions from the consulting surgeon. The team then discussed the possible location of the lesion producing the symptoms, its possible nature, and what the best treatment might be. After reaching a decision on treatment, the team began the required operation on the experimental animal. Each team carried out a complete operative procedure from the preparation of the animal, the selection of instruments and the anesthetic, to the post-operative care. Throughout the whole procedure, they treated the animal as if it were a human patient. They used aseptic technique, and the anesthesiologist monitored the blood pressure, pulse, respiration, and body temperature continuously throughout the operation. If the animal patient died, they performed a post-mortem examination.

The teaching at the Hunterian Laboratory proved rewarding. Cushing was an inspiring teacher, earnest and clear. The course benefited medical students whether they were to become general practitioners, surgeons, or experimental scientists. The course acquainted the students with fundamental principles of surgical procedure. It included anesthesia, asepsis, homeostasis, the proper handling of living tissues and organs, the healing of wounds, and autopsies. It also provided teachers and students with opportunities to interact. In 1920, in a letter to Jay McLean, who was then in charge of the Hunterian laboratory, Cushing said, "I feel that this third-year Friday exercise carried on in the Old Hunterian from 1905 to 1912 was by far the most satisfactory and profitable source of contact between student and teacher that I have experienced." 

In the classroom Cushing always looked for students who had an aptitude for original research. From his observation of students during the operative course, at the end, he selected several of them and assigned each a research question. From the class of 1907, eight students published papers in the Bulletin of the Johns Hopkins Hospital based on work growing out of the operative course. Ten students from the 1908

44) His students remembered him as a stimulating teacher. See Crowe. Halsted of Johns Hopkins, pp. 71-72. For the students' appreciation of Cushing's Operative Surgery course, see Fulton, op. cit., p. 217, 222.

class also pursued original research as undergraduates in the Hunterian Laboratory, and published their papers.\textsuperscript{47} Their first experience of original research came from the experimental courses in the Hunterian Laboratory, and many of them contributed to medicine during their later careers.

Cushing thought that the success of the Hunterian Laboratory arose from the unique situation and characteristics of the Johns Hopkins Hospital at that time.\textsuperscript{48} Without any apparent departmental organization at the hospital in those days, the professors' junior associates had much room to develop and practice their own teaching methods. The young men agreed on what they would teach, and were allowed to go about it in their own way. Cushing also attributed the success of the Hunterian Laboratory to Halsted. "Dr. Halsted always had a problem on foot and came to the laboratory frequently during its early days. His custom, to which I have already referred, of giving his juniors free swing with their own projects was what really made the laboratory a possibility."\textsuperscript{49}

Harvey Cushing’s model for surgical training in the Hunterian Laboratory was to influence surgical training at many other medical schools. In 1922 Halsted wrote:

\begin{quote}
I embrace this opportunity to express my indebtedness to Harvey Cushing, for thirteen years my brilliant assistant, for his zeal in elaborating these courses and placing them on such a substantial basis that they are now regarded as one of the dominant features of the surgical curriculum for the third year medical students at the Johns Hopkins University, and are being adopted by other medical schools in this country.\textsuperscript{50}
\end{quote}

\textsuperscript{46} They were F. W. Bancroft, E. S. Cross, G. W. Henry, W. D. Gatch, J. G. Hopkins, A. R. Dochez, W. von Gerber, and G. J. Heuer.


\textsuperscript{48} John F. Fulton. op. cit. p. 217.

\textsuperscript{49} Ibid., p. 221.

Cushing himself took the research and teaching tradition of the Hunterian Laboratory to Harvard University when he moved there in 1912. At Harvard he established a surgical laboratory, placing John Homans and William C. Quinby in charge of it. Both men had worked in the Hunterian Laboratory at Johns Hopkins. Those who took charge of the laboratory at Harvard received the Arthur Tracy Cabot Fellowship.\(^{51}\) Like those who worked at the Hunterian Laboratory in Baltimore, many of them later became eminent surgeons.\(^{52}\) In the late 1920s at the University of Minnesota, Owen H. Wangensteen introduced a similar laboratory for experimental surgery, using dogs.

7. Conclusion

Through his work on neurosurgery and the pituitary, Cushing played a significant role in the development of early-twentieth-century American medicine. Young doctors of a new generation in America, trained both in clinical medicine and experimental sciences, developed medical specialties. Distinguishing themselves from both basic medical scientists and ordinary practitioners, they pursued researches in clinical medicine. In the beginning, they used the laboratory facilities of basic medical science departments, but soon began to establish their own laboratories. Clinical medicine emerged as the most important part of medical schools, and more physicians chose to become specialists.

By studying in the laboratory questions that arose at the bedside, Cushing established neurosurgery as a specialty, and contributed to the rise of endocrinology. In America and Europe, he absorbed the new knowledge generated by late-nineteenth-century medicine, especially in such medical sciences as bacteriology and physiology, and in the development of surgery accompanying the emergence of aseptic techniques. Combining laboratory research with clinical experience,

\(^{51}\) It was given successively to Lewis H. Weed, 1912-13, Gilbert Horrax 1914, Samuel C. Harvey 1915, William S. McCann 1916, and George B. Wislocki 1917-19.

\(^{52}\) Their names were comparable to those who were in charge successively at the Hunterian :Gilman, Ortschild, Reford, Crowe, Goetsch, and Jacobson.
Cushing pioneered the new field of neurosurgery. In 1896 when he began his residency at Johns Hopkins, neurosurgery and endocrinology scarcely existed. There were no specialists in neurosurgery, and patients with neurological diseases were seldom treated successfully. When he moved to Boston in 1912, Cushing had made neurosurgery a promising field of increasingly successful treatments for patients with brain diseases. His studies on the pituitary gland, elucidating its function in normal and pathological conditions, laid a foundation for further endocrinological research. Cushing's studies on the pituitary were regarded as one of his most important contributions to medicine during his Johns Hopkins period. His pituitary monograph was a milestone in the history of endocrinology, demonstrating the power of clinical studies to integrate the results of experiment, clinical observation, and surgical intervention.

From the beginning of his work in neurosurgery, Cushing repeatedly emphasized the importance of experimental studies for the progress of surgery.

Though an occasional technical stride may be made through the operative courage of a McDowell, the permanent advances are far more often the result of patient laboratory investigations: such, for example, as led Hunter to ligation for aneurysm, Bigelow to reduction at the hip, Billroth to intestinal anastomosis, Horsley to the first removal of a spinal cord tumor, Carrel to a perfected blood-vessel suture. The real leaders of to-day in surgery owe their place not to any special brilliancy in operative manipulations, but to their laborious experimental investigations of certain problems of disease, whereby has been disclosed a rational mechanical basis for a surgical therapy which can then be safely and successfully adapted by their many followers.53)

How did Cushing's physiological studies influence his clinical work? Cushing used experimental studies to solve problems arising at the bedside, such as the pathophysiology of diseases, the invention of

methods for diagnosis, and the establishment of effective treatment. He performed experiments to understand such symptoms and signs of the eye in brain tumor patients as choked disc, and visual field deviations. From animal studies on pituitary functions, Cushing was able to identify hypopituitarism in patients. From his experiments on total hypophysectomy, he concluded that surgical treatment for pituitary tumors or cysts should be confined to partial hypophysectomy. Total hypophysectomy would cause the patient's death. Cushing's established reputation as an expert on the pituitary allowed him to see pituitary patients referred from all over the country.

**Key Words**: Harvey Cushing, Experimental Surgery, Neurosurgery, Clinical Medicine, Basic Science
=초록=

생리학적 외과학의 발전과 하비 쿠싱

김옥주*

20세기에 들어오면서 실험의학이 임상분야에 영향을 미치기 시작하였다. 이 과정은 매우 복잡하였고, 의학사가들 사이에도 기초과학과 임상의학의 당시 관계가 협력관계인지 갈등관계인지에 대해 의견이 양분되어 있다. 19세기말과 20세기 초 실험과학이 과학적 의학의 기초로 등장한 이래, 실험과학과 임상의학은 미국에서 서로 상호의존적인 관계를 유지해 왔다. 그 역사적 관계는 복잡하다. 본 논문에서 필자는, 미국 신경외과의 창시자 하비 쿠싱(1869-1939)의 예를 들어 20세기 초 미국에서 임상분야와 실험과학 사이의 상호관계를 하비 쿠싱이 생리학적 의사가 되는 과정을 통하여 살펴보기로 한다.

20세기 초 미국 실험의학이 발전하던 시기에 쿠싱이 신경외과 의사로 활동한 존스홉킨스는 과학적 의학을 발전시키기에 적합한 환경과 조직을 갖고 있었다. 특히 쿠싱은 1900년과 1901년에 걸친 유럽 여행에서 발달된 생리학을 공부할 기회를 가지게 되었고, 이를 통하여 생리학적 지식에 근거한 외과의사가 되었다. 1896년에서 1905년 사이 신경외과 의사 훈련을 받은 쿠싱은 효과적인 신경외과적 치료법의 고안, 교과서와 논문의 출판, 레지던트 훈련 등의 방법을 통해 1905년에서 1912년에 걸쳐 신경외과를 하나의 분과로 성장시켰다. 1901년 그가 존스홉킨스에서 최초로 뇌하수체 환자에 대해 수술을 행한 이후 쿠싱은 뇌하수체에 대해 관심을 가지게 되었다. 1908년에서 1912년 사이에 헌터리안(Hunterian) 실험실과 임상영역에서 뇌하수체의 정상 기능 및 비정상 조건, 그리고 수술적 치료법에 대해 연구하였다. 1912년에는 10년간의 연구를 집대성한 저서『뇌하수체와 그 질환(The Pituitary Body and Its Disorders)』을 발표하였으며, 이 저서로 인해 그는 해당 분야의 권위자가 되었다. 이 시기 새롭게 등장한 대학에서 일하면서 병원에서 가르치는 임상연구자의 일원으로서, 쿠싱은 외과수술·실험과학·임상관찰을 통합해서 얻은 지식으로 초기 신경외과 분야의 새로운 의학지식을 개발하였다.

색인어 : 하비 쿠싱, 생리학적 외과, 신경외과, 임상의학, 기초의학

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