A History of Cardiac Auscultation and Some of Its Contributors

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Before the 19th century, physicians could listen to the heart only by applying their ear directly to the chest. This "immediate auscultation" suffered from social and technical limitations, which resulted in its disfavor. With the invention of the stethoscope by Laennec in 1816, "mediate auscultation" became possible, introducing an exciting and practical new method of bedside examination. Over the past 2 centuries, many illustrious physicians have contributed to the understanding of cardiac auscultation by providing an explanation for the sounds and noises that are heard in the normal and diseased heart. This article traces the lives and achievements of those who have contributed importantly to cardiac auscultation. Auscultation remains a low cost, but still sophisticated procedure that intimately connects the physician to the patient and transfers that all-important clinical power known as "the laying on of the hands." When used with skill, it may correctly determine whether more expensive testing should be ordered. In this way, the stethoscope deserves our continued respect and more attention as an indispensable aid for the evaluation of our patients.

(Am J Cardiol 2002;90:259–267)

. . .I forthwith commenced immediately at the hospital Necker a series of observations, which has been continued to the present time. The result has been that I have been enabled to discover a set of new signs of diseases of the chest, for the most part certain, simple, and prominent, and calculated, perhaps, to render the diagnosis of the diseases of the lungs, heart and pleura, as decided and circumstantial, as the indications furnished to the surgeon by the introduction of the finger or sound. . .

R.T.H. Laennec, 1819[1]

Before the 19th century, physicians could listen to the heart only by applying their ear directly to the chest. This "immediate auscultation" suffered from social and technical limitations, which resulted in its disfavor. The invention of the stethoscope by Laennec in 1816 introduced a practical method of bedside examination, which became known as "mediate auscultation." Over the past 2 centuries, many illustrious physicians have used this technique to provide an explanation of the sounds and noises heard in the normal and diseased heart. In this article, we review historical developments in cardiac auscultation, highlighting some key figures who have contributed importantly to its understanding and practice.

Hippocrates and the practice of immediate auscultation: Auscultation was practiced during the Hippocratic period (460 to 370 BC) by the direct application of the ear to the patient's chest and abdomen, a process known as immediate auscultation. Using this technique, Hippocrates described a "succussion splash," a noise heard when a body cavity containing air and water is shaken briskly.[2] Stressing the diagnostic value of auscultation, he wrote: *"You shall know by this that the chest contains water but not pus, if in applying the ear during a certain time on the side, you perceive a noise like that of boiling vinegar."* Hippocrates also described the friction rub of pleuritis, comparing it to the creaking sound of leather.[3]

William Harvey and the first description of heart sounds: From Hippocratic Greece to 17th century England, little knowledge was added to auscultation until William Harvey's 1628 monumental publication of *De Motu Cordis* (On the Motion of the Heart and Blood) in which he concludes that *"the chief function of the heart is the transmission and pumping of the blood through the arteries to the extremities of the body."* Harvey's treatise also provides the first description of the heart sounds: *"So it is with each movement of the heart when a portion of the blood is transferred from the veins to the arteries, that a pulse is made which may be heard within the chest. . . (and I describe the sound) as. . . two clacks of a water bellows to raise water."*[4]

Examination before Laennec: Before the 19th century, physical examination was mostly limited to inspection and palpation. Although percussion had been introduced by Auenbrugger in 1761, the technique received scant attention until it was revived by Jean-Nicolas Corvisart in 1808. Similarly, only a few medical writings referred to the use of auscultation before the invention of the stethoscope by Laennec in 1816. Among these writings, a clear reference to the heart sounds is that of Robert Hooke (1635 to 1703) who foresaw the importance of auscultation in his *Posthumous Works*: *"I have been able to hear very plainly the beating of a Man's heart. . . Who knows, I say, but that it may be possible to discover the Motions of the Internal Parts of Bodies. . . by the sound they make,*

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0002-9149/02/$–see front matter
PII S0002-9149(02)02465-7

FIGURE 1. Rene Théophile Hyacinthe Laennec (photograph courtesy of the National Library of Medicine).

that one may discover the Works performed in the several Offices and Shops of a Man's Body, and thereby discover what Instrument or Engine is out of order."[5]

Laennec and his discovery of the stethoscope: Mediate auscultation, a technique in which an instrument is interposed between the ear of the examiner and the body, was discovered by René Théophile Hyacinthe Laennec, a pupil of Corvisart (Figure 1). Laennec (1781 to 1826) was born in Brittany, France. When he was 4 years old, after the death of his mother, he was sent to live with his uncle, then Dean of Medicine at the University of Nantes. At the age of 20, Laennec studied at the École de Médecine in Paris. Under Napoleon Bonaparte, Paris was considered the leading center of medicine in the world with such great clinician-teacher-researchers as Xavier Bichat, Gaspard-Laurent Bayle, Guillaume Dupuytren, and Jean-Nicholas Corvisart. Laennec obtained his medical degree in 1804, having already published papers on peritonitis, amenorrhea, and establishing that phthisis was due to pulmonary tuberculosis. As a young clinician, he quickly gained a widespread reputation, and his patients included the French nobility. In 1816, Laennec was appointed chief of the Hopital Necker in Paris, which specialized in the care of patients with chest afflictions. He later wrote that direct auscultation was *"as uncomfortable for the doctor as it was for the patient, disgust in itself making it impracticable in hospitals, It was hardly suitable where most women were concerned and, with some the very size of their breasts was a physical obstacle to the employment of this method."*[6] Motivated by Corvisart's translation to French of Auenbrugger's treatise on percussion and his own distaste for the practice of direct auscultation, he sought his own physical method to improve the clinical diagnosis of chest diseases.[7] In 1816, Laennec discovered the use of the cylinder, an improvised instrument that amplified cardiac and pulmonary sounds. Laennec's account of the event remains one of the most famous in medical literature. *"In 1816, I was consulted by a young woman laboring under general symptoms of diseased heart, and in whose case percussion and the application of the hand were of little avail on account of the great degree of fatness. The other method just mentioned* [immediate auscultation] *being rendered inadmissible by the age and sex of the patient, I happened to recollect a simple and well-known fact in acoustics. . . The fact I allude to is the augmented impression of sound when conveyed through certain solid bodies, as when we hear the scratch of a pin at one end of a piece of wood, on applying our ear to the other. Immediately, on this suggestion, I rolled a quire of paper into a sort of cylinder and applied one end of it to the region of the heart and the other to my ear, and was not a little surprised and pleased, to find that I could perceive the action of the heart in a manner much more clear and distinct than I had ever been able to do by the immediate application of the ear . . . I shall now describe the instrument which I use at present, and which has appeared to me to be preferable to all others. It consists simply of a cylinder of wood, perforated in its center longitudinally, by a bore three lines in diameter, and formed so as to come apart in the middle, for the benefit of being more easily carried. . . . The complete instrument,—that is, with the funnel-shaped plug infixed,—is used in exploring the signs obtained through the medium of the voice and the action of the heart, the other modification or with the stopper removed, is for examining the sounds communicated by respiration. This instrument I commonly designate simply the Cylinder, sometimes the Stethoscope."*[1] (Greek: stethos = chest, skopein = to view or to see.)

Despite his frail health, he carried on his research on diseases of the chest, carefully auscultating close to 3,000 patients between May 1817 and May 1819, while correlating his antemortem observations with the necropsy findings. In 1819, Laennec published his discovery and findings in *Traité de L'auscultation Médiate* (On Mediate Auscultation).[8] His ability to play a variety of musical instruments enhanced his appreciation of the acoustic discoveries, and he provided elaborate terms, including bruit (French meaning sound or murmur), egophony, crepitations, pectoriloquy, rales, and rhonchi in his descriptions.[2]

Laennec's contribution to cardiac auscultation resides mainly in his provision of the stethoscope and a scientific approach to the physical examination. However, his conclusions derived from auscultation provided an erroneous explanation of the physiology of the heart sounds. Although Harvey had long ago observed that the contraction of the auricles preceded that of the ventricles, Laennec insisted that the ear was a better judge than the eye, leading him to conclude that atrial contraction occurred after ventricular contraction and caused the second heart sound: *"One of these is clear and rapid, and somewhat resembles the sound produced by the valve of a pair of bellows: this corresponds to the systole of the auricles. The other is more dull and prolonged, coinciding with the beat of the pulse and with the shock or impulse communicated to the parietes by the motion of the heart:—it indicates the contraction of the ventricles."*[1] Laennec deduced that the first heart sound ("bruit ventriculaire") was of ventricular origin because it occurred simultaneously with the increase in the carotid pulse and was of maximum loudness at the apex. He then went on to assume that the second heart sound ("bruit auriculaire") was generated by the contraction of the atria, a supposition supported by his observation that it was loudest at the upper sternal border. Because of his confusion about the heart sounds, Laennec failed to relate the cardiac sounds and murmurs to specific pathology. Furthermore, he incorrectly attributed the generation of cardiac murmurs to spasms of the heart and the great vessels.[9] Laennec's faulty conclusions went unchallenged until 1828 when John Turner, a professor of surgery at Edinburgh, corrected Laennec's view by reasserting the Harveian knowledge that the atrium contracts before the ventricle.[10] In 1861, working in Lyon, France, J.B.A. Chauveau, a veterinarian, and E.J. Marey, a physician who was a pioneer in the sphygmographic method, would further resolve the continuing controversy over the sequence of the heart sounds. Using a novel double-lumen technique that allowed simultaneous recordings of the apex impulse and the intracardiac pressures in the horse, their work provided a scientific basis for correlating the events of the cardiac cycle.[11]

Laennec struggled with his own lung disease, including asthma and tuberculosis. In August of 1826, at the age of 45, he succumbed to tuberculosis at his village of Kerlouanec.[12]

The dissemination of auscultation: The French reception to Laennec's discovery was to some extent cool, and he was even treated with ridicule, with the resistance against the stethoscope organized mostly by Francois Broussais.[13] An influential French physician of the time, Broussais was a fierce critic who accused Laennec of plagiarism, and labeled his treatise on mediate auscultation as "*obscure. . . sad, and cluttered with a mass of meaningless facts and useless peculiarities.*"[13,14] Nevertheless, stethoscopy attracted many supporters, including Monsieur de Chateaubriand, a famous writer and one of Laennec's patients, who wrote in 1819: *"By means of a tube applied to the outer parts of the body, our learned compatriot Laennec has succeeded in recognizing, by the nature of the sounds of respiration, the nature of the complaints of the heart and the chest. This great and wonderful discovery will mark an era in the history of medical art."*[7] Students from around Europe were soon flocking to Paris eager for Laennec's instruction. According to an account kept by Laennec, nearly 300 foreign students had attended his demonstrations and lectures by 1826.

In France, one of the earliest proponents of the new method was Jacques Alexandre Le Jumeau de Kergaradec (1787 to 1877) who pioneered fetal auscultation. In 1803, after completing 3 years of medical studies, Kergaradec traveled to Paris and studied anatomic pathology under Dupuytren and Bayle. There he met Laennec, whose treatise he would later defend. In 1819, Kergaradec first applied the stethoscope to the abdomen of a pregnant woman and noted the tic-tac of the fetal heart. He wrote: *"It seemed to me that I was hearing the movements of a watch placed very close to me."* He also described the placental souffle and wrote *Memoire on Auscultation as Applied to the Study of Pregnancy*.[15]

By the 1830s, the stethoscope was widely used and expected by patients, and the 19th century became known as "the golden age of stethoscopy."[2,14] Greatly aided by John Forbes, a Cornwall physician who translated Laennec's book in 1821, the English were quick to realize the advantages of the new technique, Forbes wrote in the preface: *"In short. . . he [Laennec] may be said to have realized the wish of the ancient philosopher, and to have placed a window in the breast through which we can see the precise state of things within."* Nevertheless, Forbes was skeptical of its widespread adoption stating *"That it will ever come into general use, not withstanding its value, I am extremely doubtful; because its whole hue and character is foreign, and opposed to all our habits and associations. It must be confessed that there is something even ludicrous in the picture of a grave physician formally listening through a long tube applied to the patient's thorax, as if the disease within were a living being that could communicate its condition to the sense without."*[1] Early English enthusiasts also included Thomas Hodgkin, who demonstrated the stethoscope at Guy's Hospital, James Clark, a Scottish physician to John Keats and Queen Victoria, who introduced it to his English practice in Italy, and Mathew Baillie, an important anatomist and physician to King George III.[16]

William Stokes (1804 to 1878), the son of the Regius Professor of Medicine at the University of Dublin, was so impressed with Laennec's invention that he wrote a comprehensive monograph, *Introduction to the Use of the Stethoscope*, which was published in 1825 just before his graduation from the University of Edinburgh Medical School. This was the first English book written about the stethoscope, although it did not provide any original contributions. Stokes wrote *"a new source of knowledge has been lately added to medicine; the sense of hearing has been called to our assistance, and has, I will affirm, added more to the facility, certainty, and utility of diagnosis than anything which has been done for centuries. By the stethoscope we substitute the ear for the eye; penetrate into the mysteries of hidden disease, and throw light on a class of affections perhaps more* *important than most of those to which the human frame is liable."*[17] His 1854 book, *Diseases of the Heart*, stressed the importance of correlating the symptoms with the examination and cautioned against relying too heavily on physical signs. He called attention to the alteration in the intensity of murmurs with a change in position, distinguishing functional murmurs from organic ones, and not judging the severity of heart disease solely on the murmur, emphasizing the role of the heart muscle.[18,19] He is remembered today for his descriptions that led to the recognition of "Stokes-Adams attacks" (1846) and "Cheyne-Stokes respiration" (1854).

Joseph Skoda (1805 to 1881) from Bohemia, a renowned diagnostician and Chair of Internal Medicine at the University of Vienna, is credited with promoting auscultation in Europe.[20] Skoda was schooled in pathologic anatomy by Karl von Rokitansky and had a special knowledge of acoustics. Because he did not study under Laennec, he had to learn auscultation from his own careful experiments on patients and cadavers. His examinations were so exhaustive that patients complained, and he was transferred to work on a mental ward. His book, *Auscultation and Percussion*, published in 1839 and later translated into English in 1853, provided an inductive approach to heart sounds and murmurs based on physical principles of pitch and tone.[21] His refined approach simplified the more complex and empiric French terminology, which taught that each noise meant a different disease, and he helped to popularize both techniques.[19,20]

The origin of heart sounds: James Hope and C.J.B. Williams in England were auscultatory advocates who also investigated the mechanism of heart sounds. James Hope (1801 to 1841) was born in Stockport, England, the son of a wealthy merchant.[22] As a student in Edinburgh, he attended a discussion of the Royal Medical Society about the merits of Laennec's new invention, which stimulated his interest in cardiology. After graduating in 1825, Hope became a clinical clerk under Auguste-Francois Chomel, successor to Laennec at La Charité in Paris, where he adopted the French technique of careful note taking correlated with postmortem findings. He was a skilled artist and anatomic illustrator who later published *Morbid Anatomy*, an atlas containing 260 beautifully drawn color plates. After 2 years in Europe, Hope returned to England in 1829 ambitious to write a textbook on the heart and establish himself as the authority on the practical use of the stethoscope. In 1831, at the age of 30, he published *Diseases of the Heart and Great Vessels*. His book, one of the earliest texts in cardiology, provided the clinical and pathologic findings of different types of heart disease and discussed his experimental studies on the second heart sound. Using an open chest, stunned donkey and inserting a hook into the heart to interfere with valvular function while observers listened to the cardiac surface with a stethoscope, he presented evidence for the valvular origin of the second heart sound.[23]

"Obs 10: Before the pericardium was opened, both sounds were very distinctly heard.

Obs 11: Both were also distinctly heard through the lung interposed between the heart and the end of the stethoscope.

Obs 12: About 2 or 3 inches up the aorta from its origin, the second sound was heard (but not the first), alternating with the impulse as felt on the ventricles.

Obs 13: The second sound was decidedly more distinct over the origins of the aorta and pulmonary artery than on the body of the ventricles; and, in that situation, it was louder than the first sound at the same point. It has exactly its natural short, clear, flapping character.

Obs 14: The aorta and the pulmonary artery being compressed between the fingers, the first sound was accompanied by a loud murmur, and the second was stopped.

Obs 15: A common dissecting hook was passed into the pulmonary artery, so as to prevent the closure of the semilunar valves: the second sound was impaired, and a hissing murmur accompanied it. A hook was passed into the aorta so as to act in the same way on the aortic valves: the second sound entirely ceased, and was replaced by a prolonged hissing.

Obs 16: When the hooks were withdrawn, the second sound returned and the hissing ceased."[23]

Hope also provided early descriptions of valvular disease, the jerking pulse of aortic regurgitation, the correct location of the venous hum, and was the first to use the term "cardiac asthma."[22] His description of mitral stenosis and regurgitation was memorable: *"When the valve is permanently open, admitting of regurgitation, the first sound is attended with a murmur. It may be rough (rasping), or smooth (bellows murmur) according to the nature of the contraction. Its key is low, more like whispering Who; yet it sounds loud and near if explored about the apex of the heart, and a little to the sternal side of the nipple. . . When the mitral valve is considerably contracted, a murmur attends the ventricular diastole and the second sound. From the weakness, however, of the diastolic current out of the auricle, the murmur is always very feeble, soft like the bellows-sound, and usually on a rather lower key than a whispered Who."*[23]

To promote his cause of auscultation, Hope staged public demonstrations to show that novice medical students, given only a 10-minute instruction on the stethoscope, could correctly diagnose valvular disease in complicated patients.[24] His showmanship and willingness to risk his reputation was successful in convincing physicians that auscultation could be valuable, whereas others saw it as self-promotion. His easily aroused combative nature and fierce determination to keep his name in the forefront brought him into public disputes with other leading physicians.[19,25] His health, never robust, worsened after the third edition of his book, and he was forced to retire in 1840. After working hard to achieve acceptance for mediate auscultation and his own priority for the discoveries, Hope died at the age of 40 from pulmonary tuberculosis.[22]

Charles J.B. Williams (1805 to 1889) attended Laennec's clinic and lectures at La Charité in 1825 and 1826. Although he admired Laennec's technique and powers of observation, Williams found his approach to be dogmatic and lacking a scientific explanation, a problem that could lead to incorrect diagnoses and disbelief in its value.[24] Williams believed that the auscultatory signs should be related to physical laws that would aid in their interpretation,[26] and in 1828 he published *Rational Exposition of the Physical Signs of Diseases of the Chest*.[27] He attributed the first heart sound to muscular contraction of the ventricles and the second to "tightening" of the semilunar valves from reaction to the arterial blood. Williams was the first to appreciate the diastolic timing of mitral stenosis. He also devised a flexible monaural stethoscope with a trumpet-shaped head and coined the term "lubb-dupp."[15] Sharing a similar interest in the origin of the heart sounds, Williams and Hope, once friends, became bitter rivals, each claiming priority for the discovery of the origin of the heart sounds.[25]

Joseph Rouanet (1797 to 1865) was also one of the first to investigate the origin of the heart sounds. After initially preparing for the priesthood, Rouanet became a medical student in Paris, graduating in 1832. During the same year, he experimentally determined that heart sounds were generated by valvular motion. However, Rouanet's theory was not accepted by the scientific community, primarily because of a competing proposition by the widely respected Francois Magendie. In 1834, before the French Academy of Science, Magendie postulated that heart sounds were produced by the movement of the heart against the thoracic cavity during the cardiac cycle. Rouanet further refined his experiments and supported his case with physiologic and clinical data. From his studies on the effect of various pathology on the heart sounds, he concluded, "*The force* [of the first heart sound] *is related to the energy of contraction of the ventricles and to the exact occlusion of the auriculo-ventricular orifice; thus, when presented with unusual weakness, we should look into whether ventricular systole lacks vigor and whether the large valves close their valves incompletely.*"[2]

The discovery of gallop rhythms: Further characterization of the components of the second heart sound, as well as the description of gallop rhythms, resulted from the observations in France of Jean-Baptiste Bouillaud and his student Pierre-Carl Potain. Bouillaud (1796 to 1881) was born near Angouleme, France. Under the influence of his uncle, a surgeon in the army, Bouillaud left his hometown to study medicine in Paris under Corvisart, Laennec, and Magendie, graduating in 1823.[28] Shortly thereafter, he joined the staff of the Hôpital de la Charité where he became known as a prolific writer, a famous practitioner, and a respected teacher. His scientific contributions included the description of the endocardium and endocardial inflammation. Bouillaud made a number of contributions to cardiac auscultation. He was the first to note the mitral opening snap, which he called the "*bruit de rappel.*"[28] William S. Thayer, in 1909, later introduced the English term "*opening snap.*"[2] Bouillaud was credited by Potain with the original description and use of the term "gallop rhythm," although in 1838 Charcellay in Tours had already discovered a presystolic sound at the time of atrial contraction.[2] Bouillaud also described splitting of the second heart sound and the pericardial rub.[2,28]

Pierre-Carl Potain (1825 to 1901) was born in Paris. Influenced by his father, he decided to go into medicine. Upon graduating from the University of Paris Medical School in 1853, he became an assistant to Bouillaud at La Charité Hospital and eventually the leading physician in Paris.[29] Potain made numerous scientific contributions throughout his career, including an early analysis of the jugular venous waves, the development of the sphygmomanometer, an instrument to count erythrocytes, and the design of a thoracocentesis apparatus.[2] His contribution to the field of cardiac auscultation began in 1866 when he described inspiratory splitting of the second heart sound.[20] In 1876, he wrote his classic description of gallop rhythm, a term he attributed to Bouillaud. About the fourth heart sound, he said: "*The formation of the rhythm of which I wish to speak is as follows: we distinguish here three sounds. . . the two normal sounds show most frequently their normal characteristics, without any modification. The first especially maintains its normal relation to the apex of the heart and to the arterial phase. As to the abnormal sound, it is placed immediately before it, preceding it sometimes by a very short time; always notably larger, however than that which separates the two parts of the reduplicated (first) sound.*" Distinguishing the fourth heart sound further from the split first heart sound, he wrote: "*. . . the abnormal sound has, in no way, the timbre or usual characteristic of a valvular sound. . . Finally, I have heard, in certain patients, successively, and in the same cardiac revolution, the 'bruit de gallop' itself and a reduplication of the first heart sound.*" Potain believed that the fourth heart sound resulted from "*. . . the abruptness with which the dilatation of the ventricle takes place during the presystolic period, a period which corresponds to the contraction of the auricle.*" He attributed the third sound to "*. . . the sudden cessation of distention of the ventricle in early diastole.*"[30] His conclusions about the mechanism of gallop sounds has continued to be upheld. In 1894, he described "*small, sharp clicking sounds*," which he thought resulted from pericardial adhesions. In retrospect, these sounds were likely the systolic clicks of mitral valve prolapse.[29]

The description of aortic insufficiency by Dominic Corrigan: The elucidation of the physical basis of cardiac murmurs by Dominic Corrigan in Ireland was a major step in understanding the relation between murmurs and valvular heart disease. Dominic Corrigan (1802 to 1880) was born in Dublin. He studied medicine at the University of Edinburgh in Scotland and graduated in 1825, returning at the time of the great Dublin school of medicine, which included Robert Graves, William Stokes, and John Cheyne.[31] Corrigan is best remembered for his vivid description of the murmur and pulse of aortic insufficiency. Although other investigators had already written on that subject, Corrigan's account was the most complete. In his article *"On Permanent Patency of the Mouth of the Aorta or Inadequacy of the Aortic Valves,"* he described the characteristic murmur: *"The bruit de soufflet characterizing this disease, is heard, . . . in the ascending aorta, its arch, and in the carotids and subclavians. It can be followed upwards from the fourth rib along the course of the aorta, increasing in loudness as it ascends, until it is heard of great intensity at the upper part of the sternum, where the arch of the aorta most nearly approaches this bone. . . In those cases in which the deficiency of the valves is considerable, allowing a full stream of blood to rush back into the ventricle, there is heard in the ascending aorta a double bruit; the first accompanying the diastole of the artery, the second immediately succeeding; and, in listening to the two sounds constituting this double bruit de soufflet, the impression made distinctly on the ear is, that the first sound is from a rushing of blood up the aorta, the second from a rushing of it back into the ventricle."*[32]

Three years earlier, Corrigan had published "Inquiry into the Causes of *'Bruit de Soufflet'* and *'Frémissement Cataire'*." pointing out that murmurs and thrills were manifestations of the same physical phenomenon, namely vibration.[33] This contradicted Laennec. Corrigan might have been the first to describe the pericardial knock, although credit is usually given to Potain. In 1842, Corrigan presented a paper in front of the Pathological Society of Dublin in which he described the findings in a patient with pericardial effusion. He wrote: *"There had been in this case a very loud bruit de frappement, which was most remarkable when the patient lay on his back."*[34]

Austin Flint and auscultation in America: The publication of Forbe's translation of Laennec's book in America in 1823, and the postgraduate return of influential American physicians trained in Europe, introduced the stethoscope in America; however, it was slow to be adopted.[19] Although Henry Bowditch published a book *The Young Stethoscopist* in 1846, and George Cammann in New York invented the first practical binaural stethoscope in 1855, Austin Flint was the acknowledged leader in the American development of auscultation.[35] William Osler, who taught that auscultation was 1 of the 4 points of a medical student's compass, told his students at the University of Pennsylvania: *"Not one of you who takes a stethoscope into his hands is but a debtor to Dr. Flint for simplifying much that was complicated in the auscultation of the heart and lungs."* Austin Flint (1812 to 1886) was born in Massachusetts. At Harvard Medical School, he learned stethoscopy from James Jackson, an enthusiastic teacher who had spent time in Paris. During Flint's professional life, he practiced at the Buffalo Medical College, which he helped found, the University of Louisville, New Orleans Charity Hospital, and Bellevue Hospital in New York.[26] His book, *Diseases of the Heart*, published in 1859, and a subsequent article classifying cardiac murmurs in 1862, were influential. Flint left New Orleans in 1861 for the newly opened Bellevue Hospital Medical College in New York. At Bellevue, Flint was a beloved teacher who inspired many by his twice-daily, bedside clinical instructions.

Not relevant

While at the New Orleans Charity Hospital, he first heard the diastolic murmur that bears his name. Flint noted a presystolic murmur at the cardiac apex in a patient with aortic insufficiency and stenosis who was found to have a normal mitral valve on autopsy. He did not publish his findings until 1862 when he described *"the mitral direct murmur."* His article stated: *"The mitral direct murmur is produced by the mitral direct current of blood forced by the auricular contractions through a contracted or roughened mitral orifice. . . . The murmur occurs just before the ventricular systole or the first sound of the heart; it continues up to the occurrence of the first sound, and instantly ceases when the first sound is heard. . . . The mitral direct is a presystolic murmur. . . it becomes more intense, and appears to abruptly arrested, in its greatest intensity, when the first sound occurs. . . The mitral direct murmur is heard loudest at or little within the apex."*[36]

Systolic clicks and late systolic murmurs: The understanding of ejection sounds, nonejection systolic clicks, and late systolic murmurs was a later event. Nineteenth century physicians attributed these clicks to pleuropericardial adhesions, or other ill-defined noncardiac sources, and considered late systolic murmurs to be a component of "functional" heart disease.[37,38] In 1871, Jacob DaCosta in Philadelphia, trained in Vienna and Paris and called the greatest clinical teacher of his time,[19] published his classic observations on the association between "curiously broken" heart sounds, a particular systolic apical murmur, and a clinical syndrome characterized by fatigue, chest pain, and cardiac irregularities in young soldiers without evidence of organic disease. This constellation of history and physical examination findings, referred to as "DaCosta's syndrome" by 19th century clinicians, established a distinction between functional and organic heart disease. The concept was further supported by James Mackenzie, Thomas Lewis, and William Osler at the British Heart Hospital, who described a functional cardiac disease termed "Soldier's Heart," which shared significant similarities with DaCosta's syndrome, including the presence of an apical systolic murmur in the absence of clear cardiac pathology. Later, Samuel Levine and Paul Dudley White in America defined neurocirculatory asthenia, a condition that blended with DaCosta's syndrome and the Soldier's Heart.[38,39]

Not relevant

The notion of the innocent nature of apical systolic murmurs was further strengthened by the work of Louis Gallavardin (1875 to 1957) in France who attributed the origin of systolic clicks to chronic pericardial adhesions. In 1913, he reported the necropsy findings of 4 patients known to have midsystolic clicks and late systolic murmurs. All displayed pleural and pericardial adhesions, leading him to postulate an extracardiac origin for these sounds. Although mistaken in his conclusion, Gallavardin's great reputation resulted in the widespread acceptance of this explanation.[40] The auscultatory phenomenon most frequently associated with Gallavardin remains his description of a high-pitched, musical apical murmur heard with aortic stenosis. Gallavardin described this finding in 1925, attributing it to the transmission of the musical component of the harsh murmur of aortic stenosis from the aortic area through the chest to the apex. This became known as the "Gallavardin effect."[41]

The dogma on the extracardiac origin and innocent nature of the nonejection systolic clicks and late systolic murmurs prevailed despite the insightful contributions of J.P. Crozer Griffith, J.N. Hall, and Morton Prince during the latter part of the 19th century. Prince linked these findings to the yielding of the mitral valve during systole, a postulate revived by John Reid in the 1950s[38,39] and firmly established through the work of John Barlow[42] and J. Michael Criley.[43]

An early systolic snapping sound heard in a patient with pulmonary stenosis was reported by André Petit in 1902.[44] Later, this was termed "claquement arterial pulmonaire protosystolique" by Lian and Welti in 1937,[45] a "semilunar opening snap" by Wolforth and Margolis in 1940,[46] and a "pulmonary early systolic sound" by Latham and Vogelpoel in 1954.[47] This is now known as a pulmonary ejection sound. A similar aortic systolic ejection sound was described by Lian and Welty in 1941, Wolferth and Margolies in 1940, and analyzed phonocardiographically by Reinhold, Rudhe, and Bonham-Carter in 1955.[48]

Twentieth century advances in the understanding of auscultation: Major advances in the understanding of cardiac sounds and murmurs, including their clinical significance and prognostic implications, had to await the advent of new technology. This has included cardiac fluoroscopy and chest x-ray, right and left heart catheterization, angiographic studies, external and intracardiac phonocardiography, and echocardiographic-phonocardiographic correlations.[49–51]

Willem Einthoven, the inventor of the modern electrocardiogram, was also the first to record heart sounds successfully in 1907.[52] High-fidelity phonocardiographic recordings and precise measurements of heart sounds and murmurs, provided by simultaneous phonocardiographic, electrocardiographic, and pulse recordings became the basis for the modern era of auscultation. Maurice Rappaport and Howard Sprague related the physical principles of cardiovascular sound with its phonocardiographic registration, and showed how the stethoscope and chest modified the frequencies perceived by the human ear. Their work improved the bedside understanding of auscultation and led to the design of a stethoscope with a bell and diaphragm combination.[53,54] In 1933, Harold Segall, a Canadian cardiologist who trained under Paul Dudley White, devised the written method often used today to diagram heart sounds and murmurs and to describe their characteristics.[55]

Contributions of Paul Wood and Aubrey Leatham in England: Influential British cardiologists included Paul Wood, the first to correlate the examination with cardiac catheterization, and Aubrey Leatham who utilized phonocardiography to provide a more scientific approach to cardiac auscultation. Paul Wood (1907 to 1962) was educated in Australia and New Zealand and came to London in 1933. He was introduced to the new technique of cardiac catheterization by John McMichael at the Hammersmith Hospital just after World War II. In 1947, he became the Dean of the Institute of Cardiology in London where his reputation attracted postgraduate students from around the world.[56] At the National Heart Hospital, Wood developed a quantitative approach to the examination by grading the history, cardiac examination, chest x-ray, and electrocardiographic findings on data cards, which were carefully correlated with the physiologic parameters found at cardiac catheterization. His publications on aortic and mitral stenosis, atrial septal defect, pulmonary stenosis, Eisenmenger's disease, and constrictive pericarditis provided much of the basis for our current understanding of these conditions. He was also one of the first to observe the auscultatory findings in hypertrophic cardiomyopathy and to publish on the fixed, split second heart sound of atrial septal defect, a finding that Wood attributed to W.W. Dicks, a cardiac technician at the London Hospital.[57]

While at the London Hospital from 1948 to 1950, Aubrey Leatham (1920-) developed a phonocardiogram with the unique capability of recording multiple precordial sites with a simultaneous carotid arterial pulse and electrocardiogram.[58] His phonocardiogram was equipped with a low-frequency filter to mimic the acoustic properties of the human ear and the stethoscope. In his Lancet article of October 4, 1958, he wrote: *"The improvement* [achieved with the phonocardiogram] *is mainly in appreciating the timing and relation to each other of heart sounds and murmurs, rather than in an increase in perception of faint murmurs, for here phonocardiography does not compete advantageously with the remarkable sensitivity and selectivity of the human ear."* Leatham demonstrated that the first component of the second heart sound was generated by aortic valve closure and the second component was the result of pulmonary valve closure. *"Using the double string galvanometer we made simultaneous phonocardiograms from the pulmonary and the mitral area together with an electrocardiogram or a recording of the carotid pulse. The first component of the second heart sound was the major one; it timed with the dicrotic notch of the carotid pulse, and was the sole component at the apex. The second component was confined to the pulmonary area and nearby, and its delay during inspiration was the major cause of the physiological splitting of the second heart sound."* His studies led to the identification of the abnormal splitting of the second heart sound in a variety of cardiac disorders, including bundle branch block and atrial septal defect. Using the radiologic findings described by John Parkinson, he was able to link atrial septal defect with the fixed splitting of the second heart sound. He further analyzed the first heart sound, and attributed its 2 components to mitral and tricuspid valve closure, later confirmed by obtaining simultaneous echocardiogram and phonocardiogram recordings at high paper speed. Leatham also published important information on aortic and pulmonary ejection sounds. By timing systolic murmurs according to their relation to the second heart sound, he created a helpful new classification of systolic murmurs, classified into ejection or pansystolic murmurs, that became universally adopted. He commented: *"It was soon clear . . . that the systolic murmur of aortic stenosis finished before the aortic component of the second heart sound, as indeed it had to, bearing in mind the cessation of forward flow before closure of the valve, and it seemed logical to describe these murmurs as ejection murmurs. On the other hand, with mitral regurgitation the systolic murmur always reached A2 and it was termed pansystolic. . ."* His work, published in the Lancet in 1958, remains a landmark in cardiac auscultation.[59]

Recent advances in the understanding and teaching of auscultation: Between World War II and the 1975 publication of the American Heart Association monograph, *Physiologic Principles of Heart Sounds and Murmurs*, numerous studies attempted to determine the genesis of cardiovascular sounds.[51] Many physicians have contributed to this scientific era of auscultation, and their work is well documented in the American Heart Association monograph. These studies are the basis for our current understanding of auscultation which can be summarized as follows: Heart sounds are attributed to a brief vibration of the cardiohemic system occurring when an accelerated pool of blood is checked by the closure of a normal valve (S_1, A_2, P_2); thrusts open an abnormal valve (ejection sound, mitral opening snap), or tenses a portion of an abnormal valve or membrane (nonejection click).[60] This acceleration-deceleration theory was first proposed by the physiologist Robert Rushmer.[61] By a similar mechanism, atrial and ventricular gallop sounds originate within the ventricular wall when onrushing blood from atrial contraction or rapid ventricular filling impacts against and interacts with the compliance of the ventricular wall. Others suggest that the gallop sound can also be generated by the expanding heart striking the inside of the chest wall. Heart murmurs are thought to be created by turbulence related to an increased blood flow, flow disturbed by an abnormally shaped orifice, or the combination of the 2. The 1 to 6/6 grading system of systolic murmurs still used today was introduced by Samuel Levine in 1933.[62]

Important teachers of auscultation in America: Among the outstanding teachers of auscultation in the United States, Samuel Levine, W. Proctor Harvey, J. Willis Hurst, Joseph K. Perloff, and J. Michael Criley are especially well known. Innovative audiovisual aids have been developed by Scott Buttersworth, Abe Ravin, W. Proctor Harvey, Michael Gordon, Robert J. Hall, J. Michael Criley, and others working together with creative audio engineers. The most sophisticated has been "Harvey," a full-sized mannequin developed by Michael Gordon and named after W. Proctor Harvey. Among the many fine textbooks written on auscultation, the ones by Samuel Levine, W. Proctor Harvey, Abe Ravin, Scott Buttersworth, Aldo Luisada, J. Willis Hurst, Joseph Perloff, and Jules Constant can be singled out for special mention.

Final thoughts: Laennec's revolutionary discovery of the stethoscope in 1816 introduced an original method that became indispensable to the bedside diagnosis of diseases of the chest. More recently, with the decrease in rheumatic valvular disease, the advent of echocardiography and other sophisticated diagnostic modalities, as well as the loss of important teachers who were the gold standard for trainees, the once-prized value and art of auscultation has seemed to diminish. Is the stethoscope, once the proud symbol of the clinician, at risk for becoming merely a cherished relic of the past? Although the answer has yet to be fully determined, auscultation remains an invaluable screening technique for the presence of heart, lung, and vascular disease, as well as for providing an estimate of its severity, evolution, and prognosis.[63] It is a low cost, but still sophisticated and enjoyable procedure that intimately connects the physician to the patient and transfers that all important clinical power known as "the laying on of the hands." When used with skill, it may correctly determine whether more expensive testing should be obtained. In this way, the stethoscope deserves our continued respect and increased attention as an indispensable aid for the evaluation of our patients.

Acknowledgment: We are grateful to Earnest Craige, Jacqueline Duffin, Christian Legnier, Alex Sakula, James Shaver, Charles B. Upshaw, and Charles F. Wooley for their suggestions. The librarians of the Sauls Memorial Library at Piedmont Hospital and Linda Mason provided invaluable assistance.

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