WILLEM EINTHOVEN

1860-1927
IT IS a privilege to join this assembly in paying tribute to Willem Einthoven on the Centenary of his birth. His introduction of a new tool—the string galvanometer—opened new fields of cardiovascular research and unquestionably catalyzed progress in cardiac diagnosis to a greater degree than any other development early in the present century.

So many facets of his life have already been recorded in numerous memorials and so very completely in a recent monograph by de Waart¹ that I shall limit my discourse to a personal assessment of: (1) the impact that his early work had on cardiac research and diagnosis, (2) the character and personality of the man behind the scenes, and (3) some incidents and accidents that developed his natural talents and directed him into a brilliant academic career. Such an approach should be appropriate since few members of this Congress are old enough to have experienced the immediate impact of his investigations on contemporary physiology and cardiology, and still fewer have been privileged to know him personally. To most of you, Einthoven represents only a name or a legendary figure.

**Impact of Einthoven’s Work on Cardiac Research and Diagnosis**

The first generally accessible description of the string galvanometer appeared in 1903, the year that fortuitously coincided with my appointment as a student assistant in physiology at the University of Michigan.

Our information about action currents at that time was limited to that which had been gained in the preceding century largely by cleverly circumventing the deficiencies of slowly reacting coil galvanometers and partly by use of Lippmann’s capillary electrometer. This electrometer had been available since 1872 and was converted to a photographic recording instrument by E. Marey in 1876. In my hands, as a young assistant attempting to demonstrate action potentials of a frog’s heart, the electrometer proved a temperamental instrument, usually performing well during rehearsals but quite regularly preferring to remain static before an audience.

Despite such technical handicaps some information regarding action currents of the heart was already available. In 1873, Engle-
mann in Utrecht had demonstrated that the ventricular action potential was diphasic, and during 1879 to 1881 Burdon Sanderson and Page had shown that this was but an initial deflection that was followed by a period of isopotential and this, in turn, by a final monophasic wave. In 1889, A. V. Waller had reported that electrical currents generated during the heart beat could be tapped from the body surface and recorded by a capillary electrometer. Human electrocardiography may thus be said to have been born in Oxford, England. However, since Waller went to great pains to rule out any possible clinical application of the procedure, this proved to be a stillbirth. Waller’s conclusion need not surprise us, if we view again the wholly unsatisfactory character of his records, for instance the one shown in figure 1 which was recorded by placing one electrode on the left arm and a silver spoon in the mouth.

It is at this point that we gain a good insight into Einthoven’s genius—a human trait that Carlyle has defined as “the ability to take infinite pains.” Einthoven, like several other physiologists, was naturally impelled to repeat Waller’s significant observations. Instead of merely using such capillary electrometers as were available in his laboratory, he first tested their physical characteristics and found that their performance could be materially improved by attention to minor expedients, including the resistance of the external circuits. Through technical improvements of the capillary electrometer he was able to publish in 1895 tracings such as are reproduced in figure 2. As shown by the sharp spike alone, these records were immeasurably superior to those recorded by Waller. Einthoven labeled the successive deflections A, B, C, and D.

Meanwhile, Einthoven and Burch had independently devised procedures by which capillary electrometer records could be corrected. Applying this mathematical treatment to curves shown in figure 2, he derived the successive deflections labeled P, Q, R, S, and T in figure 3. Thus, the true characteristics of the human cardiac action potentials were established by Einthoven even before the beginning of the present century. Continuing his investigations, in 1900 he again reported, with de Lint, that while leads from different surface areas of normal persons displayed only minor differences, those from patients with cardiac affections often showed marked dissimilarities. Einthoven envisioned the possibility that electrocardiography might have great clinical value in diagnosis, but the report with de Lint in 1900 was regarded as of academic interest only.

It was obvious, however, that the indirect registration of cardiac action potentials would have little appeal unless an instrument could be designed that was sensitive enough to respond to minute action currents, but at the same time possessed a natural frequency adequate to follow the successive fluctuations accurately, thus obviating the use of complicated and tedious correction procedures. Einthoven, therefore, undertook careful mathematical studies of the characteristics of moving coil galvanometers which eventually led him to employ the principle that a wire placed between two magnets bows when traversed by an electric current. The principle was apparently employed as early as 1828 by Cumming in the design of his gold leaf telegraph. After several preliminary descriptions of a “new galvanometer” in 1901, Einthoven designated it as the “string galvanometer” in 1903.

During the decade following this description he published 18 additional papers dealing with various areas of its usefulness; details of design and improvements; tests of efficiency and calibration; illuminating, timing, and recording systems; artifacts and their avoidance; the derivation of the three standard leads; and its employment for the registration of heart sounds. (For a complete list of Einthoven’s publications, see de Waart.)

While the string galvanometer attracted the attention of physicists, it still aroused little interest among physiologists and clinicians until 1906 when its usefulness in research and diagnosis was dramatized by a paper entitled.
“Le Télécardiogramme,” published in the *Archiv internationale de physiologie*. In retrospect, the announcement that cardiac action potentials of patients in the Leyden Hospital could be transmitted over wires to the physiological laboratory, 1.5 km. away, and there recorded as elegant electrocardiograms was quite as sensational at the time as placing an object in orbit was in the present era. The article contained so many fine examples of electrographic abnormalities in patients with heart disease that its usefulness in cardiac research and diagnosis could no longer be questioned. Recognizing that some atypical electrocardiograms could not be explained satisfactorily, Einthoven sought to clarify them by taking records from dogs under different experimental conditions. This report, therefore, also gave an impetus to a trend that was just beginning, viz., to shuttle problems from the clinic to experimental laboratories and back again to the hospitals.

In 1908, Einthoven published another paper of a similar nature which dealt with the principles and practice of electrocardiography, analyzed the effects of heart rate and respiration on the deflections of the electrocardiogram, and presented additional atypical records from patients. The usefulness of the new tool was, of course, severely limited, for the only string galvanometer that existed was in the Leyden laboratory. Sufficient demand for such instruments was soon created in Europe to justify the manufacture of commercial models. As these became available to men like Cremer, Samojloff, Kraus, Nicolai, Kahn, P. Hoffmann, Rothberger, Winterberg, and Lewis, our understanding of normal and abnormal processes of impulse conduction grew by leaps and bounds by 1913. In the U.S.A., electrographic research still lagged, owing partly to the great cost of equipment and lack of research funds for its purchase, and partly to lack of experience in operating the cumbersome equipment available at the time. Thus, when I acquired my first electrocardiograph in 1914, there were to my knowledge only five others in the whole country and only that of Eyster and Meek at Wisconsin was used for basic experimental studies. References cited in the classical monograph of T. Lewis make us realize that the bulk of experimental progress in electrocardiography previous to 1920 had been European.

Thus, as phrased by Einthoven in his address at the ceremonies of the Nobel Prize Award (1924), "A new chapter in our understanding of cardiac disease has been achieved, not through the work of any single person, but through that of many talented individuals, who in their investigations did not allow themselves to be influenced by political boundaries, but distributed over the entire surface of the earth, have dedicated their forces in ideal manner to the development of science, and through this eventually benefited suffering mankind." Despite such generosity in crediting the work of others, it is also apparent from the record that the electrocardiographic analysis of arrhythmias was inspired by, or founded on, the two papers of Einthoven published in 1906 and 1908.

Einthoven’s influence during the first quarter of the present century in establishing electrocardiography as a science was not limited to continued improvements of apparatus and technique and to his contributions to clinical electrocardiography; it extended also...
to mathematical and theoretical analyses of the mechanisms by which action potentials generated by the heart spread in a quantitatively predictable manner through surrounding tissues to and over the surface of the body. Owing to many complexities not recognizable at the time, this has led to numerous reinvestigations of the spread of electrical currents through volume conductors that continue to the present day.

In 1913, Einthoven, Fahr, and de Waart introduced the concept that, at successive

moments of the cardiac cycle, myriads of minute action potentials summate and create "resultant potential differences," manifested on the anterior chest wall as "manifest potential differences" the magnitude and direction of which can be indicated by arrows fitted into an equilateral triangle. While the validity of the triangle hypothesis became the subject of serious debate in later years, it is now recognized that it was the precursor of vectorcardiography.

*Figure 2*  
Electrocardiograms from five subjects recorded by a capillary electrometer, by Einthoven.
If we judge the stature of an investigator not only by the quality of his work but by the catalytic influence he exerted on the investigations of others, Einthoven must be acclaimed the first among the first in the founding of electrocardiography.

Time is lacking for a review of his electrophysiological studies of the retina, the vagus and sympathetic nerves, muscle tonus, and psychogalvanic phenomena (for references see de Waart). It would be a serious omission, however, if we failed to recall his employment of the string galvanometer in the cognate field of phonocardiography. The records published in 1907 with Flohil and Batteard not only portrayed the temporal relations of the heart sounds to other cardiac events, but for the first time, characterized their duration, intensity, and quality as well. Indeed, until comparatively recent times their records remained a standard by which sounds recorded by other devices needed to be compared.

The Man

Behind the image that an investigator creates in the minds of his readers, there is often a quite different man. Likewise, the assessment of personality or character by first impressions or casual acquaintance is not always exact or necessarily correct. In fact, we may recall that the Latin word *persona* means literally "a face mask used by actors on a stage, hence a character" (Webster).

My initial impressions of Einthoven at an International Congress of Physiology at Edinburgh (1923) were not altered by subsequent closer contacts. In 1923, he had already reached the zenith of his career as attested by the bestowal of an honorary doctorate degree by the University of Edinburgh. Nevertheless, new acquaintances recognized only a modest, cordial, and earnest man. He spoke English, German, and French as well as his native language and was always surrounded by friends from many lands. I was particularly impressed with his greeting of younger persons. His mind was not affected with an inertia against interruption of its mental routine; he never dismissed young men introduced to him with the common, "Glad to meet you. Goodbye." On the contrary, he was inclined to inquire about the locale of their work, its direction and their areas of interests, frequently adding a few words of encouragement. Those of us who have reached maturity too often forget how exhilarated and inspired youngsters may be by a little display of interest in their ideas and aspirations. I later learned that he was equally generous in showing "unimportant people" through his laboratory and, if requested, offered them advice in matters pertaining to electrocardiography. In fact, he appeared more interested in displaying his equipment to the common man than to noted colleagues. Otto Frank once remarked that in visits to Leyden Einthoven had never invited him into his laboratory. It may be added parenthetically that Einthoven made a similar remark about O. Frank.

In September, 1924, Einthoven accompanied by his wife and her sister were our guests in Cleveland. Our department of physiology had recently occupied quarters in a new building and was equipped with most modern types of apparatus for the study of cardiodynamic and electrographic problems. We felt honored in having so eminent a man as Einthoven include Cleveland in his limited tour of our country. His keen mind allowed no detail of building construction or equipment to escape him. He accepted all of our exhibitions and demonstrations as a favor to him, rather than as a privilege for us, as it was. In a Hanna Lecture, he dealt with his more recent experiments supporting his life-long contention that electrical and mechanical manifestations were inseparable. The modesty yet earnestness with which he presented factual material, and the logical way in which he derived deductions made a deep impression on faculty and students alike.

Since my experiments at the time seemed to lead to a different conclusion, I hesitated to broach the subject to so gracious a guest. Einthoven, however, insisted on scanning my original records and inquired as to details of procedure. Now, in the discussion of data, there are two kinds of arguments, the uncom-
promising and the conciliatory. In the first, an irresistible force impacts upon an immovable object; in the second, arguments become a game with the objective of winning confidence rather than the argument. The former is apt to lose friends, the latter gains them. We mutually agreed that our evidence pointed toward different conclusions. Einthoven then made a significant statement that I have never forgotten: "When evidence is at variance, the respective investigators should spend more time in attempting to harmonize differences, rather than to direct their energies toward procurement of more data for a favored hypothesis. The truth is all that matters; what you or I think is inconsequential."

Shortly after his visit to Cleveland and while still in the United States, we were delighted with the news that the Nobel Prize in Physiology and Medicine had been awarded to him, "for his discovery of the mechanism of the electrocardiogram." In return for my felicitations, Einthoven favored me with an autographed photograph which I have always treasured (Frontispiece).

Einthoven was always cautious in accepting conclusions based on incompletely presented data at meetings. Thus, at the International Congress of Physiology held in Stockholm in 1926 I sought his reactions to a new hypothesis of Craib, namely, that an electrical impulse is conducted along a muscle strip as a series of longitudinal dipoles, positivity preceding negativity. Einthoven preferred not to commit himself until published data could be scanned more leisurely and the data could be confirmed by others. It was his view that a seemingly new discovery should be looked at, pondered over and weighed in perspective with previous work. He expressed himself as particularly averse to untimely publicity of new advances presented at scientific meetings which so often turn out to be apparent rather than real.

Shortly before the Stockholm meeting, I was invited to be a guest at Einthoven's home. Here it was my privilege to see something of his home life as well as his institution. This was a real experience, for it frequently happens that the impression of a person gained on fraternal or social occasions is but a mask of his real self. The Einthovens lived in a quaint old house with the bank of the Rhine at its rear. Their home life was as placid as the stream; it was marked by simple comfort, serenity, and absence of ostentation. There was no change of routine as to services or meals such as sometimes makes a guest feel uncomfortable from overattention.

The many eminent colleagues who visited Einthoven in Leyden all remarked that his hospitality was far beyond the requirements of courtesy. In my own case he interrupted a family gathering to meet me at the station on his bicycle and arranged for the transfer of my baggage to his home. He guided me through his laboratory and those of his colleagues. He was a bit apologetic for the lace curtains that Mrs. Einthoven had hung in his office during his temporary absence; a gesture that he condoned as a good husband, but did not exactly welcome.

Einthoven was then engaged in composing a section on electrocardiography for Bethe's Handbuch der Physiologie. In conversations pertaining to the script, I realized his earnest desire to give credit to the accomplishments of others but was a bit sensitive when others failed to credit him fully for his own contributions, or when they misinterpreted or misquoted his views. He chided me mildly for having stated in a monograph that he had suggested calling direct leads from the heart "electrograms" and indirect ones "electrocardiograms." "I never made such a statement and do not regard such a differential nomenclature desirable."

Einthoven has a naive sense of humor, the best illustration of which is recorded in de Waart's biography of him. It seems that his friend Samojloff had addressed a congratulatory letter to the string galvanometer on the occasion of its twenty-fifth birthday. It ended: "Dear Einthoven, I beg you to read this letter to the string galvanometer, since it can write but not read."

Einthoven facetiously responded as follows: "I have carried out precisely your request and read to the galvanometer your letter."
Apparently he listened and took in with pleasure and joy all that you wrote. He had not suspected that he had done so much for humanity, but at the place where you said he does not read, he all of a sudden became furious, so that I and my family became even alarmed. He cried: 'What, I can’t read? It is a terrible lie. Do I not read the secrets of the heart?' I calmed him and advised him in the future to toil as much as he could for the benefit of humanity and not to think of gratitude.”

Notwithstanding the fact that Bethe was pressing him to complete his monograph, Einthoven took time to guide me through art galleries, museums, and other points of historical interest, insisting that the exercise of walking clarified his mind. He appeared to be in good health; he seemed to be active and almost sprightly. It was, therefore, a surprise and shock to learn the next year that he had died (September 28, 1927).

In retrospect, I surmised that perhaps Mrs. Einthoven had been aware of some existing ailment, that he himself did not reveal. She seemed somewhat solicitous about his welfare and feared that he was maintaining a too hectic life at his age. At the time I attributed her solicitude to the natural concern of an affectionate spouse for the temperamental reactions her husband experiences while in the process of writing a book. As my wife has expressed it, “the period of writing a book is one of ‘blood, sweat and tears’ for the whole family.”

Whatever the reason for her concern, she insisted that he retire at 10 o’clock, after which we chatted for a while about many matters, ranging from souvenirs of their travels and servant problems to incidents connected with the ceremonies attending the Nobel Prize Award. Mrs. Einthoven was a highly intellectual person, but regarded her role as a wife and mother as her greatest obligation. One could sense that her philosophy was that “home loving hearts are happiest.”

In various memorials, Einthoven’s friends and colleagues praised his modesty, his gracious manners, his unpretentious habits, his natural curiosity, his warm hospitality, his zeal for work, his resilient mind, and his devotion to the search for truth. He exemplifies to us all, the need for remaining humble in the face of the vast ocean of ignorance that still confronts us. Every man is indeed replaceable but no man can be exactly replaced.

**Incidents and Accidents**

Willem Einthoven was born May 21, 1860 in Semorang, Java (now Indonesia), where his father, a physician, was stationed as Health Officer. His mother was the daughter of Willem de Vogel, the Director of Finance. Thus he was endowed with a good heritage. But as phrased by Shakespeare, “There is a destiny that shapes our ends.” We shall briefly assess the incidents and accidents that affected Einthoven’s life, developed his native talents, and perhaps determined his scientific career.

Destiny interfered for the first time when, four years after his father’s death, the family returned to Holland, settling in Utrecht. Einthoven was then 10 years old. After completing his primary and high school education, he enrolled as a medical student in the University of Utrecht at the age of nineteen. His course of study was made possible by a government grant which, however, obligated him to practice in the Dutch East Indies after attaining his medical degree. This resolve to follow in his father’s footsteps he maintained until the end of his student career, despite the fact that the scientific atmosphere throughout Europe and the local scientific climate were operating insidiously to entice talented young men into investigative careers.

During Einthoven’s student years (1879-1885) leaders in physiology like Helmholtz, Du Bois Reymond, von Brücke, and Ludwig were demonstrating that body functions hitherto attributed to vital forces could largely be explained by application of physical and chemical laws. Claude Bernard (1813-1878) who had made a strong impact on medical thinking by espousing the study of disease through biological experimentation had died the year before Einthoven’s matriculation.
E. J. Marey (1830-1904) who had recently succeeded Flourens at the College de France was circumventing the difficulty of detecting obscure circulatory phenomena by the unaided senses by the introduction of graphic methods that could translate phenomena into forms that the human mind could grasp.

In Utrecht, the new outlook on medicine was promulgated by distinguished members of the medical faculty, among whom Donders and Snellen, Sr. exerted a profound influence on the development of the young Einthoven.

F. C. Donders was trained as an army surgeon but became a professor at the University in 1848. Even before a definite department of physiology existed, he made notable contributions to physiological optics and applied many of his discoveries to the treatment of eye diseases. He had become one of the foremost ophthalmologists of Europe when in 1863 he was appointed professor of physiology. In 1866 he constructed one of the finest Institutes of Physiology in Europe and then relegated direction of the Eye Hospital he had established to H. Snellen, Sr. We may recall incidentally that he was the grandfather of our distinguished Dutch colleague, H. A. Snellen, the cardiologist. Many will recall his tribute to Einthoven on the occasion of the Second World Congress of Cardiology at Washington, D. C. in 1954.

It may here be noted that when Einthoven reached the zenith of his career, he had many characteristics in common with Donders. Both were meticulous experimenters. Both were intent on constantly improving apparatus for studying living processes. Both attempted as far as possible to reduce functional processes to physical and mathematical terms. Both were not merely concerned with the orderly solution of problems for the sake of science, but were anxious to apply them to practical clinical problems. Both were brilliant scholars, competent linguists, and charming, modest persons. It is, therefore, not unreasonable to conclude that however deep Elthoven’s scientific, scholarly, and personality characteristics may have been rooted in heredity, they were certainly enhanced and strengthened by his association with Donders during his student days.

Since ophthalmology was far in the lead among medical specialties as an exact physiological science, Einthoven decided to specialize in this branch of medicine. Thus he became directly associated with Snellen. Having chosen what he believed to be his life career, the young man sought first to obtain a good grounding in physical optics. The knowledge thus gained made it possible later to design a unique illuminating system for the optical projection of a sharp string shadow. Incidentally, he demonstrated that the intensity of illumination and definition of the string shadow depend more on the proper placement of lenses than on the glass of which they are made. The next step was to carry out a research problem and present the results as a thesis for his doctorate in medicine. Under the guidance of Snellen and Donders, he selected a problem in color stereoscopy. Donders had found that when two colors at different ends of the spectrum, such as red and blue, are placed on a dark background, one of the colors appears to be in front of the other. Donders had attributed this optical illusion to different focal lengths of the two colors. Einthoven’s reinvestigations revealed that the phenomenon is caused by slight eccentricity of human pupils; individuals with slight displacement of the pupils to the temporal side of the optical axis see the red in front of the blue, while those in whom pupillary displacement is toward the nasal side, see blue in relief. This graduation dissertation subsequently published was awarded a "cum laude" and later led Wenekebach, a fellow student, to write, "One recognized already the coming man."

The biographies of a number of noted physiologists reveal that unexpected opportunities caused them to be deflected from the practice of medicine into an academic work in physiology. As already mentioned, Einthoven was training for the practice of ophthalmology in the East Indies. In 1885, when Einthoven had not yet passed his state examinations for the practice of medicine, Hensyus retired as Professor of Histology and Physi-
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ology at Leyden. Strongly impressed with Einthoven’s research talents, Donders strongly supported his nomination for the post.

The decision upon a future career must have been a difficult one for him. It does not require much strength to do things, but it requires great strength to decide on what is best. He had become enamored of physiological research and appreciated the opportunities and privileges of an academic career. However, he realized all too well the difficulty of maintaining an active brain on an empty belly. His family was not affluent and could benefit from some financial support. Furthermore, his medical studies had been financed by a grant from the government with the understanding that he was training for colonial service. If he failed to keep his contract, he would be under obligation to repay 6,000 guilders, with a university salary of only 4,000 guilders.

Einthoven’s decision to enter an academic career under conditions that required great frugality in living contrasts with the current demand of young men for guarantees of comfortable and gracious living before they commit themselves to becoming career investigators. It is true that in the present era, investigators, as well as factory workers, are entitled to higher living standards and the enjoyment of more elegant workshops. It still remains to be demonstrated that such social and economic betterments can produce cardiovascular investigators that compare with Einthoven in stature. Could it be that destiny favors those whose stamina and fortitude have been tried in the fiery furnace of hardship? At any event, Einthoven, like many of the giants of the 19th century, was rewarded by a satisfying career and a good, comfortable life—a reward that was sweetened by contrast with early hardships.

In conclusion, may I say that this dissertation is primarily intended to be a tribute to Einthoven and to his work for the benefit of science and humanity. May I, however, remind our younger cardiologists that reverence for the past is futile unless we derive therefrom a concept of the meaning of greatness and draw the strength and encouragement to fulfill our obligations in the advancement of cardiology to the limits of our training and native abilities.

“For life is the mirror of king and slave, ’Tis just what we are and do; Then give to the world the best you have, And the best will come back to you.”

Madeleine Bridges, Life’s Mirror.

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SPECIAL ARTICLE: Willem Einthoven (1860-1927) Some Facets of His Life and Work

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