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HISTORY OF CARDIOLOGY

How electricity was discovered and how it is related to cardiology

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Abstract We relate the fundamental stages of the long road leading to the discovery of electricity and its uses in cardiology. The first observations on the electromagnetic phenomena were registered in ancient texts; many Greek and Roman writers referred to them, although they provided no explanations. The first extant treatise dates back to the XIII century and was written by Pierre de Maricourt during the siege of Lucera, Italy, by the army of Charles of Anjou, French king of Naples. There were no significant advances in the field of magnetism between the appearance of this treatise and the publication of the study *De magnete magneticisque corporibus* (1600) by the English physician William Gilbert. Scientists became increasingly interested in electromagnetic phenomena occurring in certain fish, i.e., the so-called electric ray that lived in the South American seas and the Torpedo fish that roamed the Mediterranean Sea. This interest increased in the 18th century, when condenser devices such as the Leyden jar were explored. It was subsequently demonstrated that the discharges produced by ''electric fish'' were of the same nature as those produced in this device. The famous ''controversy'' relating to animal electricity or electricity inherent to an animal's body also arose in the second half of the 18th century. The school of thought of the physicist Volta sustained the principle of a single electrical action generated by metallic contact. This led Volta to invent his electric pile, considered as the first wet cell battery. Toward the middle of the XIX century, the disciples of the physiologist Galvani were able to demonstrate the existence of animal electricity through experiments exploring the so-called current of injury. On the path of Volta's approach, many characteristics of electricity were detailed, which ultimately led to their usage in the industrial field. The route followed by Galvani-Nobili-Matteucci led to the successes of Waller, Einthoven, etcetera, enabling the modern conquests of electro-vectorcardiography.

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PALABRAS CLAVE
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Cómo se llegó al descubrimiento de la electricidad y su utilización en cardiología

Resumen Se relatan las etapas fundamentales del largo camino que llevó al descubrimiento de la electricidad y su utilización en cardiología. Las primeras observaciones de fenómenos electromagnéticos se realizaron en la antigüedad clásica y se señalaron por autores grecoromanos, aunque no podían ser interpretados correctamente. Sólo en el siglo XIII apareció un escrito de Pierre de Maricourt, redactado durante el sitio de Lucera, en Italia Meridional, por las huestes de Carlos de Anjou, rey francés de Nápoles. Entre la redacción de este ensayo y la publicación del tratado *De magnete magneticisque corporibus* (1600) por el médico inglés William Gilbert, no hubo avances importantes en el campo del electromagnetismo. Pero los investigadores comenzaron a interesarse en los fenómenos electromagnéticos que se producían en ciertos peces, por ejemplo la llamada anguila eléctrica, que vivía en los mares de Sudamérica, y también en el pez Torpedo morador del mar Mediterráneo. Tal interés aumentó a mediados del siglo XVIII, cuando se elaboraron condensadores del tipo de la llamada botella de Leyden. Pudo demostrarse, por tanto, que las descargas de los ''peces eléctricos'' son del mismo tipo de las que pueden producirse en dicho aparato. En la segunda mitad del siglo mencionado, se originó la famosa ''controversia'' acerca de la llamada electricidad animal, o sea de la electricidad inherente al cuerpo de animales. La línea de los investigadores de la escuela del físico Volta, sustentaba la existencia de la sola electricidad ''de contacto'' entre cables metálicos. Esto llevó a su jefe a lograr el invento de la pila eléctrica. Los discípulos del fisiólogo Galvani llegaron a demostrar hacia mediados del siglo XIX, la existencia de una verdadera electricidad animal en forma de corriente de lesión. Por el camino de Volta, se llegó a detectar muchas características de la electricidad, lo que permitió su utilización esencialmente en campo industrial. Por la vía Galvani-Nobili-Matteucci, se llegó a los éxitos de Waller, Einthoven, entre otros, lo que hizo posible lograr las modernas conquistas de la electrovectocardiografía.

In the journal *Elements: science and culture* (*Elementos: ciencia y cultura*) published by the meritorious University of Puebla, one finds the reproduction of an excellent and well documented paper ''The electric fish and discovery of animal electricity'',[1] which encouraged us to complement it and focus on the use of electricity in the fields of medical specialties, such as cardiology. These studies were evidently developed following observations on phenomena occurring in certain fishes. The earliest written reference to the so-called electric fish dates back to an ancient Hippocratic treatise.[2] The fish is referred to by its original Greek name, *narké*, derived from the verb *narkéo* = ''to benumb'', and which led to the modern term narcosis. In a paragraph of Plato's dialogue Meno, the capacity of Socrates to ''electrify'' or ''stun'' his audience is compared to that of an electric fish ''which causes numbness to all who approach and touch it...''.[3] Other classical writers, like Tito Lucrecio Caro, author of the didactic poem *De rerum natura*, mention the properties of magnetite and magnets. However, it was not until the beginning of the first millennium of our era that a notable progress in the field of magnetism was achieved: insight into the magnetic polarity. It is plausible that polarity was known to the Arabs in the 11th century of the Christian era, and that they, in turn, transmitted the knowledge to the Chinese as well as to the dwellers of Western Europe. Towards 1442, Arab sailors used a transitorily magnetized needle over a straw floating on water to recognize the north-south direction thanks to the magnetic orientation. During the 12th and 13th centuries every scientific and encyclopedic text pointed to this property of the magnetic needle.

In the 13th century the work of the French scholar Pierre de Maricourt appeared in his treatise *Epistola de magnete* dated August 8, 1269 (Fig. 1). This monographic article, of considerable length for its time, was written in the South of Italy whilst the army of Charles of Anjou laid siege to the city of Lucera, in Apulia, and constitutes a true scientific treatise. In it, the scientific method reaches its fullest expression and the characteristics of magnets are comprehensively and carefully examined. A far-reaching improvement was achieved around 1300: the system of the floating needle was replaced by one of fixed suspension. The compass rose was added to this new instrument and, thus, the nautical compass emerged, which was of seminal importance to the development of navigation.

There were no significant advances in the science of magnetism in the time between the publication of the aforementioned *Epistola de magnete* and that of the work *De magnete magneticisque corporibus* written by the English physician William Gilbert (1600).[4] The only noteworthy advances were the discoveries of magnetic declination, attributable to Christopher Columbus during his first voyage to the New World (1492), and magnetic inclination by Georg Hartmann in 1544. Robert Norman described magnetic inclination more precisely in 1576 and 1581. Ultimately, the aforementioned physician William Gilbert (1544-1603) achieved not only a significant advancement in the study of magnetism but managed to catch a glimpse into the science of electrology. His treatise *De magnete*, along with his *Compendium medicinae*, were featured in the library of the old University of Mexico.[5] Both works are also mentioned

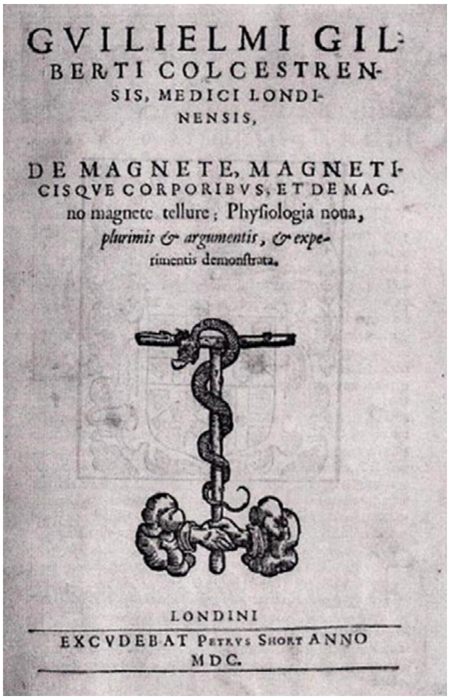

Figure 1 Front cover of the book *De magnete*... by Dr. William Gilbert (London, 1600).

in the inventory of the prized private collection (1663 volumes) belonging to master builder Melchor Hernández de Soto, compiled in the mid 17th century.[6] It should also be mentioned that a device, envisioned by the Italian poet and physician Girolamo Fracastoro of Verona (1483-1533), had tended the field for Gilbert's invention. The device constructed by the English physician, which was similar to that described by Fracastoro in his scientific work *De sympahtia* in 1546, was termed ''versorium'' and emerged as the first electroscope. At the time, Gilbert established the following distinction: while the action between a magnet and iron is reciprocal, and rubbed amber may attract smaller objects these do not attract amber. However, this statement could not be proved experimentally by scholars at the Florentine ''Accademia del Cimento'' (Academy of Experiment), as related by Lorenzo Magalotti (1637-1712), secretary of the academy and author of ''Saggi di naturali esperienze'' (Essays on Natural Experiments), 1667.

His scientific spirit and methods distinguish Gilbert as one of the most iconic figures of the scientific world of the 16th century. His book *De magnete* is a fatiguing read, but his over 600 experiments, are meticulously described to the last detail, which in Agnés Heller's[7] opinion does not reduce but, on the contrary, enhances its intrinsic value.

Among the numerous followers of the English scientist, it seems only fair to mention the priest Niccoló Cabeo S. J. of Ferrara, Italy (1585-1650). He established a very important phenomenon in his *Philosophiamagnética in qua magnetis natura penitus explicatur*: *electric repulsion*. This finding, however, remained mostly inadvertent and the concept had nearly been forgotten when it was re-discovered by an illustrious German scientist. This task was up to Otto von Guericke (1602-1686), who is best known for the invention of his pneumatic machine ''The Magdeburg Hemispheres'', constructed in the mid 17th century and later redesigned by Guericke and the English scientist Robert Boyle (1626-1691), independently, set out to improve the device. Guericke's only printed work *Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio* in seven volumes saw the light in 1672. His theories on magnetism and electricity as well as related experiments are found in the fourth volume *De virtutibus mundanis et aliis rebus independentibus*. According to other documents of that time, this work had been finished before 1661, revealing that the author had built the first electric machine prior to this date.

On the other hand, the Tuscan physician Francesco Redi, member of the ''Accademia del Cimento''[8] and later his disciple Stefano Lorenzini[9] were the first to dissect the Torpedo electric fish. Another member of the ''Accademia del Cimento'', Giovanni Alfonso Borelli[10] tried to explain that the electric organ of the mentioned fish was a special type of muscle.

The concept of electricity

During the 18th century, reports on the South-American electric ray were increasingly received in Europe. Pieter van Musschenbroek, Professor at the Leyden University, concluded experimentally[11] that the effects observed in the South American ray were similar in nature to the properties displayed by the Leyden jar, an early condenser he had invented. ''That is why I inferred that the Torpedo fish was also an electric fish''. In turn, the North American Edgard Bancroft, who had observed the effects of the South American electric ray in Venezuela,[12] and had gone to England to join the circle of English electrologists, prompted John Walsh, a member of the London Royal Society, to conduct experiments on the properties of the Torpedo fish. Additionally, the anatomist John Hunter, who had dissected the South American electric ray, published a comprehensive study on the anatomy of the Torpedo fish.[13]

Decisive advances in the field of electromagnetism well into the 18th century are owed to Stephen Gray (¿1666?-1736) and Charles François Cisternay Du Fay (1696-1739). Gray's work started in 1720. After numerous experiments with materials that exhibited known properties, he set out to investigate if other materials could also become electrified by friction. His many efforts led him (1739) to the important discovery of the property displayed by many objects, particularly metals, to act as conductors (the term was introduced by Jean-Theophile Desagulier, 1683-1744, disciple of Gray). Furthermore, he concluded that there were two types of materials: conductors and insulators. The later were easily electrified by friction, whereas conductors, for example metals, could not be electrified by the procedures employed at the time. Another relevant contribution of Gray's work concerns electrical induction (1729-1730).

The publications by Du Fay appeared during a briefly spanned period: 1733-1734. His fundamental discovery regards the description of two electricities, which he termed vitreous and resinous electricity. According to him, vitreous electricity was found in glass when rubbed by certain materials, whereas the second electricity was produced in resin, amber, and sealing wax. Electricities of the same sign are repelled; whereas electricities of the opposite sign are attracted. Du Fay also studied the ''sparks of fire'' that could be released from appropriately electrified objects.

In January 1746, the French naturalist René-Antoine Ferchault de Réaumur (1683-1757)[14] received a letter sent at the end of the previous year by Pieter van Musschenbroek (1692-1761), a professor at Leyden University.[11] In the letter, the author described his experiments with a new condenser he had invented: the Leyden jar. With this device, which worked even better if lined with a metallic foil, it was possible to obtain electrical sparks of a —previously inexperienced— magnitude and other extraordinary effects.[11]

The French abbot Jean-Antoine Nollet (1700-1770) ventured on experiments discharging a battery of Leyden jars through a human ''chain'' and registered his observations systematically. It is worth mentioning that Nollet's Physics Treatisewas also found in the Turriana Library in Mexico.[15]

Louis Guillaume Le Monnier (1717-1799) managed to make the mentioned condenser transportable. In his paper ''Electricité'' destined for the ''Encyclopédie'', this wise French scientist tried to explain the phenomenon as ''the effects of a very fluid and subtle matter, distinguishable by its properties from all other known fluids''. Soon scientists investigated whether the presence of water in the device was indispensable or if other liquids or metallic armatures as inside and outside linings could replace it. The term ''armatures'' is owed to Franklin and was used to name the metallic laminates or foils used to line the jar. The Leyden jar thus evolved into its current form. Between 1746 and 1748 it also took on other shapes as that of the ''Franklin square'' and the analogous condenser plate.

At that time, Franklin initiated his experiments on the electrical ''capacity'' and the influence of the armatures on the condensers' charge. William Watson (1707-1787) explicitly asserted that —as in other similar conditions—, the electric charge was proportional to the surface area of the armatures. These speculations by Watson vaguely foreshadowed the concept of ''potential'', which would be later included in Franklins ideas.

The theoretical and experimental work of this scientist (1706-1790) is essentially exposed in his book ''Experiments and observations on electricity'',[16] which comprises a series of letters addressed to his Londoner friend, Peter Collinson (1694-1768), member of the London Royal Society. The last edition of this work, to which the author had made numerous changes and additions, dates back to 1774.[16] In the second letter, dated May 25, 1747, Franklin explained his theories on electricity. Opposing the idea of two electricities set forward by Du Fay, Franklin proposed that there was one single electrical fluid present in all matter. He posited that friction caused some of this fluid to be displaced, from a negatively charged to a positively charged condition. This fluid is distributed in ''atmospheres'' over the surfaces of objects. The terms ''positive'' and ''negative'', introduced by the extraordinary North American scientist, remain in use in scientific language, even though the one-electricity theory has been discarded. However, in the 18th century this theory was widely accepted by electrologists, including the father Giovanni Battista Beccaria[17] and Volta himself. This theory was substituted by a new theory, admitting the existence of two electrical fluids, which was accepted throughout the 19th century. According to Robert Symmer (?-1763), who proposed this theory in 1759, both fluids are present in equal quantities in all neutral objects and when they are separated (for instance by friction) the action of the predominant fluid is manifested.

Among the principal electrologist of the 18th century, a special mention is reserved to the Italian clergyman Giulio Cesare Gattoni (1741-1809), who showed remarkable interest in physics and had mounted a well and expensively equipped laboratory in his house. Herein, Alessandro Volta was able to perform his first experiments and find all the books he needed.[18] In turn, the English scientist Joseph Priestley (1733-1804) had compiled, following Franklin's advice, a Treatise on Physics (1775),[19] based on original works. This treatise, which examines the trajectory of the knowledge on electricity with a fine critical spirit, constitutes one of the most valuable and extensive expositions of electrical developments of the time.

Galvani's physiological approach

The theories on electricity proposed by Benjamin Franklin (1706-1790) were widely accepted and distributed in the Italian peninsula, where the last edition of his book (1774) was soon translated into Italian by the abbot Carlo Giuseppe Campi, a good friend of Volta. The group of enthusiast followers of the North American scientist included the aforementioned father Beccaria (1716-1781), professor at the Turin University, who had published his results on the electrical stimulation of exposed muscles in a live rooster in 1753.[17] Franklin refers to this publication as ''one of the best works on the theme ever written in any language''. Beccaria's book and the comprehensive Physics Course of the abbot Nollet were found in the private library of Juan Benito Díaz de Gamara (1745-1783),[20] keen divulger of the scientific advances of his time among Mexican youth[21] and exhibitor of the inventions mentioned in his students' theses.[22]

Leopoldo Caldani (1725-1813), immediate predecessor to Galvani as Professor of Anatomy at the University of Bolonia, and the —also anatomist— Tommaso Laghi, author of the merited memoir on Hallerian irritability,[23] were among the first to perform electrical stimulation on nerves and muscles. According to Albrecht von Haller (1708-1777), who had initiated these studies,[24] the naturalist Felice Fontana (1720-1805)[25] had previously suggested an analogy between the nervous system and an electrical device.

Thus, Luigi Galvani (1737-1798) (Fig. 2), who in 1772 presented his memoir ''On Halllerian Irritability'' at the Arts and Science Institute in his city, was not the author of the concept of ''animal electricity'', i.e., electricity inherent to animals,[26] but rather ignited a discussion on the experimental evidence and submitted it to consideration by physicists, physiologists, and physicians. His first observations on the muscular contraction in frogs were recorded in September 1786 and described by the author in his laboratory notes.[27] In these experiments, the frog acted as the revealer of the electromagnetic waves emitted during the spark, though it was later evident that muscular contractions could be obtained even without the electrical spark. It was Galvani who sustained and proved that by employing two metals to close the circuit it was possible to elicit,

Figure 2 Luigi Galvani (1737-1798).

what was later called, electrical current. This thesis along with his numerous experiments is described in his treatise *De viribus electricitatis in motu musculari. Commentarius*.[28] Galvani sustained that animals can produce, devoid of external intermediation, particular electricity that can be justly called animal electricity. The muscles, by way of the nerves, can be charged in the same way as the Leyden jar, so that their outer part is negatively charged whereas their inner part is positively charged. The contraction mechanisms would depend on the discharge emitted by the nerves when the exterior is in communication with the interior.

It was still possible to obtain a muscular jerk when a glass rod substituted the metals of the circuit between the muscles and nerves. In an anonymous publication of 1794,[29] perhaps owed to Giovanni Aldini (1762-1834), Galvani's nephew, an experiment on the frog's muscular contraction without intervention of any metals is described. In 1795, Galvani also explored the electrical phenomena, characteristic of Torpedo fish.[30] Ultimately, in a letter dated 1797 addressed to the biologist Lazzaro Spallanzani, professor of Natural History at the University of Pavia, our scientist admitted to the existence of two classes of electricity: animal and common electricity.

It was not until the 19th century, when Michael Faraday (1791-1867) managed to demonstrate that ''electricities'' —regardless of origin— had the same effect and thus were identical.[31]

Volta's physics approach

Alessandro Volta (1745-1827) (Fig. 3), then tenure professor of Physics at the University of Pavia (*Studium Ticinense*)[32] was caught up in the general enthusiasm generated by Galvani's experiments. He had developed a scale, which arranged metals from zinc, charged by excess, to carbon, charged by defect. He was also the author of an extensive memoir in Latin on the theme of electricity: *Novus ac simplicissimus elasticorum tentaminum apparatus*... addressed to Lazzaro Spallanzani. In letters sent in 1775 to the English scientist Joseph Priestley, the priest Carlo Giuseppe Campi and the count Carlo Giuseppe di Firmian (1716-1782), then Austrian Governor of Lombardy, Volta described a new invention of his: the perpetual electrophorus. In November

Figure 3 Alessandro Volta (1745-1827).

1778, he was invited to the *Studium Ticinense* to occupy a chair as Physics Professor. There he completed another invention: the condenser of electricity or micro electroscope, which was a variation of the electrophorus. During the time he worked on the electrophorus and modified it to develop the condenser, he also worked on new ideas and improved instruments to detect and measure electrical signals.

Initially somewhat skeptic regarding animal electricity, Volta publically acknowledged the ''wonderful discoveries by Mr. Galvani'' in a letter dated April 3, 1792 addressed to Doctor Baronio.[33] A little later, while compiling his laboratory notes, he expressed some doubt as to whether the different conducting metals or metals applied differently in the animal preparation ''were passive or positive agents that move the electrical fluid within the animal''.[34] In another publication of the same year, he observed that the movements observed in the frog's muscles by the Bolognese physiologist could result from electrical currents generated by friction, rather than from intrinsic animal electricity. Later, his theory on electricity generated by contact between two metals in a circuit led him to believe that the observed electromotive force was produced by contact of the two metals included in the circuit. According to Pedro Laín Entralgo[34] these effects, which could easily be termed metallic electricity, were in no way different from common electricity.

Despite all controversies, the experiments by Galvani and his followers were both stimulating and influential to Volta and his adherents. The Lombardian professor, in turn, invented the electric pile, which he communicated in a letter dated March 20, 1800 addressed to Sir Joseph Banks, the English naturalist and explorer, who was then President of the London Royal Society. This communication was read in a scientific session of this society on June 26.[34] It is worth mentioning, however, that the electromotive force generated in the pile is not truly due to contact, but rather results from electricity induced by chemical reactions that develop within the device. With the discovery of galvanic polarization and the principle behind batteries, the professor of the University of Pavia completed the electrostatic doctrine and, ultimately, forged the branch of electrodynamics.

By proceeding in Volta's path, the English scientist Humphry Davy (1778-1829),[35] who lived a short but intense live, broadened the field of electrolysis and, in 1807, discovered and named potassium —from the Dutch *potash* meaning pot ash—. He also isolated boron, magnesium, and silicon and was the first to isolate strontium by electrolysis of a strontium compound. In 1810, he demonstrated that chlorine was in fact an element and gave it its current name due to its greenish yellowish coloring. In collaboration with W. T. Branda, in 1818, he isolated lithium from its salts by electrolysis of lithium oxide. In 1814, he visited Volta in Milan in the company of his protégé Michael Faraday (1791-1867). It should be mentioned that Faraday, English physicist, enounced the laws of electrolysis and introduced the terms anode and cathode. He also discovered electrolytic and electromagnetic induction and the rotary action of magnets on polarized light (Faraday effect).

Electrometers

An Italian scientist, whose name remains unknown, concocted a pith-ball electrometer to detect the presence of electricity.[36] John Canton (1718-1772) improved this instrument in 1752, as did Tiberio Cavalli (1749-1809) two decades later and Volta himself in 1781. Regarding this invention, the most significant advance was introduced in 1787 by Abraham Bennet (1750-1799), who substituted the small straws by gold leafs. This substitution was performed, independently, during the same year by the Piedmontese physicist Anton María Vassalli Eandi (1761-1825).

In 1771, the English scientist Henry Cavendish (1731-1810), one of the forefathers of electrostatics and author of an important essay on electricity, published his paper ''An attempt to explain some of the principal phenomenon of electricity by means of an elastic fluid''. In it, he discussed the concepts set forth by Ulric Theodor Aepinus (1724-1802), intended to ''explain the laws of electrical attraction and repulsion'' and developed the modern concept of potential. His 1776 publication[37] describes an artificial Torpedo fish, similar to a live fish in its capacity to generate spasms, even when submerged in water. The author also enounced the notion of ''electrical resistance''. It seems appropriate to mention that, in 1773, John Walsh (?-1795) had also tried to demonstrate in a letter to Benjamin Franklin that the spasms delivered by the Torpedo fish were of an electrical nature.[38] A much-debated controversy emerged then with no resolution found until 1788, when Giuseppe Francesco Gardini (1740-1816) obtained an electric spark in the Torpedo fish.[19] The works of Henry Cavendish, published after his death, show an even greater precision in his conceptions and measurements of electrical potentials, capacity and resistance. Concomitantly, Charles Augustin Coulomb (1736-1806) published six monographs between 1784 and 1788, establishing the rigorous foundations of electrical attraction and repulsion, which also govern other magnetic phenomena.[19]

Initially, most scientists exploring animal electricity used Galvani's rheoscopic frog, a preparation in which the electrical current was measured in a qualitative rather than a quantitative sense. After the construction in 1811 of the first galvanometer, i.e., an instrument that detected and measured the electrical current, and its improvement by Leopoldo Nobili (1784-1835) inventor of the thermopile, it was possible to prove the existence of electrical activity in the frog's muscles. However, it was no longer considered as animal electricity. Although demonstrated by Nobili in 1827, it was only until the experiments of Carlo Matteucci, Professor of Physics at the University of Pisa, were published that it was objectively established that the effect is due to ''a difference in potential between the frog's dissected and the corresponding injured muscle'' (1842). It is this path trailing from Galvani to Nobili and Matteucci that led to the concept of animal electricity as current of injury.[39,40] This was the parting point for the decisive work of Emile Du Bois-Reymond, who paved the way for the development of electrophysiology. The final victory is, thus, not owed solely to Volta, but rather —in the words of Cohen—[31] belongs jointly to Galvani and Volta.

The discovery by Oersted, in 1820[41] of the intimate relationship between magnetism and electricity enabled the construction of instruments capable of measuring the intensity of the electrical current originating in muscular tissues. In fact, the electrical charge and the magnetic field constitute two facets of a single force (electromagnetic). Continuation of this research prompted the construction of the rheotome by Du Bois-Reymond (1849)[42] and the differential rheotome by his disciple, Bernstein (1864).

In 1872, the French physicist Gabriel Lippmann (1845-1921) obtained a capillary electrometer that enabled the external tracings of the myocardial electrical activity by the English physiologist Augustus Desiré Waller[43] (Fig. 4), giving rise to the immediate precursors of the clinical electrocardiogram. At the beginnings of the 20th century, the Dutch scientist Willem Einthoven, professor of Physiology at the University of Leyden built the first electrocardiograph devised by a string galvanometer.[44] The publication of his first clinical tracings in 1903 was the runway that launched modern electrocardiography, a simple yet invaluable and essential procedure to examine functional aspects of the myocardium. Electrocardiography was later complemented by vector-cardiography,[45] which allows exploration of the same electrical phenomena in their spatial orientation. By virtue of the studies of Sir Thomas Lewis, Frank N. Wilson, and Demetrio Sodi Pallares, it has been possible to accomplish the success of modern electrovectorcardiography.

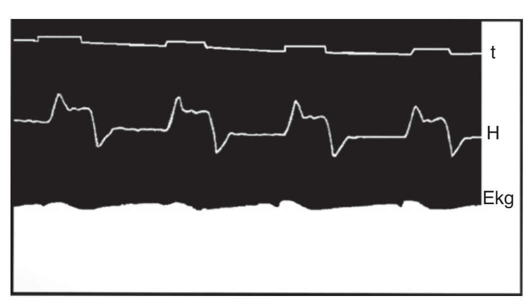

Figure 4 Ancestors of electrocardiographic tracings, published by A. D. Waller in 1887.

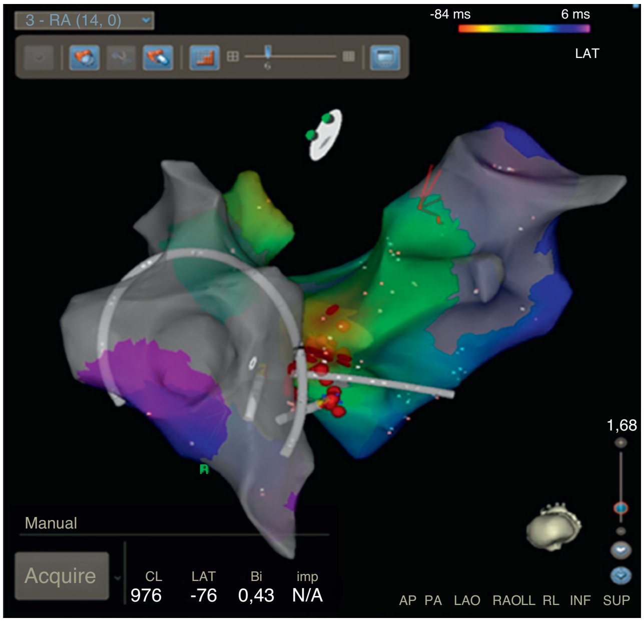

Figure 5 Electroanatomic mapping in left slanted projection with the CARTO 3 system of an atrial tachycardia, showing both atria, right and left, with a halo catheter in the right atrium, and catheter inside the coronary sinus for mapping of the lower portion of the left atrium. The tachycardia originated in the left septal region, and it is observed in the map with the ablation points in red.

Conclusions

The crucial foundations of the research concerning the bioelectric properties of cardiac tissue were sown in the 18th century with the publication by the Italian Naturalist Felice Fontana, a follower of Albrecht von Haller's (1708-1777) research, and were ultimately harvested a century later in the classical work of Marey (1876),[46] which established the relationship between the ventricular refractory period and the phases of the cardiac cycle. This was the first decisive step in the current knowledge of the recovery curve of myocardial excitability. The concept of the functional refractory period in nerves emerged later in Mexico thanks to the work of Arturo Rosenblueth,[47] head of the Physiology Department at the National Institute of Cardiology. Rafael Mendez and colleagues further investigated this concept as related to different cardiac tissues under normal[48] and pharmacological conditions.[49]

Later, researchers embarked in registration of potentials in specific cells of the atrioventricular excite-conduction system in the isolated perfused canine heart,[50] *in situ*,[51] and in human hearts through the Holter system.[52] Today, electro anatomical mapping using the CARTO[53] system (Fig. 5) is carried out at this Institution. Gradually the principles, teachings, and sustained work have given rise to a doctrine that has contributed significantly to the enlightened trajectory of Mexican cardiology.

References

1. Wu CH. El pez eléctrico y el descubrimiento de la electricidad animal. Elementos: Ciencia y Cultura 2007;14:49–62.
2. Hipocrates. On Regimen. II. XLVIII. Trans. En: Jones WHS, editor. Hippocrates, vol. 4. Londres: William Heinemann; 1931. p. 321.
3. Platon. Meno. (Transl. B. Jowett). En: Dialogues of Platon translated into English with analysis and introduction. 2.ª ed. vol. 1. Oxford: Clarendon Press; 1875. p. 280–1.
4. Gilbert W. De magnete magneticis que corporibus. Londres 1600.
5. Inventario de la Biblioteca de la Nacional y Pontificia Universidad de México (October 24, 1833). Bibl Nac Mex. Fondo de origen MS 6431.
6. Una biblioteca del siglo XVII. México: Impr Universitaria (UNAM); 1947.
7. Heller A. El hombre del Renacimiento. Barcelona: Ed. Península; 1980. p. 390.
8. Redi F. Esperienze intorno a diverse cose naturali e particolarmente a quelle che ci sono portate dalle Indie. En: Giacosa P, editor. Le piú belle pagine di Francesco Redi. Milán: Fratelli Treves, ed.; 1925. p. 105–9.
9. Lorenzini S. Osservazioni intorno alle Torpedini. Florencia: Impr Onofri; 1678.
10. Borelli GA. De motu animalium, 1680 Leyden. P. Vander Aa; 1710. p. 276–7.
11. Musschenbroeck P. Cours de physique expérimentale et mathématique. 1762. Vol. 1. Trans. S. de la Fond. París: Desventes de la Doué; 1770. p. 392–3.
12. Bancroft E. An essay on the natural history of Guyana in South America. Londres: T. Becket & P. A. de Hondt; 1769, 190–201.
13. Hunter J. Anatomical observations on the torpedo. Phil Trans Roy Soc 1773;63:481–9.
14. Ferchault de Réaumur RA. Des effets que produit le poisson appellé en français torpille ou tremble, sur ceux qui le touchent, et de la cause dont ils dependent. Mémoires de l'Academie Royale des Sciences 1714:447–68.
15. Bibliotheca Turriana. México. Bibl Nac Fondo de origin MS 38.
16. Franklin B. Experiments and observations on electricity. 4.ª ed. Londres; 1774.
17. Beccaria GB. Dell'elettricismo artificiale e naturale. Turín Impr de Filippo Antonio Campana 1753.
18. Mieli A. Volta y el desarrollo de la electricidad. Buenos Aires: Espasa Calpe Argentina S. A.; 1945.
19. Priestley J. The history and present state of electricity with original experiments, vol. 2, 3rd ed. Londres: C. Bathurst; 1775.
20. Herrejón Peredo C. Benito Díaz de Gamarra a través de su biblioteca. Bol Inst Invest Bibl 1988;2:149–89.
21. Díaz de Gamarra, Dávalos JB. Máximas de educación. En: Academias de ciencias y Academias de filosofía. Zamora, Mich.: El Colegio de Michoacán; 1985.
22. Fernández del Rincón JI. En: Reyes Coria B, editor. Lecciones de filosofía. México: UNAM; 1994. p. 21–5.
23. Laghi T. De insensibilitate atque irritabilitate halleriana. De Bononiensi Scientiarum et Artium Instituto atque Academia. Commentarii. Vol. 4. 1757. p. 208–17.
24. Von Haller A. Mémoires sur les parties sensibles et irritables, vol. 3. Lausana: Impr. de Sigismond d'Arnay; 1760. p. 20.
25. Fontana F. De irritabilitatis legibus nunc primum sancitis et de spirituum animalium de movendis inefficacia. Lucca 1767.
26. Walker WC. Animal electricity before Galvani. Ann Sci 1937;2:84–113.
27. Memorie ed esperimenti inediti di Luigi Galvani. Bolonia: Licinio Cappelli; 1937.
28. Galvani L. De viribus electricitatis in mot u musculari. En: Commentarius. Bononiae: Ex Typographia Instituti Scientiarum; 1791.
29. Anónimo. Dell'uso e dell'attivitá dell'arco conducttore nelle contrazioni dei muscoli. Bolonia: Tip. S. Tommaso d'Aquino; 1794.
30. Taccuino delle esperienze del Galvani sulla Torpedine fatte a Senigallia ed a Rimini l'anno. 1795. Gherardi, ed.

Memorie dell'Accademia delle Scienze dell'Istituto di Bologna. 1869. Serie 2, Vol. 9: 177—9.

31. Galvani L. Commentary on the effects of electricity on muscular motion. Trasl. M. Glover Foley. With notes and critical introduction by. I. Bernard Cohen Norwalk: Conn. Burndy Library; 1953.
32. Scolari F. Alessandro Volta. Roma 1927.
33. Volta A. Opere. Milán: Edizione Nazionale. Ed. Ulrico Hoepli 1918-1930.
34. Laín Entralgo P. Historia de la medicina. Barcelona: Salvat Eds. S. A.; 1978. p. 309.
35. Biography of Humphry Davy, Chemical Heritage. 2008. Org 15-5.
36. Gliozzi M. L'elettrologia fino al Volta 2 vols. Nápoles 1935.
37. Cavendish H. An account of some attempts to imitate the effects of the torpedo electricity. Phil Trans Roy Soc 1776;66:196—225.
38. Walsh J. On the electric property of the Torpedo. In a letter addressed to Benjamín Franklin. Phil Trans 1773;63:461.
39. Matteucci C. Sur le courant électrique de la grenouille: second mémoire sur l'électricité animale faisant suite à celui sur la torpille. Ann Chim Phys 1842;6:301.
40. Matteucci C. Sur un phénomène physiologique produit par les muscles en contraction. Ann Chim Phys 1842;6:339—41.
41. Oersted HG. Experimenta circa effectum conflict selectrici in acum magneticam. Copenhague; 1820.
42. Du Bois-Reymond E. Untersuchungen über thierische Elecktricität. Berlín: Verlag von G. Reimer; 1849.
43. Waller AD. A demonstration on man of electromotive changes accompanying the heart's beat. J Physiol (Lond) 1887;8:229—34.
44. Einthoven W. Un nouveau galvanomètre. Arch Neerl Sci Exper Nat 1901;6:625.
45. Schellong F. Wektordiographie als die Untersuchungs methode der Herzer Krangungen. Verth Dtsh Inn Med 1936;48(2): 288.
46. Marey EJ. Des excitations électriques du coeur. Travaux du laboratoire París: Ed. G. Masson; 1876. p. 63—86.
47. Rosenblueth A, Alanís J, Mandoki J. The functional refractory period of axons. J Cell Comp Physiol 1949;33:405—40.
48. Mendez R, Mandoki JJ, Méndez C. La période refractaire fonctionnelle de l'oreillette et du ventricule de mammifère. En: Mémoires du ler congrés mondial de cardiologie. Paris, September 1950. Vol I. París: Ed. J. B. Baillière & Fils; 1951. p. 210.
49. Méndez R, Mendez C. The action of cardiac glycosides on the refractory period of heart tissues. J Pharmacol Exp Ther 1953;107:24—36.
50. Alanís J, González H, López E. The electrical activity of the bundle of His. J Physiol (Lond) 1958;142:127—40.
51. Sodi Pallares D, Medrano GA, Bisteni A, et al. The electrograms of the conductive tissue in the normal dog's heart. Am J Cardiol 1959;4:459—63.
52. Holter N. New method for heart study. Science 1961;134: 1214—20.
53. Iturralde P. Arritmias Cardiacas Ablación con radiofrecuencia y mapeo electroanatómico (sistema CARTO de las arritmias cardiacas). 3.ª ed. México: McGraw Hill Interamericana; 2008. p. 929—43.