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Articoli/*Articles*

X-RAYS: LAYING THE FOUNDATION OF MODERN RADIOLOGY, 1896-1930

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SUMMARY

The authors describe the initial impact and far-reaching consequences of the discovery of x-rays in 1895. Roentgen was quick to realise the importance of this mysterious new kind of ray he had discovered. As early as 1896 x-rays were already being used in surgery and medicine, replacing Bell's telephonic needle probe, which could only detect metallic objects by sound and was therefore limited to the location of objects such as bullets for removal. As x-ray diagnosis became more accurate, radiological techiques were gradually improved over the years and progressed from examination of the skeleton to imaging complex internal organs. The x-ray became vital in the detection of tubercolosis, for which it is still used today. Through the use of opaque substances such as barium sulfate it became possible to visualise the digestive tract and later advances in photographic techniques made visible the brain and almost all parts of the body. Meanwhile the dangers of radiation were recognised and after 1930 safety measures were introduced to protect radiologists and patients against overexposure. In the hundred years since its discovery the ever-widening scope of radiology has made it a fundamental resource in medical diagnosis and treatment.

Parole chiave/*Key words:* X-rays - Roentgen-radiology

I saw a strange thing today in the laboratory, I may be on a trail.... With these words Wilhelm Conrad Röntgen revealed to his wife the discovery of x-rays. In the nearly 100 years since their discovery in early November 1895 x-rays have had a tremendous impact on science, especially in medicine where they gave physicians eyes to peer inside the body. Röntgen recognized this from the beginning. So did Walther Peterson, a Heidelberg physician. Upon reading that a French astronomer had described the photographic plate as the retina of science, Peterson commented that x-rays would make the photographic plate the retina of medicine[2].

X-rays have contributed significantly to success in medical diagnosis and led to the establishment of radiology as a new and important medical field that has aided all other areas of health care[3]. Radium, and more recently nuclear isotopes, have played important roles, but in early radiology x-rays had by far the greatest impact. From 1896 to 1930 x-rays contributed to the development of radiology in three essential ways: x-ray photography of the skeleton and internal organs, x-ray photography of soft tissues using contrast media, and x-ray photography of the brain. By 1930 radiologists had visualized all of the body's main components and forever transformed medicine.

Discovery of X-rays

The discovery of x-rays is one of the best known examples of serendipity in science. Their discoverer, Wilhelm Conrad Röntgen (1845-1923), received the PhD from Zurich Polytechnic in 1869 and from 1895 directed the Physics Institute of the University of Wurzburg[4]. During that year he began experimenting with cathode rays[5]. Julius Plucker (1801-1868) in Bonn first studied the passage of cathode rays in rarefied gases 40 years earlier in 1858-1859 using small, nearly-evacuated gas discharge tubes that his colleague Heinrich Geissler (1815-1879) had con-

structed. Plucker's studies centered on the structure of matter, and later in 1897 they made possible J. J. Thomson's (1856-1940) determination of the electron's charge-to-mass ratio and his identification of the cathode ray as the electron[6].

In his repeating of earlier cathode ray experiments, Röntgen connected the electrodes of an induction coil to a Hittorf-Crookes gas discharge tube. This tube, which Plucker's former student Johann Wilhelm Hittorf (1824-1914), and William Crookes (1832-1919) in London had developed independently, like the Geissler tube, consisted of an anode and a cathode sealed in a nearlyevacuated glass bulb[7]. Working in a darkened room on November 8, 1895, Röntgen passed a high-voltage current through the tube and saw some barium platinocyanide crystals fluorescing brightly on a distant table. Röntgen was not certain if the fluorescence resulted from another type of cathode ray or from an entirely new kind of ray, and he therefore tested the rays' penetration through the air. When fluorescence occurred on a screen placed at a distance farther than cathode rays generally travelled, Röntgen realized he had discovered a strange, new phenomenon. The fluorescence on the screen also persisted after passing the rays through heavy objects, such as books and metals. Upon allowing the rays to pass through his hand, a clear outline of the bones appeared on the screen[8]. The mysterious new rays needed a name, and because "x" represents the unknown in mathematics Röntgen decided to call them x-rays.

Before revealing his discovery, Röntgen gathered tangible evidence in the form of x-ray photographs that he produced by replacing the screen with barium platinocyanide plates. Images of the objects he placed in the path of the x-rays appeared on the developed plates. After nearly two months of experimenting, on December 28, 1895 Röntgen presented his findings to the Physical Medical Society of Wurzburg in a paper entitled *A New Kind of Ray.*[9] Clearly, Röntgen's grasp of the importance of an apparently insignificant observation and his subsequent investigation of it give credit to his scientific insight. His discovery is a good example of Pasteur's dictum, *chance favors the prepared mind*. The scientific world quickly recognized the importance of his discovery, and in 1901 Röntgen received the first Nobel Prize in physics awarded by the Swedish Academy of Sciences in Stockholm[10].

The Emergence of Radiology as an Independent Medical Field

Publication of Röntgen's paper and x-ray photographs aroused great interest in the possibility of applying the new rays to visualize the internal body. Their use grew so rapidly that by early 1896, x-rays became an important component of the surgeon's and internist's tools as they made possible the determination of when and when not to operate[11]. Their discovery was a significant medical advancement because until that time the only apparatus available for examining the internal body was Alexander Graham Bell's (1847-1922) telephonic needle probe.

In the course of his experiments on the transmission of sound Bell had devised an electric circuit consisting of an induction balance that canceled any interference produced by currents in a telephone line. He noticed that metallic objects near the balance disrupted it and caused a click in the line. On July 2, 1881 when news broke that Charles J. Guiteau, a disappointed office seeker and tireless self-promoter, had tried to shoot the president, James A. Garfield, and that the president's physicians were unable to locate the bullet, Bell tried to adapt his circuit in an effort to save the president's life. Two attempts, on July 26 and August 1, failed. Bell returned to his laboratory in Boston to improve the induction balance, and in the process invented the telephonic needle probe. The instrument consisted of two electrodes and a telephone receiver connected in a series circuit. One electrode was a flat metal plate, the other was a needle probe protected by shellac insulation except at its tip. Contact between the needle and metal produced an audible click

in the receiver. Bell, however, never tested the probe on Garfield who was already near death with a severe infection caused by the fisted probing of the examining physicians' unsterilized hands. It eventually proved successful, and physicians employed Bell's probe in locating bullets for removal from the wounded during the Sino-Japanese War (1894-1895), the Boer War (1899-1902), and World War I[12].

Bell's probe was limited because it detected only metals inside the body. Also, detection was by sound and not sight. Therefore, enthusiasm surrounding the application of x-rays as a new diagnostic tool in medicine was extremely high, especially in the United States. By February 1896 American physicians already were asserting that surgery without the aid of x-rays was unjustifiable[13]. They needed x-rays to protect their patients from unnecessary treatment and themselves from malpractice.

X-ray photography's formative years, which lasted from 1896 to 1913, were the gas-filled tube years, so-called because the high voltage applied to the gas in the tube ionized the gas to produce the electrons that bombarded the anode and released x-rays. These years also witnessed the emergence of a group of physicians who were proficient in both the physics of the gas tube and the practice of medicine and called themselves radiologists. Indeed one of the group, S. H. Monell, a New York City physician, had proposed the establishment of an x-ray society in 1896. Monell found no support, but four years later J. Rudis-Jicinsky, of Cedar Rapids, Iowa, revived the idea in a letter to Heber Robarts in St. Louis. On March 26, 1900 the two physicians, together with representatives from nine states, held a meeting in Robarts' office and established the Roentgen Ray Society of the United States. The representatives elected Robarts president and Rudis-Jicinsky secretary. In 1902 the society changed its name to the American Roentgen Ray Society and to this day has remained a fuctioning organization. Establishment of a professional society lent support to radiology's developing prestige and encouraged a more favorable view of radiology as a legitimate science. From the beginning its admission standards were strict and by 1911 required a medical degree, two years of x-ray experience, letters of recommendation, and submission of a scientific paper to its executive committee[14]. At the same time the society implemented special curricula and licensing procedures, all of which made radiology an official part of medicine[15].

A problem that immediately arose was the failure of radiologists to make sound diagnoses from the photographic plates. Because they did not know how to interpret the image on a plate, radiologists employed a technique called retrospectroscopy in which they compared a patient's autopsy diagnosis with the x-ray photograph. In this way radiologists began to learn from the plate readings[16]. Retrospectroscopy was difficult, but it was the only way of linking diagnoses with x-ray photographs.

Several major improvements in equipment soon occurred to make x-ray diagnosis more accurate. One of first improvements, the introduction of greater penetrating rays in the second half of 1896, enabled radiologists to photograph larger parts of the body, including the skull. Prior to this time only the extremities were visible[17]. A second major advance in equipment marked the end of radiology's gas tube era. In 1913 William David Coolidge (1873-1975), a physical chemist at the General Electric Company in Schenectady, New York, invented the Coolidge tube[18]. In the Coolidge tube, a heated tungsten filament, instead of a rarefied gas, supplied electrons to the anode. No gas was present in the tube and the result was clearer pictures and more certainty in determining the amount of radiation a patient received during examination[19]. Using the Coolidge tube Marie Curie (1867-1934) constructed portable x-ray units which in World War I French physicians used in battlefield conditions to determine the locations of fractures and to pinpoint shrapnel[20]. Coolidge's tube greatly enhanced the performance of x-rays in medicine and with it modern radiology began.

Radiology attracted many talented individuals in its early years, among them the physicians Antoine Béclère (1856-1939) and Francis H. Williams (1852-1936) in the United States.

Béclère was the founder of radiology in France, having established in 1896 the first radiological department in a hospital, at the Hospital Tenon in Paris where he practiced. The following year Béclère transferred to the Hospital Saint-Antoine where he continued to investigate and teach the use of x-rays in medical diagnosis and treatment until his retirement in 1922.

One of Béclère most significant contributions to the science of radiology was his construction in 1897 of the first x-ray machine used in a standing examination. The machine had a wooden frame with an arrangement of fluorescent screens and tubes that moved around the patient thus enabling it to photograph much of the body without having to move the patient. Béclère also produced the first x-ray photograph of an appendix in 1906, and in 1908 he successfully treated a tumor in the pituitary gland with x-rays[21]. His achievements did much to refute any doubts about radiology's practicality.

Williams, at MIT and Boston City Hospital from 1893 until his retirement, was America's first radiologist and well-known to medical researchers for his use of x-ray photographs to compare pathological tissues with normal tissues. He became a firm advocate of retrospectroscopy[22]. Though half a world apart Béclère and Williams sparked the development of radiology in Europe and in the United States. Each firmly believed that *of all the new physical aids to diagnosis 'none' was so unexpected, unhoped for, and consequently, unlooked for, as the Roentgen rays*[23].

Advances in X-ray Photography: From Fractures to Internal Organs

The history of x-ray photography in the first half of the twentieth century shows that it progressed from examination of the skeleton and simple diagnosis of fractures, to fetal x-ray photography, to chest fluoroscopy, and finally to imaging complex internal organs[24]. As early as February 1896 F. Konig, a Berlin physician, correctly diagnosed sarcoma of the tibia using x-ray photography[25]. That same month Edwin Brant Frost (1866-1935), professor of astronomy at Dartmouth, made the first diagnostic x-ray photograph in North America. Frost successfully photographed a fractured ulna only weeks after learning that on January 17, 1896 Arthur Williams Wright (1836-1915), an experimental physicist at Yale University, had made the first x-ray photograph in North America. Using a Hittorf-Crookes gas discharge tube, Wright placed lead pencils and other small objects on a photographic plate and exposed them to x-rays for fifteen minutes[26]. By the end of March 1896 J. Hall Edwards of Queen's Hospital in Birmingham, England, produced skeletal photographs of the backbone, vertebrae, and spinal cord[27].

Photographs of the skeleton were not enough to satiate the curiosity of physicians when so much more of the internal body remained invisible. The discovery that x-rays made visualization of living fetuses possible opened a whole new area for experimentation in radiology. Among the first x-ray photographs of a living fetus in utero were those that Edward Parker Davis (1856-1937), professor of obstetrics at Jefferson Medical College in Philadelphia, produced in February 1896[28]. Detection of lung diseases soon followed. Tuberculosis, in particular, always had been a serious problem because it was extremely contagious, making early diagnosis crucial to checking its spread. The first correct diagnosis of tuberculosis from an x-ray photograph by Francis Williams in April, 1896 was therefore a pathbreaking advance[29]. Radiologists today continue to use x-rays to confirm positive TB skin tests.

Other advances in the study of internal organs occurred in 1896 with the discovery that x-ray photographs made possible the detection of gallstones, kidney and bladder stones. On July 11, John MacIntyre (1859-1928), a physician in Glasgow, Scotland, reported a case in which surgery confirmed the

diagnosis and location of a kidney stone he had observed on an x-ray photograph. That same summer, Max Levy, an engineer at the A. E. Company in Berlin, detected arteriosclerosis after examining his x-ray photographs of the aorta and coronary arteries. Levy also photographed tumors of the lung and stomach[30].

MacIntyre's and Levy's investigations had occurred within one year of Röntgen's initial discovery and revealed much about human anatomy. Yet the application of x-ray photography to medicine still had limitations. Radiologists could not study soft tissues, such as the digestive tract and the circulatory system, because of their relative transparency compared to the skeleton. The differential opacities of air and water provided the first clue to solving this problem[31]. If the complete transparency of air spaces to x-rays permitted detection of an air space, then why couldn't x-rays photograph substances more opaque than organic tissues? In 1896 E. Sehrwald in Freiburg, Germany, answered this question by demonstrating the absorption of x-rays by chlorine, bromine, and iodine, and by organs filled with solutions of these elements[32].

The following year, George Edward Pfahler (1874-1957), a Philadelphia physician, accidently discovered that bismuth compounds also were opaque to x-rays. From that time on radiologists regularly employed bismuth compounds instead of the halogens in the x-ray photography of the gastro-intestinal tract. There were several reasons for choosing bismuth compounds. In the 1890s physicians commonly prescribed bismuth compounds in treating gastric ulcers. When Pfahler examined plates he had made of a patient who had taken bismuth for a stomach ulcer he therefore saw the visible outline of the patient's stomach. Pfahler did not immediately follow through with his discovery, but he had demonstrated bismuth's potential as a contrast medium. Bismuth compounds have another advantage in that they are unlikely to alter the chemical reactions of the gastric liquids, which is a potential problem when using halogens.

The pharmacopoeial preparation, bismuth subnitrate [$4BiNO_3(OH)2BiO(OH)$], a white water insoluble, non-toxic compound used in cosmetics, became the choice for early research in digestion. Walter B. Cannon (1871-1945), professor of physiology at Harvard Medical School, used it in his pioneering studies of 1897-1898 to elucidate the physiology of the intestinal tract.

Cannon recognized that he could administer the subnitrate orally, and in this way he monitored its movement through the entire digestive system. On April 23, 1897 he fed bread mixed with the subnitrate to a cat and noted a series of wavelike contractions of the cat's stomach. That autumn he tested the subnitrate on a human patient for the first time. Though it worked well, Cannon soon found that the subnitrate caused uncomfortable and sometimes serious side effects in patients. He experimented with barium sulfate, a white or yellowish tasteless powder, and discovered that it produced the same results without causing any harmful effects. Cannon reported his findings in the *American Journal of Physiology* in 1904. Radiologists continued to use bismuth subnitrate extensively until 1910 when barium sulfate replaced it on a significant scale. Barium sulfate's low cost also increased its attractiveness as a desirable substitute[33].

Further advance in x-ray research of the digestive system occurred in 1913 when Lewis Gregory Cole (1874-1954), a New York City physician, designed a semi-automatic photographic camera that advanced film at the press of a lever. Cole's camera followed the movement of an opaque substance through the digestive system taking a rapid succession of photographs that roughly resembled actual motion[34]. His camera was the first attempt at cineradiography, a modern technique used today.

Applications of opaque substances to the circulatory system followed within a few years. In this case halogen compounds provided the contrast medium. In 1919 Carlos Heuser (1878-1934), a physician in Buenos Aires, Argentina, discovered that water-soluble iodine compounds made the veins and arteries opaque to x-rays[35]. Because all blood eventually filters through the kidneys, iodine compounds also made possible study of the urinary tract[36]. Six years later, Warren Henry Cole, a second-year resident, and Evarts Ambrose Graham (1883-1957), professor of surgery, at Washington University's School of Medicine in St. Louis, used tetraiodophenolphthalein to diagnose gall bladder problems. This procedure is the well-known Graham-Cole test[37].

A different type of iodine-containing medium introduced in the 1920s was an oil called lipiodol. Jean-Athanase Sicard (1873-1929), professor of medicine and physician at the Hospital Necker in Paris, was the first to recognize the value of lipiodol in radiology. Working with Jacques Forestier, a young intern at the hospital, Sicard injected lipiodol into the subarachnoid space of the spinal column. Because of its oily properties lipiodol did not mix with the spinal fluid and enabled Sicard and Forestier to monitor its migration through the column. X-rays easily detected any blockage resulting from a tumor or lesion. In 1922 Sicard used the Sicard-Forestier technique, to visualize the structure of the bronchial tubes by injecting lipiodol through an aspiration tube. Lipiodol provided good x-ray photographs, but it had a slow absorption rate and irritated the tissues within the subarachnoid space[38]. Despite these disadvantages, the early applications of lipiodol and other opaque compounds to x-ray photography opened another world of diagnosis for physicians, enabling them to visualize actual physiological processes in motion.

Beginning in 1918 x-ray photography research focused on the brain. The brain was difficult to distinguish on film because of its low opacity, but physicians nevertheless believed that x-rays had the capability to detect brain abnormalities. Walter Edward Dandy (1886-1946), professor of pathology and surgery at Johns Hopkins University, first demonstrated the potential of x-rays in 1918, when he replaced fluid in the brain ventricles with air. Being more transparent than brain tissue, the air-filled ventricles provided sufficient contrast to make visible any tumors in the ventricles. Dandy called this procedure ventriculography[39]. Later he developed pneumoencephalography, a similar procedure that involved injection of air into the spinal canal to fill the subarachnoid space[40].

Though important, Dandy's advances were limited in scope because they failed to detect tumors inside the brain tissues. Building on Dandy's work Antonio Egas Moniz (1874-1955), professor of neurology at the University of Lisbon, experimented with a sodium iodide medium. Moniz injected the iodide into the inner carotid artery and obtained an x-ray photograph of the brain's arterial network that enabled him to locate a tumor-caused deformation. He also constructed equipment capable of taking instant x-ray photographs before the sodium iodide was diluted in the blood stream[41]. By 1930, the photographic techniques developed by Moniz, Sicard, and the others had made visible all parts of the body. Later, in 1949, Moniz won the Nobel Prize in medicine for discovering frontal leucotomy (surgical division of the nerves between the frontal lobes and the rest of the brain) for treatment of certain psychoses[42].

Safety Concerns about X-rays

By 1930 the results of x-ray research clearly were monumental, but questions arose about the rays' safety. Almost from the time of their discovery, scientists, physicians, and a curious public had used x-rays without caution. Their harmful effects were not known and, consequently, x-rays had many diverse uses, including some that were not even scientific.

In 1899 at an Oakland, California, industrial fair, Frederick Cottrell (18771948), later inventor of the Cottrell precipitator, used x-rays to confirm a glassblower's claim of being able to eat glass. The glassblower received one and a half hours' exposure to the rays, and Cottrell earned twenty dollars for his services. One week later the glassblower became dangerously ill and threatened a lawsuit. He dropped the suit only after the

two doctors who cooperated with Cottrell in the test agreed to provide the glassblower with free treatment. Understandably, Cottrell's interest in x-rays waned[43].

Clarence Dally, a co-worker of Thomas Edison in West Orange, New Jersey, became the first martyr to the new science. Dally worked extensively with x-rays in Edison's laboratory and in 1904 died from resulting complications[44]. The hand was the most frequently exposed body part and experienced radiation dermatitis, chronic ulcerations, and cancer. Hair loss usually accompanied the exposure, and sometimes amputations were necessary[45]. Deformity and death of early x-ray researchers were cruel lessons on the radiation's harmful effects. The tragedies of radiology's early days were as unfortunate as the deaths that resulted from exposure to radioisotopes in the first decades of the twentieth century[46]. Concern about overexposure to x-rays remains strong and put an end to the common and foolish practice in the 1950s and 1960s of having a salesperson determine proper shoe size by photographing the bones of the foot.

Because of the danger radiologists have designed x-ray equipment and techniques with an emphasis on safety. Béclère was a tireless promoter of x-ray safety and insisted on the wearing of anti-x-ray goggles of lead glass, lead aprons, and lead rubber gloves. To protect the patient he initiated the technique of having x-rays enter the body through multiple points. His technique reduced damage to skin and remains in use today. Béclère also played a major role in setting radiological standards. He succeeded in establishing the *röntgen* (r) as the international unit for quantitative measurement of x-rays, thereby enabling radiologists to determine how much radiation a patient received[47]. Because of the ever-increasing use of x-rays, post World War II studies on radiation's harmful effects have created an important and expanding field in medicine and public health[48].

Conclusion

X-rays, the fruit of Röntgen's discovery, have saved countless lives through diagnosis and therapy. We cannot overestimate their contribution to the development of radiology as an invaluable branch of medicine, particularly in making possible visualization of the entire body, from the skeleton and internal organs, to soft tissues, and finally the brain. In the period 1896 to 1930, which were a time of intense experimentation and application of x-rays, Röntgen, Béclère, Cannon, and many others provided a strong foundation for radiology. Since 1930 radiology has continued to grow and is now a high-tech specialty capable of complex procedures and diagnoses. It has come a long way since the first x-ray photographs of 1896.

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Articoli/*Articles*

A FRAGMENT OF GEORGIA-BYZANTINE MEDICAL HISTORY

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SUMMARY

This article trows light on the role of Georgia ranging from the ancient Greek cultural to the Byzantine periods.

Drawing on similarities between proto-Georgian and proto-Greek culture, the author mentions the strong ethnic linguistic and mythical hands. In particular stress the special place of Georgian medicine in the texts of ancient Greek and Roman historians, geographers and doctors.

In a more detailed discussion of historical sources particular attention is paid to the role of prominent Georgian figures in the Byzantine period including their important role in the translation of scientific and philosophic treatises and their active partecipation in the foundation of hospital and quarantine facilities.

Georgian-Byzantine relations represent an integral part of permanent Georgian-Greek, Georgian-Roman relations which had been established long before Christ, namely, in the period which can be characterized as proto-Georgian and proto-Greek ethnic and language one. This is a unified cultural and ethnical layer which formerly had turned into a number of largely differentiated national cultures of the region. Sumerian, Kheta-Subarul, Minos, Knodos, Mycenaean and other myth-based cultures which had by then turned into reality. The undoubted parallels between the *Amirani* and *Prometheus* legends as well as the *Argonauts* are a set of subjects and facts which enable us to judge on the base of something more than mere close neighbourhood relations[1].

Parole chiave/*Key words:* Georgia - Medical Relationship - Byzantine period