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History of X-ray therapy

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THE HISTORY OF X-RAY THERAPY

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FOREWORD

Roentgenology, as such, is a fairly recent development in the fields of diagnosis and treatment of medicine. The X-ray itself is only forty years old and is a mere child among the other important branches of medicine.

Many of the first workers in roentgenology are still living and active in the field, which makes early reports and papers on the development of the science very accurate.
EARLY ELECTRICITY

As Coolidge has stated, there seem to be two classes of investigators, one comprising those who delight in very accurate measurements with refined apparatus and another made up of those who get new results with crude and sometimes old apparatus. Rontgen certainly belongs to the latter class. His great discovery was made with a device which had attracted the attention of the physicist ever since 1859, when Plucker was studying the green fluorescence of the glass of an evacuated tube through which a discharge was passing.

These studies in turn were outgrowths of the fundamental activators of X-rays, namely, electricity, and in reviewing the history of Roentgenology, a brief history of the phenomena of electricity must be considered.

Away back, in the earliest periods of written history, when myths, legends and facts were inseparably linked together in the minds of the people, the phenomena of electricity attracted the attention of students and philosophers.

As early as the Sixth century before the Christian era, Thales of Miletus, in Phoenicia, studied the effect of friction on amber (which he named the electron.)

Some three hundred years later, Theophrastus, the Greek philosopher, took up this subject and after enlarging considerably upon it, handed it down to Pliny, Socrates and others of the Peripatetic school of philosophy; but it was not until nearly 1300 years had passed, when in 1590, Gilbert,
Physician in ordinary to Queen Elizabeth, in his celebrated work "De Magnete" described experiments, produced shocks, sparks and other strange physical sensations. Gilbert did not apply this knowledge to medicine but gained great renown from it. Of him, John Dryden wrote, "Gilbert shall live till lodesstones cease to draw, or British fleets the boundless oceans awe."

About 1650, Otto Von Goericke invented a static machine for producing electricity and twenty years later Stephen Gray expounded the principles of electricity. In France, shortly afterward, DuFay and Nollet studied, experimented, and brought the knowledge of electricity decidedly forward. In 1726, Muschenbroek, of Leyden, invented the Leyden Jar, and after having been shocked by its full charge, he wrote to Reamur that he would not permit a second such shock for the whole Kingdom of France.

Soon after Muschenbroek's invention, Benjamin Franklin constructed a battery of Leyden Jars capably of producing enormous discharges and shocks which are reported as closely approaching the phenomena of natural lightning.

In 1791, Luigi Galvani, an Italian of Bologna, published "De Viribus Electricitatis in Motu Musculari Commentarius" as the result of over twenty years study and experimentation upon the relation of animal functions to electricity.

In 1769 and 1771 Volta published two Treatises and discussions in which he describes the phenomena and construction of the voltage pile.

Static electricity was first used as a curative agent in the practice of medicine by Von Haen in 1745, by Jallabert in 1748 and by Abbe Nollet in 1749. In 1759 Benjamin Franklin treated paralytics with electricity and one year later the
famous divine John Wesley published a treatise entitled "The Desideratum, or Electricity Made Plain and Useful by a Lover of Mankind and a Common Sense."

Our first authentic records of the use of electricity in medicine in England was in 1767 when the static machine was installed in the Middlesex Hospital. In 1769 John Birch, a surgeon of St. Thomas Hospital, London, wrote an essay of fifty pages on Modern Electricity for John Adams' book, "An essay on Electricity."

One of the important steps between the elementary work with electricity and the advent of the X-ray was the work done with exhausted tubes and bell jars. Faraday in 1806 after passing the electric currents into and through more or less exhausted tubes and bell jars, discovered changes in color and reduction of resistance in the greater degrees of exhaustion. The study, experimentation and writings of Harris, Geissler, Maxwell, Hittorf and others, made rapid strides toward our present knowledge of the subject.

Professor Hittorf about 1860 discovered that the luminous stream of discharge in a Geissler tube could be deflected by a magnet--a fact which has an important bearing upon the subsequent experiments of Crookes, whose tube Rontgen used when he discovered the X-ray.

Several years after the work of Geissler and Hittorf, Crookes, experimenting with discharge tubes of a vacuum of about 0.00001mm. found that with this higher vacuum (that used by Geissler being about 0.0025mm.) the luminous glow within the tube disappeared and demonstrated that within it there was a rectilinear radiation from the cathode which was a projection of particles of highly attenuated gas at exceedingly high
velocity. He called this radiation cathode rays and on account of the peculiar behavior of gas in this exceedingly rarefied state he conceived it to be as different from gas in its properties as ordinary air or gas differs from a liquid. He spoke of this condition as the fourth or radiant state of matter. He found that cathode rays were intercepted by metallic plates within the vacuum tube, that their impact against the glass wall of the tube produced in it a greenish phosphorescence and fluorescence and an increase in temperature.

In 1892, Hertz, after a series of experiments, announced that the cathode rays would penetrate gold leaf and other thin sheets of metal, within the tube. Soon after he died, his assistant, Lenard, observed this same phenomena of the cathode rays outside of the Crookes tube.
THE DISCOVERY

Late in April, 1895, Wilhelm Konrad Rontgen, director of the Department of Physics of the University of Wurzburg, while experimenting with Crookes and Hittorf tubes, discovered the X-rays but he did not report his discovery until nearly the end of that year. There are several different versions regarding the details of this discovery, as well as varying dates of the same. The actual incident of the discovery is described by E. E. Burn in Popular Science Monthly for December 1908 who attributes the following to Dr. E. S. Middleton of Chicago, who was a student in the Department of Physics at Wurzburg at the time of Rontgen's discovery of the X-rays.

Middleton stated that "Rontgen had a Hittorf tube covered by a light tight paper, energized by a coil, and was studying the fluorescence of the screen, one afternoon, and, being called away for a few minutes he laid the glowing tube upon a book which contained a large flat key, which was being used for a book mark. A loaded photographic plate holder happened to be lying under the book. When he returned he shut off the current from the tube, stood the plate holder with several others and spent the afternoon out of doors, exposing several plates in the practice of his favorite hobby, photography.

On developing the plates he found the shadow of the key book mark on one of them. He wondered how this happened and questioned several of his students, but none could explain
Fogging of photographic plates lying near energized vacuum tubes had occurred before, but to the scientific inquiring mind of Rontgen, this key shadow demanded explanation. Remembering having laid the tube on the book, he replaced the tube upon the book and a photographic plate beneath it, and energized the tube. After developing the plate he found the same shadow of the key. Soon afterward he made a plate of his own hand, and at once began a thorough study of the phenomenon. He realized at once that he had a new form of radiation and studied the subject for eight months before reporting the result.

Dr. Middleton states that April 30, 1895 was the date of the discovery.

Rontgen apparently appreciated the great value of his discovery to the medical profession and on December 28, 1895, presented a paper entitled, "A New Form of Radiation" before the Wurzburg Physiomedical society and a further report to the same body on March 9, 1896. In one of the most epoch-making papers read before a scientific society under the title "Concerning a New Kind of Ray" Rontgen presented before the Physical Institute of the University of Wurzburg his rationation on the phenomena observed:

"If a Hittorf tube, a Leonard tube pumped sufficiently high, a Crookes tube or similar apparatus is covered with a rather closely fitting shell of thin, black pasteboard, if then the current from a rather large induction coil is sent through this tube, and if a paper screen, covered with barium platinocyanide, is brought near the tube in a completely darkened room, the screen will be seen to light up brilliantly and to fluoresce, regardless whether the coated side or other side is
turned toward the apparatus.

It is easily proved that the cause of the fluorescence has its source in the tube and in no other place.

Most surprising in this phenomenon is the fact that some agent penetrates a black paste-board shell, which does not allow the passage of visible or ultra-violet rays of the sun or of the electric arc, and that this agent can cause brilliant fluorescence. The next question is whether other bodies possess the same property, that is, are transparent to this agent.

It soon became evident that all the other bodies are transparent, but in greatly varying degrees. For example, paper is very transparent. Behind a bound book of about one thousand pages, I saw the screen light up distinctly, the black ink of the print apparently offering no resistance. In the same way the screen lit up behind a double pack of cards. The effect of a single card between the apparatus and the screen could hardly be noted by the eye. Also, a piece of tinfoil had little appreciable effect, and only when several layers were placed one on top of another could a shadow be distinctly seen on the screen. Thick blocks of wood are transparent. Two or three centimeters of pine wood absorbed very little. A layer of aluminum, 15 cm. thick, weakened the effect very much but was not sufficient to efface entirely the fluorescence. Gard rubber discs, even several centimeters thick, were transparent to the rays. Glass plates of the same thickness differed according to whether they contained lead or not, the former being much less-transparent than the latter. If one holds his hand between the tube and the screen he sees the darker shadows of the bones in the lighter shadow of the hand itself.
Rontgen's conclusions still hold good, namely, that the transparency of different substances to the rays assuming equal thickness, is regulated by their density.
LIFE OF RONTGEN

William Konrad Rontgen was born in Lennep, Germany, March 27, 1845. He was the only child of a Dutch mother and a German father.

His early life was spent in Utrecht, Holland, the birthplace of his mother and where his father, Frederich Rontgen, was a farmer. His parents were thrifty, industrious, sturdy and very religious and he inherited these traits and developed along these lines, into all that such parents could hope for or expect.

His parents intended that he should take up farming as a livelihood, and after the local primary schooling obtainable at Utrecht, he was sent to the Agricultural school at Apeldoorn, in Holland. During his fifth year at this institution of learning, he was dismissed in dishonor, because he would not disclose the names of his associates in some boyish prank, although admitting his participation in the frolic. He afterward failed in the examination for advanced standing in a German university, but was subsequently admitted to the Polytechnic Institute in Zurich where he became an indifferent student, paying more attention to matters outside of the college curriculum, than to his scientific studies. Only one of the instructors was particularly attractive to him, and to that one, Clausius, he gave wapt attention.

At a later period, he was a student at the School of Experimental Physics in Munich, where he accepted the oppor-
tunity to spend much time in experimentation, and which in-
cidentally fitted and prepared him for his future work. The
high character of the reports of the results of this experiment-
ation induced Kundt, whose favorite pupil he soon became, to
secure for him a position as assistant, which position he re-
tained for many years, and for which he received his Doctorate
in Physics from the University of Munich.

When Kundt moved to Wurzburg, Rontgen went with him,
and it was here that he met the young woman who later became
his wife and lifelong companion.

Owing to the snobbishness and other social conditions
which prevailed at the University of Turzburg, Rontgen could
not be advanced beyond an assistantship at that place, but follow-
ing Kundt, who was called to Strassburg, he in two years was
made Decent in Physics and in 1875 at the age of 30 years, he
was appointed Professor of Mathematics and Physics in the Acad-
emy of Hohenheim. Here he remained only a year, returning to
the University of Strassburg to become Associate Professor of
theoretical Physics. After three years he received a call to
become professor of Experimental Physics at the University of
Giessen, at which institution he remained a little over nine
years, and where he devoted much time to high grade experimen-
tation, profound study and teaching.

In 1888, he was called to the University of Wurzburg
where he became Director of the Physical Institute and worked
about as he pleased. It was in the Physical Laboratory at
this university where the momentous and epoch making discovery
of the X-rays took place in 1895.

Rontgen received numerous honors, among which were
the award of the Barnard Medal of the National Academy of
Sciences and in 1901 he was awarded the Nobel Prize. He died in Munich March 10, 1923 at the age of 78 years.
THE X-RAY TUBE

From many standpoints the history of the advancement of the X-rays in diagnosis and treatment is a study of the advancement made in the tube itself.

Thirty-nine years have now passed since the scientific world was startled by the announcement by Professor Rontgen of the discovery of a "new kind of rays" and the vacuum tube in which alone they can be generated has passed from a piece of delicate apparatus, little known and rarely seen outside the laboratory of the "elite" to an every-day article of commerce that can be safely manipulated by any moderately skilful person. To trace the origin and development of the X-ray tube is a matter of very great interest.

At the time of Rontgen's discovery, and for several years afterwards, it was usual to call it a "Crookes' tube" in honor of the one to whose classic researches in high vacua the discovery was largely due; but as the term also applies to many other forms of vacuum tubes that produce effects quite apart from Rontgen radiations, this term has not been universally applied. "Rontgen tube" has been proposed, and is often used, but the discoverer of the rays has taken little or no part in the origin or development of the tube, therefore this designation is hardly suitable. "Jackson tube" has been suggested because the form of tube universally used for a long time was designed by Professor Herbert Jackson, but it seems that it is better to avoid making distinctions and adopt the
term X-ray tube which immediately conveys the sense of what one is speaking about. In past years since 1913, many speak of the tube as the "Coolidge tube" because of the great step in advancement that Coolidge made in the designing of most of the tubes that are used today.

In following the development of the X-ray tube through the many stages that lead up to the present efficient piece of apparatus it will be necessary to continually refer to the researches of Roentgen. I refer, of course, to Sir William Crookes, for in almost every instance of advance that has been made in the X-ray tube up to the present time the seed from which that advance sprang will be found in the work of that investigator.

The Crookes tube with which Professor Roentgen's famous discovery was made, was pear shaped, having a flat circular cathode, and its narrow end an anode in a small tube at the side. The cathode rays fly off at right angles to the surface of the flat cathode plate and strike against the large end of the tube, producing there vivid phosphorescence, heat and X-rays. The life of these tubes, as everyone who worked in the early days has sad cause to remember, was very brief; a few exposures at most and the tube was either pierced by a spark or cracked on account of the heat generated by the bombardment of electrons. Many devices were suggested to prolong the life of such tubes and one of the earliest that was developed was a prototype of the water-cooled electrode made by Silvanus P. Thompson, for in a letter to J.H. Gardiner he gave a sketch of what he then considered would be the ideal form of tube for producing X-rays. The large end of the pear shaped tube when in use was to be kept in water contained in a thin celluloid dish, and the photographic plate placed below. At that time
it was generally thought that the production of X-rays was dependent upon the phosphorescence of the glass, and it is interesting to recall that this idea, although a false one, was the means that led to the discovery of radium and radio-activity, and all that has been built up on that discovery. For the suggestion was thrown out by M. Poincare, in France, that if, X-rays were generated in the phosphorescing walls of a vacuum tube, was it not possible that X-rays would be produced by other phosphorescing bodies. As is now well known the idea was put to the test by Henry Becquerel and resulted in the discovery of the radio-activity of the compounds of uranium, followed quickly by the discovery and isolation of radium by Madame Curie and the recognition of the other radio-elements.

Just about this time a very interesting tube was devised by A.A. Campbell Swinton. This tube illustrates how very near it is often possible to get to a mark without actually hitting it. In this tube the cathode rays were received, not on the glass end of the tube, but upon a sheet of platinum supported a short distance from it. It only needed the cathode to be curved to have anticipated by some months the tube proposed by Professor Jackson, which marked the greatest advance that had been made up to the work of Coolidge.

The radiographs produced in these early days, before the so-called focus tube came into use, were of course, lacking in sharpness and long exposures were needed; but one will never forget the creepy sensation experienced when looking for the first time at a photograph of the bones of the hand and wrist of a living person. The first radiograph of the kind exhibited in England was the work of Swinton and it was exhibited at the meeting of the Royal Photographic Society and im-
mediately afterwards at the Royal institute.

One can have no hesitation in saying that exact radiography dates from the time when Jackson advocated the employment of a tube in which the cathode rays were brought to a focus onto a plate of platinum, which could be either an independent pole or the anode itself.

That the cathode rays could be brought to a focus by curving the cathode had been amply demonstrated years before, and the tube which is the prototype of our present X-ray tube was fully described in a paper by Crookes that appears in the transactions of the Royal society for 1874.

After the X-ray tube had become an instrument in constant use, a difficulty that had always been noticed became a serious source of trouble. This was the gradual increase in hardness or electrical resistance of the tube. At first it was the practice to lower the resistance by the application of heat from a spirit lamp or gas burner; it was even proposed to bake the tube in an oven, but the lowering of resistance was only temporary, and soon numerous devices came into use whereby the resistance could be lowered by the introduction of a small quantity of gas. Generally there are two ways of doing this, either by liberating gas enclosed in various substances contained in the tube itself, or by letting in gas from the outside. The former method was employed by Crookes in his experiments in 1874. The vacuum tube which in this case is cylindrical has a small tube attached containing some caustic potash, application of heat by a lamp immediately liberates gas and lowers the vacuum. This device has been utilized by various makers.

A novel and ingenious plan was patented by Harrison Glew. In his tube, a narrow tube was connected, containing a
number of very small pieces of iron coated with sealing wax; it was only necessary to isolate one by means of a magnet and heat it with a flame to liberate sufficient gas to lower the vacuum.

Very soon this adjustment method was made to work automatically. The substance containing the gas was mounted in a small tube attached to the main bulk and as the resistance increases, sparks pass to the small bulk, liberating sufficient gas to lower the resistance.

The next method for introducing gas was by what was called the osmosis method, which was the device of Professor Villard of Paris. A small tube of palladium closed at one end was sealed into the bulk and the closed end allowed to project outside. Palladium has the property of being transparent to hydrogen at a red heat; if, therefore, the little palladium tube is heated by a gas flame, hydrogen immediately enters the tube, so lowering the resistance. This is a very convenient and practical method, but the improvement over that was the Bower valve, in which it was only necessary to "press a button" and a minute quantity of air was allowed to enter the tube.

The gradual increase in the resistance of a tube by use was a matter of considerable interest, and it was invariably accompanied by a darkening of the glass walls of the tube due chiefly to a deposit of matter torn off the electrodes by the electrical excitation. This disintegration of electrode matter takes place in the cathode only, and the property, called by Crookes "electric volitalization" is possessed in varying degree by all metals. The matter was a subject of a paper by Crookes that appeared in the proceedings of the Royal Society in 1891, and in that paper he presented a list showing the rel-
ative volatilities of many of the metals.

Advances in X-ray work made it necessary to employ much heavier currents than had been used formerly and instead of one to two milliamperes, as high as 100 milliamperes are often passed for short periods. With much heavy currents it has been necessary to introduce more or less complicated devices for preventing the anticathode surface from overheating. Two methods were used: one first adopted by Swinton, is to back up the anticathode surface with a mass of metal so as to dissipate the heat generated by conduction, the other to make the anticathode form the end of a box or tube that can be kept full of water from the outside. A third plan is to make the anticathode of a metal with a higher fusing point than the platinum generally used. A very early instance of this was the introduction by Davidson of the omium anticathode. Very good results were obtained by these tubes, but the difficulty in obtaining the metal prevented their general adoption.

Most of the troubles experienced with the gas tubes was associated with the gas itself and the rapid changes in degree of vacuum causing higher resistance to the current.

In 1913 Coolidge, after developing with other men the most efficient types of targets, turned his attention to the other shortcomings of the tube itself and found them to be: With low discharge currents the vacuum gradually improved, with high discharge currents there are very rapid vacuum changes, sometimes in one direction and sometimes in the other, If a heavy discharge current is continued for more than a few seconds the target is heated to redness and then gives off so much gas that the tube may have to be re-exhausted, of the tubes tested, many have failed from cracking of the glass and this always at
the same point, that is, in the zone around the cathode, the focal spot on the target in many tubes wanders about very rapidly, while it is relatively easy to lower the tube resistance by means of regulators, it is a relatively slow matter to raise it much. No two tubes are exactly alike in their electrical characteristics.

As was stated, most of these limitations were incident to the use of gas in the tube and they could therefore be made to disappear if a tube could be operated with a much higher vacuum.

The idea of a hot cathode was not new as Richardson and Langmuir had shown good results from the use of heated cathodes in higher vacuums and it was from the inspiration of Langmuir's work that Coolidge became encouraged.

The description of Coolidge's work is long and very technical in nature, too much so to describe in this paper, but he did develop a tube which overcame the distressing shortcomings of the gas tubes and his tube has been almost universally accepted in modern usage today.

The tube allows current to pass only in one direction, and therefore can be operated on either direct or alternating current.

The intensity and the penetrating power of the rays produced are both under the complete control of the operator, and each can be instantly increased or decreased, independent of the other. The voltage is controlled directly from the input source and the milliamperage is controlled from the amount of heat applied to the cathode.

The tube can be operated continuously for hours, with either high or low discharge currents, without showing an appreci-
iable change in either the intensity or the penetrating power of the resulting radiations.

Thus, from very uncertain and relatively feeble source of radiation, the roentgen tube has been developed to the point where it may be considered as a precision tool of great stability, flexibility and ease of control, permitting of the accurate reproducibility of results and capably of operation with currents and voltages of any desired magnitude. From the point where only an expert, with years of experience could get the most out of it, the tube has come to be as easy to operate as an incandescent lamp.

Another interesting and intimately connected chapter to this story of the development of X-ray therapy concerns the development of the exciting apparatus from the static machine through the transformer and valve tube rectification, the development of the fluoroscopes, films, stereoscopes, and apparatus lending its part to the efficient type of machines which we have today but they cover too great a field to include under this heading.
X-RAY THERAPY

From the first, it became evident that the X-rays had an effect upon the human body and tissues and it was but a short time before they were being used in the treatment of a multiplicity of conditions. An attempt to chronicle the numerous applications would entail a perusal of an impossible amount of literature on the subject on which thousands of articles have been written. Many of the early works are far from authentic and to separate the wheat from the chaff would be a well nigh impossible task.

On February 15, 1896, the Journal of the American Medical Association in its first editorial on the newly discovered roentgen rays expressed the opinion that possibly the new rays might have a therapeutic effect. In this editorial the following statement was made: "As regards their therapeutic possibilities which have already become the plaything of the popular imagination, they may be left to further investigations." Little did this writer know at that time how soon his prophecy would be fulfilled.

Unfortunately, the first physiological effects of the roentgen rays on the skin were unexpected and undesirable and they mark the beginning of the long and distressing chapter of the suffering of many roentgen pioneers. The newly discovered rays could not be expected to produce a physiological effect, therefore the pioneers could see no reason for protecting themselves against them. It is remarkable therefore, that
Rontgen himself made all his experiments with the X-rays in a large zinc box, on the outside of which the tube was placed, later he even put a lead plate on top of the zinc between the tube and himself. These precautions probably were taken to better define his beam at will by means of diaphragms in the box and also to protect the photographic plates, with which me made many of his experiments, from being fogged by the rays. At the same time, he was completely protected.

Other pioneers were equally careful. Dr. Francis Williams of Boston, one of the best known early roentgen pioneers in this country has always taken great pains to protect himself against the radiations, from the beginning of his work in 1896 up to the present time and has suffered no untoward effects. "I thought that rays having such power of penetrating matter as the X-rays had must have some effect upon the system and therefore I protected myself," said Dr. Williams in answer to a question as to what prompted his precaution.

Walter James Dodd, another great American roentgen ray pioneer and a colleague of Dr. Williams in Boston, did not take such precautions. The result was that his hands were badly burned by the rays, and in spite of many operations and skin grafts he died from the effects of these burns in 1916.

The story of these two great men shows how little any physiological effect of the rays was expected in the early days, how little the effect was explainable after it first appeared and how easy it was to forget the possibility of such effects in the midst of the enthusiasm of working with the newly discovered rays.

Edison, the great inventor, was one of the first to notice some peculiar effects after working with roentgen rays.
Ater several hours work with fluorescing tubes he would complain of pain in his eyes but he did not think that this was due to the direct effect of the rays. The New York physician, W.J. Morton, also one of the industrious roentgen pioneers, often saw flashes of light after working with the rays.

Soon, however, more definite and more serious reports of undesirable effects of the rays became known. Professor J. Daniel of Vanderbilt University reported in April 1896 that twenty-one days after taking a picture of the skull of Dr. W.I. Dudly with an exposure time of one hour, he noticed an epilation of a diameter of two inches on that part of the head which was directly under the tube.

On March 12, 1896, an Englishman, Dr. R.I. Bowen, in a talk before the London Camera Club, expressed the opinion that roentgen rays might produce a sunburn similar to that of sun rays.

Many of these effects were more than a mere dermatitis and the history of X-ray is saddened somewhat as we read of the men who actually lost their lives as a result of the pioneer work which they did and had no way of knowing the results or how to protect themselves against the ill effects of the rays.

The first person in the United States, and probably in the world to die because of X-ray exposure was a man named Clarence Lally of East Orange, N.J., a chemist in the employ of Thomas A. Edison, who died in 1904. He had carried on extensive experiments for Edison, endeavouring to produce a screen which would render the X-rays visible to the human eye.

August Luschka, who was the first man in the United States to design a successful, sectionally wound X-ray coil
was badly burned and though he lived until 1921, his death was directly due to over-exposure to the X-rays.

Dr. Emil H. Grubbe of Chicago in a paper in Radiology for August 1933 maintains that he was the first person exposed to X-rays who received sufficient cumulative effects to develop dermatitis, that he was the first person to apply X-rays to pathologic lesions on living human subjects for therapeutic purposes and that he was the first to use sheet lead or any other substance as a protective against untoward X-ray effects.

At the time that Rontgen made his discovery of the X-rays, Grubbe was a manufacturer of vacuum tubes in the United States and when the discovery was made known, he at once began some concentrated work with the rays with the material he had at hand. He noticed that the first tubes he worked with did not have a large output of X-rays and judged that this was due to the fact that the cathode rays were not concentrated sufficiently to transform them into effective X-ray value. He immediately constructed a tube after the pattern of Jackson with the curbes focusing cathode and immediately the results were much better.

He made a number of tubes, all of which he tested by exposing his left hand between the tubes and fluorescent materials. This was done many times daily for many days. These frequent and long exposures to the X-ray produced a cumulative effect and by the last week in January, 1896 he had developed a dermatitis on the back of his hand.

On January 27, 1896 he consulted his professors in the medical college for advice on treatment and it was at this meeting that his professor Dr. J.E. Gilman put forth the suggestion that any physical agent which would produce such definite
changes might have a therapeutic value in pathologic conditions where irritative, blistering or even destructive effects might be desirable. As examples of such lesions he mentioned cancer, lupus and indolent ulcer.

This statement impressed the other men present and Dr. Ludlam asked that the new rays be used in a patient of his who had an inoperable carcinoma of the breast with systemic involvement. He appreciated that this patient was doomed to an early death and thought the case was a good one to try the experiment on, and two days later this patient came to Dr. Grubbe for trial. "And so, without the blaring of trumpets or the beating of drums X-ray therapy was born. The very first application of the X-ray for therapeutic purposes was made upon Rose Lee's cancerous left breast. This occurred on January 29, 1896. This patient received an exposure of about one hour a day with the Crookes tube almost in contact with the skin. Remembering his dermatitis he shielded the healthy tissues with the sheet lead and states that he believes this was the first time that sheet lead or any other protective substance was used as a protection against X-rays. The results of this treatment were never seen because the patient died a month later of generalized carcinomatosis.

In a paper which was read before the Roentgen Society of England, on January 11, 1898, William Webster stated that he first noted therapeutic qualities in the X-ray when, during the latter part of April, 1896, he exposed the elbow joint of a patient repeatedly for the purpose of diagnosis and found that rheumatic pains, which constituted the principal symptom in the case, were relieved.

One of the pioneer experiments which proved the thera-
peutic effect of the X-rays, or more definitely destructive effects, of the rays on normal tissue was the work of Elihu Thompson who did work to prove the destructive effects of the rays to workers. To quote, "Shielding by a lead sheet my left hand with the exception of about one and one-fourth inches of my little finger, I exposed the unshielded end of the finger close to a tube yielding rather soft rays, for twenty minutes. Also, to clinch the matter, I used only a static machine discharge to excite the tube. At the ninth day after the exposure, the finger which had been exposed was inflamed and on the eleventh day the exposed skin was necrosed and shed. The burn took a long time to heal and then only by a new scar growth from the sides. Several articles were published at the time calling attention to the extreme danger.

In spite of the delivery I used, I have seen this burn of mine erroneously described as the result of an accident. Finally on the next finger to the one so burned, and in order to settle absolutely that the injurious effect was due, not to electric effects, but to the rays themselves, I cut an elongated oval in a sheet of lead, shielding the most of the finger with it, leaving for exposure the long oval, which was however, divided into three sections. One of these was bare, or fully open, unshielded. Another part was covered with heavy tin and lead foil and the third with thin aluminum foil, a perfect shield electrostatically, but transparent to the roentgen rays. After exposure, the part covered by the tin foil was free from any injury—no redness or inflammation showing any time—while the unshielded part of the finger was burned and also the skin under the aluminum foil, thus setting at rest any possible doubt.
that the rays themselves were the true cause of the lesions."

It was these accidents occurring in the course of the study of the rays and use in diagnosis that first gave early workers their reasons to suppose that the rays possessed a therapeutic value.

Soon after the advent of the Rontgen ray and the indications of a possible therapeutic power were possessed by them, the literature was literally deluged with case reports and results of experiments. There were thousands of papers written by hundreds of investigators and to competely evaluate their individual worth is an almost impossible task.

In November 1901, the McMillan Company published "The Roentgen Rays in Medicine and Surgery," by Francis H. Williams, M.D., a pretentious volume of nearly 700 pages and over 400 illustrations, many of which would do credit to any recent work on the same subject and is the first authentic work published on this subject in this country. In this work the author described a multiplicity of skin lesions with case reports and photographs which are proof of the good results which were obtained with even this crude type of apparatus which was at hand and is convincing proof that the therapeutic values of X-rays was appreciated and quite well understood at that time.

It must be remembered that in the early work on therapeutics there was no standard type of equipment and the length and frequency of the treatments must depend first upon the resistance of the tube which was an uncertain factor and practically every tube in use differed in its degree of resistance and was subject constantly to changes in resistance. There was no standard unit of measurement of the treatment dose and the dosages
varied with constant factors in practically every machine in use. All of these early workers were pioneers in the field and the material that they have handed on to us is the result of experience. Practically the only method of gauging their dosage was from the reaction of the tissues to the treatment or from the penetrating power of the rays as gauged from the distinctness of bony shadows of the hand on the fluoroscope. Among the lesions treated and described by Williams are, Lupus, eczema, nevus, sycosis and favus, hypertrichosis, psoriasis, acne, trigeminal neuralgia, and yearly the effect on new growths was recognized and used. Many of the malignant growths on the lips, tongue, face, breast and cervix uteri were treated and wonderful results obtained.

In 1903, W.B. Saunders and Co., brought out "The Practical Application of the Rontgen Rays in Therapeutics and Diagnosis" by William Pusey and Eugene Caldwell. This really magnificent work may be still considered an authority upon the subject and stands as a monument to the authors who were two of the outstanding pioneers and authorities at that time.

All during these early years there were many men working trying to standardize apparatus because when one man described his technique for treatment it was of no value to the others because of the difference in tubes, coil windings, interupters, etc.

Numerous methods of measuring the dosage of the X-ray apparatus were published and it is clearly understood that no one of them was satisfactory as evidenced by the great number and variety of the methods.

Among the different types are: measurement of the electric current entering the primary coil; penetration method of Benoist, physico-chemical methods of which the chromo-
radiometer of Holzknecht was used to quite an extent. But in spite of the difficulty in measuring and correlating dosage technique, roentgen therapy continued to develop and numerous reports in the literature indicated beneficial results from clinical experiences.

In 1903, Nicholas Senn of Chicago really founded deep roentgen therapy when he reported favorable results from roentgen irradiation of the spleen inpatients suffering from leukemia. This report proved that roentgen rays had deep effects because they reduced the size of the spleen and diminished the number of blood cells in the circulation. Senn, who was a well known surgeon, had referred a patient with leukemia for treatment to Allen Pusey, a dermatologist and roentgen pioneer, who subsequently reported on the treatment of similar cases.

Another great step forward in the therapeutic action of the X-rays came with the correlation of the clinical and laboratory applications. In 1904, J. Bergonie and L. Triboneau gave the complete histologic picture of the changes produced by irradiation upon the rat's testicle and showed the point of attack of the roentgen rays to be upon embryonic cellular structures. They formulated a new law known by their name, which is the basis of our knowledge of the effect of radiation upon all cells and tissues. The law states, "Immature cells and cells in an active state of division are more sensitive to the radiation than are cells which have already acquired their adult morphology and physiological characteristics.

The introduction of filters to eliminate the soft rays was another step in the attack on deeply seated disease. These soft rays were especially disturbing because they are so readily absorbed in the skin, and therefore, limit the inten-
inity which can be applied to the diseased area.

In 1904, G. Perthes reported an extensive investigation on the rate of absorption of the rays in tissue and proved that when the rays are filtered through aluminum the skin is protected and the intensity into the deeper layers is increased. He made the first depth dose measurements which subsequently led to the use of filters in Europe. His conclusions were that when radiating the body, the intensity of the rays diminishes very rapidly from the surface to the depth and the decrease of intensity in the depth is much less if an absorbing layer of one millimeter of aluminum is placed upon the surface of the body.

The treatment of carcinoma of the cervix began about 1902 and the difficulties encountered were the shaping of the tubes in order that the rays might be introduced through the vaginal speculum. Many tubes were designed for this special purpose which could be placed directly against the cervix. It was the attempt to better treat the gynecologic conditions that resulted in the crossfire technic which was another great forward step in roentgen therapy.

The later great steps in deep therapy must be considered in the light of the advancement of apparatus and especially in the advancement of tube construction as advanced by Coolidge. After the advent of the hot cathode tube much higher voltages were at hand for use and consequently a more deeply penetrating ray of shorter wave-length was at hand. With the aid of the filters used the long waves which created such havoc with the superficial tissues were eliminated and the therapeutic value of the rays could be directed into the deeper tissues without
harmful effects on the surface.

Mention must be made here of the work of Duane, Szilard, Friedrich and other workers in the measuring of quantity and intensity of roentgen rays by measuring with an electrometer the amount of ionization produced in a unit volume of air. These workers laid the foundation for the present unit of therapy or Roentgen Unit (designated as the r unit) and also the amount of effectiveness of dosage received by the deeper tissues after the percentages had been absorbed by the skin.

As a result of all of these physical researches, it now became known that one of the most important factors relative to deep therapy effects of the roentgen rays in the tissues of the body under treatment was the scattered radiation created in them and that the total quantity of this radiation depended upon its quality (potential and filter).

It was in 1928 that resulting from the research of the physicists, in collaboration with the radiologists that the unit for measuring the quantity of radiation finally was established and at the International Congress of Radiology held in Stockholm the unit was defined as follows: "The unit of dose is that quantity of roentgen radiation which when the secondary electrons are fully utilized and the wall effect of the chamber is avoided, produces in one c.c. of atmospheric air at zero degrees Centigrade and 760 mm. mercury pressure such a degree of conductivity that one electrostatic unit of charge is measured under saturated conditions. This unit shall be called the roentgen and designated by r."

Roentgen therapists now possess the instruments of precision for measuring the r unit output of their apparatus under standard conditions or may have their apparatus calibrat-
ed by experts.

At the present time the whole procedure of applying therapy to deeply situated organs of the body is based upon the effort to direct highly penetrating rays produced by high potentials of from 200,000 to 1,000,000 volts and thick metallic filters of .5 to 5 millimeters of copper with the source of the rays at a distance of 40 to 75 centimeters and the beam directed at different angles through a number of properly selected portals of entry arranged to give the desired quantity of radiation to the diseased portions.

These various technics in roentgen therapy are applied to many conditions. It is possible to mention only a few of the clinical aspects to illustrate the usefulness of this method for treatment because at present there are over 400 different diseases which are benefited by roentgen therapy and therefore even the indications for treatment cannot be discussed. But the rationale of modern roentgen therapeutics is not based upon special technics or methods applicable to each different disease but upon knowledge of the effects of the rays upon associated morbid anatomic changes which are the result of disease processes.

As a result of clinical observation and biologic researches, it is known that the different types of cells or tissues of which the living organism is composed vary in their sensitivity to radiation in the following order: primitive blood cells, germinal cells of ovary and testicle, blood forming tissues including the cells of the red bone marrow, lymph system and the spleen, some glands of internal secretion such as the thymus, pituitary, adrenals and the thyroid, the skin and its glands and hair follicles, the abdominal viscera in-
cluding the liver, intestines, pancreas, kidney and uterus, and connective tissue consisting of muscles, tendons, cartilage, bone, fat and nerve tissue.

On the basis of this information when the type of cells affected by a disease or which constitute a pathologic tissue are known, the influence which irradiation will have can be predicted and also the preferable intensity of the rays and the method of application can be determined. It is apparent that some conditions are highly susceptible to roentgen rays if composed of consitive cells while others are highly resis tant and therefore require other therapeutic procedures. Hence, the roentgen therapist must recognize the limitations of his own method and direct treatment of resistant conditions to include other procedures, such as the application of radium or surgical operations.

The machines capable of producing a ray at the potential of 600,000 k.v. with the resulting intense penetrating power are very new in the field of deep therapy and have been in use only in the past few years. There are only about seven machines in this country which are being used for therapy and several others being used for experimental purposes.

One of the most successful machines now in operation is the Keleket apparatus used by Dr. Roscoe L. Smith in Lincoln, Nebraska. He uses an energy of the constant potential type with cascaded transformers each of which is capable of raising the current 125,000 volts. He uses an operating potential of around 600,000 volts but the machine is capable of a voltage of 900,000 volts. He finds that using the 600,000 volts with a filter of 7mm. copper, 7mm steel and 2mm. aluminum he can produce rays on the spectrum covered by the gamma rays of
The tube of his machine is sixteen feet in length and weighs over two tons. It is constructed of glazed porcelain which is two inches thick and has the usual platinum target. The target end of the tube projects into the treatment room from above and there are five different apertures through which he can treat five patients at the same time.

Dr. Smith says that he is of course doing a pioneering piece of work but is getting results which have more than proven the value of the machine in deep therapy. He is to be especially commended in his efforts from the standpoint that he has working with him, T.R. Folsom, a physicist who has complete charge of all physical problems. Mr. Folsom is completing the equipment of a physical laboratory for continued research on problems which confront them daily, the results of which are carefully recorded and will be checked with the Bureau of Standards in Washington, D.C.

In answer to a query of the results obtained, Dr. Smith says "Already we have been most gratified by the excellent palliation, the entire absence of reactions, no nausea, no abnormal blood changes, no skin reactions and very rapid recession of tumors which result from the dense filtering out of all long waves which cause such systemic reactions and still having an abundance of deeply penetrating rays which reach the diseased tissue."
CASE REPORTS OF DR. ROSCOE L. SMITH

CASE 1.

One of the most interesting cases that it has been my privilege to have under observation and treatment is that of a Mr. L., a resident of Plymouth, Ill. Mr. L. is 65 years of age. He was referred to me by Dr. Harry Flensburg, an internist and Dr. C.C. Hickman, a proctologist. He had a large palpable mass surrounding his anal canal and extending upward involving his bowel for two or three inches. His gut was constricted until it was impossible to insert the examining finger. There was a marked loss of weight, he was cachectic, no appetite, a constant feeling of uneasiness, extreme pain and insomnia. He had constant pain and distress in his rectum. He was passing twenty or twenty-five bloody stools in twenty-four hours. He was thoroughly aware of his condition and had given up all hope of relief. A total of 6,000 R. units of 600 K.V. radiation was administered through five portals of entry between the period of October 1 and October 31, 1933. His total time under radiation was approximately ten hours. On January 5, 1934, he returned for his second series. He had gained in weight and he had the appearance of a normal man of 70. He is unusually vigorous. He has no pain. He is having normal well formed stools, one a day or one every other day. His diet consists of the ordinary food of the average family. There are no restrictions. He has remained in his present condition since the first of December 1933 and, as he expressed himself
he is not conscious of any disturbance whatever.

**CASE 2.**

Mrs. S., age 56, a resident of Lincoln.

This lady appealed to me for relief of a large tumor in her right breast. Two other members of her family had recently suffered from breast amputations and recurrences. There was considerable retraction of the breast and dimpling of the skin, all of which caused her considerable pain. 3,600 R. units of 600 K.V. radiation was delivered through three portals of entry between November 16, 1937 and December 9, 1933. According to previous arrangements she returned on December 15. The tumor had receded to one-third of its original size. The dimpling of the skin was barely visible and it was difficult to palpate the tumor mass. The breast was amputated and the entire exposed area was thoroughly cauterized with an electric iron. Her recovery was uneventful and she returned home on the 24th of December. The pathologist's report on sections is of great interest and is as follows:

"Gross: The specimen consists of an amputated breast. Externally it is not remarkable. On cut section there is an irregular hard area of tumor mass seen just beneath the skin surface. Its borders are indefinite and the cut surface is characterized by yellow streaks running through its substance. Examination of the axillary fat shows a few small lymph follicles which on cut section have the appearance of broken down tumor tissue.

"Microscopic: Sections of the breast tumor which has received deep therapy before removal show many striking changes of the tumor cells. Most of the sections show only
striking changes of the tumor cells. Most of the sections show only shadows of tumor cells remaining. Here the tumor cell is characterized by a small pycnotic nucleus and the cytoplasm is distended with a clear pale staining substance. Another area shows the nucleus to be granular and there is a marked degree of karyorrhexis. Most of these cells must be interpreted as being lifeless. At the periphery of the tumor mass there are a few cells which as judged by their staining characteristics would appear to be still viable. However, even in these areas, there is definite indication of cell damage.

About the clumps of tumor cells there is a scattered rather diffuse lymphoid infiltration. Some of the muscle cells making up the breast tissue have undergone hyalinization. However, there is no histologic evidence of an actual increase of collagen fibers. These shadows of tumor cells appear in columns and strands and an original section of the tumor would probably have shown a typical scirrhous carcinoma.

"Diagnosis: Scirrhous carcinoma of the breast.

"J. Marshall Neely, M.D. Pathologist."

CASE 3.

Mrs. B., age 45, a resident of Lincoln.

In July 1931, Mrs. B. had a radical amputation of the right breast for an advanced carcinoma. The operation was performed by Dr. H. Everett who referred her to me for 200 K.V. Therapy. The usual series of deep therapy was applied to the anterior and posterior and lateral surfaces of her right thorax. She remained well until October 28, 1933. She complained of a very severe harassing cough which could not be controlled.
She had lost weight, was suffering from insomnia, night sweats and loss of appetite. A roentgenogram of the chest showed marked consolidation in both lungs, only a small amount of normal air cells were visible. We began treatment on October 28, 1933 and administered 7,200 R. units between that date and November 27, 1933. On December 23, 1933, approximately two months from the time her treatment was begun an additional X-ray plate was made of her lung for a comparison. Much to our surprise we found that the tumor had receded and instead of the consolidated areas which were visible before her radiation, we found mostly scar tissue with marked retraction leaving large areas of normal breathing space. The most amazing change, however, occurred at the end of her first week's treatment when all of her symptoms had subsided and from that time her gain in weight was progressive.
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