REVIEW ARTICLE

# DIAGNOSTIC MEDICAL IMAGING: A REVIEW OF A CENTURY OF EVOLUTIONS

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## ABSTRACT

**Background:** Diagnostic medical imaging has continually undergone tremendous evolutions since the discovery of x-ray in 1895. While some modalities have been modified, some have been totally discarded, while new ones have also been introduced as knowledge and technology continued to advance.

**Objective:** The objective of the study is to review and highlight the major events that defined the course of development of diagnostic medical imaging in the past century.

**Methods:** Available literature on the history of events and the principles behind major breakthroughs as well as on pioneers in the medical imaging sub specialty was reviewed.

Summary: Photography, chemical processing of photosensitive materials and fluorescence all preceded the discovery of X-rays by Roentgen and laid the foundation for the eventual discovery of X-ray in 1895. Between 1895 and early 1970's, the application of X- rays in medicine, science and industry went far beyond the imagination of early researchers and medical imaging practitioners. This period is generally referred to as the analogue era. In the period, X-ray films, intensifying screens, image intensifier and the rapid serial film changer were all introduced into diagnostic medical imaging. A major feature of this period was excessive radiation dose due to high exposure time that was required to produce diagnostic radiographs.

The digital period, which commenced with the first clinical application of computed tomography (CT) in the early 1970's, has continued till now. The main feature of this period is the modernization of x-ray equipment that culminated in drastic reduction of radiation doses associated with diagnostic imaging. Other major breakthroughs in this era include magnetic resonance imaging, single photon emission computed tomography and positron emission tomography. Areas hitherto believed impossible such as metabolic, brain and soft tissue studying are now routinely studied with x-rays in the digital era. As knowledge and technology continue to advance, it is also expected that diagnostic medical imaging will witness even more evolutions in future.

**Keywords:** Medical imaging, evolution, modalities, history.

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## INTRODUCTION

Diagnostic medical imaging, also known as Radiology, became a well developed and recognized medical sub-specialty in the first decade after the discovery of x-ray in 1895 by Wilhelm Conrad Roentgen, becoming a recognized medical sub-specialty in the United states of America only in 1900[1,2]. The discoveries of photography and photographic materials preceded the discovery of x ray and helped lay the foundation for the phenomenal growth seen in medical imaging[3,4]. In fact, the discovery of x-ray occurred when a fluorescent screen (barium platinocyanide) emitted light when it was excited by radiation emerging from a Crooke's tube to produce an image on a photographic plate[5].

The development of medical imaging in the past century has been so rapid that it has presently assumed the status of one of the fastest growing and most technology-driven medical sub specialty[6]. With advancement in both knowledge and technology, especially the advent of computerization, medical imaging has evolved from the analogue era to the current digital systems presently used to obtain high resolution images of bulky objects and also used to characterize heterogeneous organic and inorganic materials to very minute details[7,8]. It is important, therefore, to review some of the evolutions of diagnostic medical imaging immediately before and after the discovery of x ray in 1895.

## THE REVIEW

Although there is no clear dividing line, major discoveries and evolutions that brought diagnostic medical imaging to its present status can be reviewed under three periods. The period 1800 to 1895 is termed the photographic period, the analogue period is the period between 1895 and early 1970's whereas the digital era presumably came into prominence with the first clinical application of computed tomography (CT) in the early 1970's and is still on going[7].

## PHOTOGRAPHIC PERIOD

The camera, photography and chemical development of photosensitive materials were all developed before the discovery of x-rays in 1895. The camera was invented by J. N. Niepce who also took the first permanent photograph with a camera in 1826. While L. J. M. Doguerre perfected the art and science of chemical processing of photographic materials in 1839, J. Herschel was credited with coining the word 'photography' later in the same year[3]. It is interesting to note that it was the photographic property of x-rays that eventually lead to their discovery[5,9]. Other important discoveries pertaining to photography made before and immediately after the discovery of x-ray are shown in table 1.

**Table 1:** +Historical Events

| Date | Person/Company | Milestone |
|---|---|---|
| 1826 | Joseph Nicaphore Niepce | First Permanent photograph with camera |
| 1839 | Louis J.M. Doguerre | Discovered chemical development of a photosensitive material |
| 1839 | William F. Talbot | Discovered negative-positive method of photography |
| 1839 | John Herschel | Coined word "photography" |
| 1851 | Frederick Scott Archer | Discovered wet collodian process |
| 1871 | Richard L. Maddox | Discovered gelatin silver bromide dry plate |
| 1879 | George Eastman | Invented plate coating machine |
| 1895 | William Conrad Roentgen | Discovered X-rays |
| 1895 | William Conrad Roentgen | First Medical Radiograph |
| 1896 | Carl Schleusner | Manufactured the first glass plates for radiography |
| 1896 | Kodak | Introduced first paper for x-ray purposes |
| 1896 | Thomas A. Edison | Recommended calcium tungstate for fluoroscopic screens |
| 1896 | Michael Pupin | First reported screen-film radiograph |
| 1896 | May Levy | Made radiograph using double emulsion coated film between two fluorescent intensifying screens |
| 1913 | Kodak | Introduced double emulsion film |
| 1916 | Patterson Screen Company | Manufactured fluorescent intensifying screens with improved characteristics |
| 1918 | Kodak | Introduced double emulsion film |
| 1921 | Patterson Screen Company | Introduced fluorescent screens with protective coating for cleaning |
| 1923 | Kodak | Introduced film with cellulose acetate safety base |
| 1933 | DuPont | Introduced an x-ray film with blue tinted base |
| 1934 | Patterson Screen Company | Introduced Patterson for Speed screens |
| 1936 | Ansco | Introduced a direct exposure x-ray film |
| 1942 | Poko | Introduced automatic film processor |
| 1956 | Kodak | Introduced roller transport process |
| 1960 | DuPont | Made firs film on polyester base |
| 1965 | Kodak | Introduced rapid process (90 second) film-development system |
| 1971 | Kodak | Introduced ultraviolet emitting screens which reduced light crossover in double-curved paneled cassette |
| 1972 | 3M | Introduced rare earth screens |
| 1977 | 3M | Introduced low crossover film |
| 1983 | Kodak | Introduced tabular grain emulsion x-ray film with crossover control emulsion |

+ Adapted from RadioGraphics 1989; 9 (6): 1223

## ANALOGUE PERIOD

It is generally assumed that the analogue period started with discovery of the camera, photography and chemical processing of films, but only becoming more prominent with Roentgen's discovery of x-rays. Included in this period are discovery of x-rays, x-ray films, cassettes, intensifying screens, the rapid film changer, the image intensifier, contrast medium, nuclear medicine and sonography.

## DISCOVERY OF X-RAY AND EARLY X-RAY EXAMINATION

X-ray was in 1895 by a German scientist named Wilhelm Conrad Roentgen. The discovery was accidental as Roentgen was investigating the conductivity of electric current in an evacuated glass tube[9]. X-ray imaging, immediately after Roentgen's discovery, was quite simple. It involved creating an image by focusing an x-ray beam to the body part of interest, directing the emergent beam from the patient onto a single sided piece of film inside a box called the x-ray cassette that was physically held by the patient himself (fig 1).

**Figure 1.** Positioning of the patient for chest x-ray in the early stages of medical imaging (adapted from History of medical diagnosis and diagnostic imaging http://www.imaginis.com/faq/history-of-medical-diagnosis-and-diagnostic-imaging)

This period was characterized by excessive radiation dose to the patient and poor quality images (figure 2).

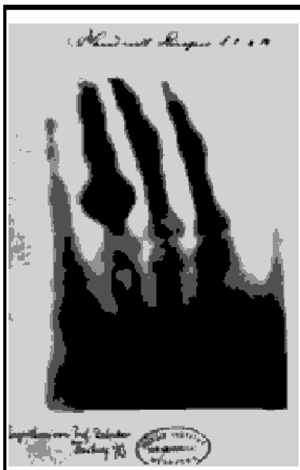

**Figure 2.** Radiograph taken by Prof. Roentgen in 1896 (of Mrs. Roentgen's hand), adapted from History of radiographic film processing, (http://www.ehow.com/about_5085161_history-radiographic-film-processing.html)

An x-ray examination of the skull then could last up to 11 minutes[7,10]. Since even small doses of radiation carry potential risks of somatic effect, it is then easy to understand why some early practitioners of the profession came down with radiation sicknesses while some even died in the process[10]. Such practitioners who paid the supreme price for pioneering work in the profession have a memorial erected for them in Hamburg, Germany[11]. Earliest x-ray tubes were of the stationary anode, 'Coolidge' type, were characterized by low output hence they were restricted to the imaging of extremities and other body parts that could be held still for quite a long time. Most modern x- units are now of the more powerful, rotating anode x-ray tubes that also safe both for the operator and the patient[3].

## X-RAY FILMS, CASSETTES, INTENSIFYING SCREENS AND FILM PROCESSING

The year 1896 was quite eventful in the annals of medical diagnostic imaging. It was in that year that Carl Schleusner invented the first glass plates (the forerunner of the present x-ray cassettes) for plain radiography. While Kodak, a Japanese company, introduced the first x-ray paper (film), Thomas Edison, an American Scientist and inventor, also introduced calcium tungstate ($CaWO_4$) intensifying screens in the same year[3].

Michael Pupin recorded the first x-ray film/intensifying screen combination in radiography while May Levy introduced double sided (duplitized) emulsion films also in 1896.

It was in 1916, however, that the Patterson Screen Company undertook the first commercial manufacture of intensifying screens[3]. It is noteworthy that the first significant step towards reduction of patient radiation dose was taken in 1916 with the commercial manufacture of both intensifying screens and double coated x-ray films. Calcium tungstate of the intensifying screens detects x-ray photons and converts them to light photons. Since the emulsion of the x-ray film is more sensitive to light than radiation, it then became possible to deploy smaller radiation doses to achieve even results[9]. Modern technology has enabled x-ray exposures to made in milliseconds, thereby reducing patient dose in diagnostic exposures to just 2% of what it used to be a century ago[7].

Film processing witnessed a major breakthrough in 1965 with the introduction of the automatic film processor by Kodak[7]. Before that breakthrough, all x-ray films were manually processed in the dark room. The auto processor is a 90-second rapid mechanical/electronic processing unit in which processing chemicals, new film emulsions, roller transport of films and high development temperature permitted the completion the processes of film processing (development, rinsing, fixing washing and drying) to be completed within 90 seconds. With this, it then became possible to process up to two hundred 35 x 35 cm films in one hour, thus increasing the throughput of processed films in shorter intervals.

Another milestone that significantly revolutionized medical diagnostic imaging was the introduction of daylight film processing in 1969 by Gunther Schmidt. Following Scmidt's discovery, the 'Production Company' in collaboration with DuPont, manufactured the first daylight processor later the same year[12]. This could be regarded as the fore runner of present time digital film processing which is fast replacing traditional darkroom film processing in both developed and developing nations of the world.

## THE RAPID FILM CHANGER

The rapid film changer was invented by George Schoenander in 1946. It was soon discovered that physicians could observe images on the fluorescent screens while exposures were being made, thus ushering in (albeit in its crudest form), the advantage of real-time studies[7]. The problem with that was that physicians were, 'looking directly at x-rays" which was rather disastrous as many early practitioners died of radiation induced illnesses[13]. The rapid film changer is a box which allowed a series of cassettes to be exposed at a fast rate (the so called movie rate) of two cassettes per second. The technique was later improved in 1953 to allow the exposure of up to six cassettes per second[7]. This allowed many films to be exposed in quick successions, so it was no longer necessary for Physicians to stare directly at x-rays.

## THE IMAGE INTENSIFIER

The image intensifier was introduced into diagnostic imaging in 1955. It allowed the pick up and display of rapidly acquired x-ray images using a combination of television camera and monitor. Most popular among early image intensifiers were the image vidicon and orthicon[14]. Image intensifiers replaced fluorescent screen image viewing in the middle of the 1960's.

## CONTRAST MEDIA

A contrast medium is a substance that has the ability to absorb radiation higher or lower than surrounding tissue and is therefore used to enhance the visualization of internal structures in the body during medical imaging. The first recognized contrast medium used in medical imaging was a thin wire inserted into the ureter by Tuffier in 1897 which enabled the shadow of the ureter to be seen in the radiograph[15]. The first iodinated, water soluble, high osmolar, intravenous contrast medium known as Iopax (Iodopyridone sodium- N- acetic acid) was introduced in 1928 by a group led by prof.

Liechwitz[16]. Iopax, because of its high osmolality, caused post injection reactions such as nausea, vomiting and rashes. In 1969, low osmolar, iodinated contrast medium was introduced by Dr T. Almen[17].

## NUCLEAR MEDICINE

The use of radioisotopes (nuclear medicine is also known as radioisotope scanning or radionuclide imaging) was introduced into medical imaging in the 1950's. It requires the use of special gamma cameras[7]. A radiopharmaceutical containing a suitable radioisotope is usually introduced into the body and is concentrated by the target organ. The faint radiation energy emitted by the radioisotope is detected and measured by the gamma camera. The camera then uses the detected signals to build 2-Dimensional spatial distribution of the radioisotope in the organ. Radioisotope scanning is more sensitive than plain x-ray examination in detecting metastatic lesions but is, however, non-specific in discriminating between primary and secondary tumours[18]. This modality has not found wide spread application especially in developing nations like Nigeria.

## SONOGRAPHY

Sonography (also known as ultrasonography) is medical imaging which uses sound of very high frequency (sound that is inaudible to man and is from 20 KHz and above) for the creation of images of tissues for diagnosis. In the 1960's, use of sound in diagnostic medical imaging was introduced. It involved placing the transducer against the skin of the patient near the organ of interest. The transducer generates the high frequency sound waves which penetrate the body, bounces off the internal organs and echoes back. The transducer again receives the returning echoes and feeds the signal into the ultrasound machine. With the aid of a computer, the signal is turned into real-time images[19]. Sonography is invaluable in obstetric, abdominal, pelvic and cardiac studies. It is also painless, non invasive and does not involve the use of ionizing radiation but is rather less sensitive than such modalities as computed tomography and magnetic resonance imaging[18].

## DIGITAL ERA

This period is characterized by computer based imaging modalities designed to achieve the same high quality images at less radiation doses[6]. Outstanding discoveries in the period include computed tomography, magnetic resonance imaging, single-photon emission computed tomography and positron emission tomography. In this period also, training of professionals involved in the diagnostic medical imaging sub-specialty became more advanced.

## COMPUTED TOMOGRAPHY (CT) SCAN

The computed tomography (CT) scanner was invented in 1972 by an English Scientist named Godfrey Hounsfield[7]. In earlier trials, he first used gamma rays, then x-rays and an array of detectors mounted on a rotating frame. As the gantry rotated, different portions of the organ are exposed to radiation. The array of detectors will detect the radiation signals emerging from the patient and feed them to a computer which turns the signals into cross sectional (slices) images of the organ[19]. The first CT scanner was a head scanner which took hours to acquire a single slice image and more than twenty- four hours to complete a head CT examination[7]. Present generations of CT scanners are much faster and can complete CT examination of the whole body in a matter of seconds[6]. CT Scanning allows discrimination to be made between tissues of only slight density difference. This allows small lesions within the cranium to be studied in greater details. Radiation dose from CT is comparable to that from conventional radiography, though the CT machine is costlier to acquire[18]. For inventing the CT, Prof. Hounsfield was awarded the Nobel Prize in physiology or medicine[7].

## MAGNETIC RESONANCE IMAGING (MRI)

Magnetic resonance imaging became a clinical diagnostic tool in 1973 when the first MRI study on a human was performed. Paul Lauterbur of the University of Illinois at Urbana Champaign, USA and Sir Peter Mansfield of the University of Nottingham, England won the 2003 Nobel Prize in physiology or Medicine for inventing the MRI

Magnetic resonance imaging visualizes both the structure (anatomy) and function of an organ in multiple planes. Powerful magnetic fields are used to align the nuclear magnetization of hydrogen atoms in water of the body. Then Radiofrequency (RF) fields are used to systematically alter the nuclear magnetization, causing the hydrogen nuclei to produce a rotating magnetic field. This field is detected by the scanner and fed as a signal to a computer which then constructs an image from the signals[22],. Spatial resolution of MRI is comparable with CT. Contrast detail is, however, better with MRI because of the complex library of pulse sequences and abundant hydrogen atoms that can be optimized to provide better contrast[23].

## SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT)

David Edwards and Roy Rull were created with inventing the SPECT Scanner in the 1950's, though the modality only gained wide clinical acceptance in the last thirty years[24]. SPECT uses gamma rays and a gamma camera to provide true 3-Dimensional information. The camera acquires multiple 2-Dimensional images from multiple angles and feeds them as signals to a computer. The computer then uses a tomographic reconstruction algorithm to reconstruct the multiple 2-D images to 3-D images. 3-D spatial resolution of SPECT is better than CT or MRI and is very suitable for the study of tumours, brain and cardiac functions. Long scanning time and high level of image artifacts are, however, some of the major limitations of the modality[25].

## POSITRON EMISSION TOMOGRAPHY (PET)

Positron emission computed tomography (PET) made its entry as an imaging modality in the 1960's. It uses short-lived radioisotopes to produce 3-D coloured images of functioning organs in the body, thus providing information about the body's metabolic activities. PET is very sensitive in detecting active tumours but it cannot be used to estimate the size of such tumours, unlike CT or MRI[26].

## PROFESSIONAL DEVELOPMENT AND TRAINING

The earliest practitioners in the diagnostic medical profession were physicists and electrical engineers before physicians followed suit. While Prof. Roentgen a physicist, made the first radiograph of a human being (figure 2), Dr. John Macintyre , an electrical engineer, is believed to have set up the first dedicated radiology department in the world at the Glasgow Royal infirmary, Scotland to provide medical diagnostic imaging services to patients[11]. The Roentgen society (the predecessor of the British institute of Radiology was established in 1897 while the American Roentgen society was established in 1900. Presently, some of the professionals involved in medical imaging are radiologists, radiographers, medical physicists and other scientists purely involved in research.

It is not very clear when diagnostic medical imaging took off as a medical sub specialty in Nigeria. The training of radiographers in the country, however, started around 1947 in the country[26]. From hospital based apprenticeship type of training, most professionals in the diagnostic medical imaging sub-specialty undergo rigorous training. Globally, the current training of such professionals has become University based degree programmes and in some countries like Nigeria, post qualification internship training for radiologists and radiographers is also required.

## CONCLUSION

Diagnostic medical imaging as a profession, passed through a tremendous evolution in the past century after the discovery of x-ray. Each evolution, from one stage to the other, was quite distinct yet seamless. In terms of both equipment manufacture and man-power training, diagnostic medical imaging benefitted immeasurably from technological advancements within the period reviewed. There was transformation seamlessly from analogue to digital imaging in some instances while in other instances, new imaging modalities were introduced to improve both spatial and contrast resolution as well as to reduce patient dose.

In spite of technological advancement and digitization, no newer modality appears able to successfully replace the one preceding it. Most of the modalities play complementary roles to each other. Since knowledge and technology are always changing, it is not difficult to predict that diagnostic medical imaging is poised to experience even greater evolutions in the near future.

**ACKNOWLEDGEMENT**

We thank Mrs. Ogundimu for type-setting the manuscript. We also acknowledge a very distinguished senior colleague who provided us with incisive historical information but true to his humility, elected to remain anonymous.

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