Abstract: In a matter of weeks following Röntgen's provisional communication of 28 December, 1895, X-rays were being used for clinical diagnosis. Starting from crude, and often dangerous, technology, progress to the production of images of excellent quality and radiation safety was inexorable. For a hundred years, X-rays have been the mainstay of medical imaging, providing invaluable information for the diagnosis and management of disease. The ability to visualise pathology within the intact body also led to advances in medicine and surgery. The introduction of Computerised Tomography, which
A CENTURY OF X-RAYS

utilises X-rays in a different manner, has, in recent years, revolutionised the practice of medicine. Recent decades have seen the introduction of imaging modalities which do not utilise X-rays — notably Ultrasound and Magnetic Resonance Imaging. Whilst these have replaced X-ray examinations to some extent, the latter remain the preponderant form of imaging, and Röntgen's X-rays are alive and well in medicine a century after this great discovery.

The discovery of the physical properties of X-rays produced a major advance in medical science. For the first time, organic pathology could be visualised within the intact body. In a matter of weeks, from Röntgen's provisional communication of 28 December, 1895, X-ray examinations of clinical value were being obtained both in Europe and America — of metallic foreign bodies, fractures and other bone abnormalities. In England, Sidney Donville Rowland began a radiology practice as early as March, 1896. In the same year, Thomas Edison developed the use of a fluorescent screen as an alternative to recording the image on a photographic plate. This method refined over the years to reduce dosage and improve contrast and spatial discrimination and remains an active service for visualisation in real-time.

Apart from the noxious effects of overexposure to X-rays, which cost the lives of many of the early pioneers, it was recognised early in the history of this new branch of medical science that there were limitations to the diagnostic information that diagnostic X-rays could provide. Essentially, conventional diagnostic X-rays allow the discrimination of only six basic densities: gas, fat, soft tissue and fluid, bone, calcium and heavy metals. A normal, or pathological structure, has to be "outlined" by tissue of different density in order to be imaged.

For instance, the multiple organs within the abdomen are largely of soft-tissue density and their outlines hard or impossible to detect on conventional X-rays. A tumour within the liver substance cannot be detected since both tumour and normal liver are of the same density. Only the gas-filled stomach and colon are clearly visualised within the soft-tissue background.

The problem was partially overcome by introducing substances of different density into body "cavities" by various means. Barium could be used to outline the digestive tract, air introduced into the brain ventricular system by lumbar puncture, or iodine compounds utilised to demonstrate the urinary tract as they were excreted by the kidneys.

The power of the X-ray beam required to penetrate and depict bony structures such as the skull or spine, was such that the important structures of the brain and spinal cord could not be seen at all, although some information could be obtained by outlining the subarachnoid space or appropriate arteries with contrast agents.

A major advance in the use of Röntgen rays occurred with the development of Computerised Tomography (CT) (Hounsfield, 1973). Although similar in principle to conventional radiography, in that the produced image is a grey-scale representation of the degree to which body components alternate the X-ray beam, CT employs multiple collimated X-ray exposures, sophisticated electronic detectors, and computer analysis and refinement, to produce a cross-sectional slice of body tissue. Movement of the X-ray source around the body allows multiple readings of small volumes of tissue within the slice to provide a cross-sectional image which avoids superimposition of structures and accurately indicates their density so that soft-tissue structures can be differentiated both in outline and density. With this method it was possible, for the first time, to depict the structures of the brain and spinal cord, and to detect soft-tissue abnormalities within soft-tissue structures, e.g., tumours, abscesses and haemorrhages in the brain and in abdominal organs.

Intravenous injection of an iodine containing contrast medium is frequently used during CT examinations to provide further contrast differentiation between normal and abnormal tissues and to visualise vascular structures.
Advances in CT technology now allow for 3D reconstruction, fine-section examination of complex and relatively minute structures and image manipulation. CT can thus be used, not only for diagnosis, but also to plan surgical, radiotherapeutic or other forms of therapy, accurately place needles percutaneously for biopsy and provide excellent visualisation for interventional procedures, such as drainage of abscesses.

There are available other important means of imaging that do not use Röntgen rays. Radioisotopes can be introduced into the body and the emission of gamma rays detected by an external gamma camera. Since the substances used have radioactivity, this method requires the same attention to dosage and safety as is required for Röntgen rays. Further, the images obtained do not provide the contrast range and anatomical detail of Röntgenograms. They do, however, provide very useful information regarding function and an area of functional abnormality, e.g., bone infection or impaired renal function, can be detected in the absence of detectable changes on radiographs. Radioisotope scanning of the lungs similarly may detect the occurrence of pulmonary embolism in the presence of a normal chest X-ray.

Ultrasound was developed as a modality for medical imaging in the early 1960s. In this system, high-frequency sound produced from a transducer of piezoelectrical material is transmitted as a longitudinal wave into the tissues. The sound wave is reflected back to the transducer from tissue boundaries and the transducer can detect these during a "listening" phase. The returned signal is converted into an electrical signal, with an electronic display which displays the returned echoes as variable levels of brightness on the screen. The information can also be manipulated by a computer. The operator, by sweeping the transducer over the body part, can build up a series of images which demonstrate the anatomy in various phases of section, and sees the image display in real-time.

A major advantage of diagnostic ultrasound over Röntgenography is the absence of ionising radiation. This has proved of particular advantage in the imaging of the foetus in utero because, not only is the danger of radiation eliminated, but also the soft tissue structures of the foetus, placenta and uterus are clearly visualised. Ultrasound has revolutionised the practice of obstetrics as CT revolutionised the practice of neurology.

Apart from obstetrics, diagnostic ultrasound has an important role in the imaging of the liver and biliary system, the kidneys, and other abdominal organs, and in the heart. Functional assessments can be made such as detection of the foetal heart beat and assessment of the function of the heart muscle and valves in the adult patient. The Doppler phenomenon of sound is utilised to determine flow in arteries and veins, and many invasive radiological procedures that were previously necessary can be avoided.

The major disadvantage of ultrasound is the difficulty of imaging where there is bone or gas-filled structures which deflect and distort the image. It has, however, been used to good effect to image the structures of joints, such as the shoulder and hip.

The latest addition to the armamentarium of the diagnostic radiologist is Magnetic Resonance Imaging (MRI). The physics of this technique is formidable but, in essence, the response of hydrogen protons to a varying magnetic field is detected electronically and their situation in the body located by gradient magnetic fields in three planes. An image can thus be formed.

MRI provides images of exquisite anatomical detail. It is of particular value in the brain and spinal cord, but also can provide detailed anatomical images of joints, muscles, abdomen and heart. Special techniques and image manipulation allow functional studies such as assessment of cardiac function and the flow of cerebro-spinal fluid.

The "magical" rays which Röntgen discussed have made an enormous contribution to medical science in the twentieth century. Without them, many other medical and surgical advances would not have been possible.

As discussed above, there are now several other forms of imaging available. How well has Röntgenography survived after 100 years?

Indeed, Röntgenography is alive, well and flourishing. It remains the predominant means of imaging the chest, since the air-filled lungs...
give excellent contrast delineation from pathological processes; it remains the best method for examining the skeletal structures, particularly for suspected fractures and joint disorders; the plain film of the abdomen remains the prime imaging tool for suspected bowel obstruction and kidney stones.

The new modalities have replaced some previously common radiographic procedures, either because more useful information is obtained or because interventional procedures are avoided. The pneumoencephalogram, in which air injected into the spinal subarachnoid space outlines the brain ventricular system, has been completely replaced by CT and MRI. This was an unpleasant procedure for the patient, gave limited information, and had potential complications. The new modalities provide much better information without the previous discomfort and dangers. Similarly, the injection of a contrast medium into the bronchial tree, bronchography, has been replaced by CT — again, discomfort and complications are reduced and more useful information is obtained.

Many radiographic procedures remain in use but have been partially replaced by other modalities: ultrasound may be used to visualise the kidneys rather than an intravenous pyelogram which involves injection of an iodine-containing compound and multiple radiographic investigations. The barium meal for stomach problems has been significantly replaced by endoscopy which allows direct inspection of the gastric mucosa; CT, rather than a skull X-ray, is the procedure of choice for a serious head injury; MRI is the definitive examination for suspected multiple sclerosis.

Angiography, although replaced in some areas by other modalities, remains an important radiological investigation. Catheters, introduced via a peripheral artery, can be introduced into the aorta or its branches and the flow of an injected contrast medium visualised in real-time or on multiple radiographic images. This technique is currently employed, particularly for atheroma and other arterial disorders which reduce blood flow to the limbs, brain or heart.

The ability to introduce catheters into the arterial system has led in recent years to the exciting, new sub-speciality of interventional radiology. Sites of bleeding, congenital vascular abnormalities and some tumours can be treated by obliterating the feeding arteries with suitable injected material. Selected vascular lesions occurring in the brain may also be treated in this manner.

Further important angiographic interventional techniques in frequent use are the dilatation of narrowed arteries by balloon catheters and the insertion of metallic filters into the inferior vena cava in the management of pulmonary embolism from venous thrombosis in the legs. The techniques of vascular intervention have been adapted for use outside the vascular system, and have allowed for the replacement of surgical techniques for some pathological procedures. For instance, catheters can be introduced percutaneously to drain obstructed kidneys, obstructed bile ducts, abscesses or other fluid collections; narrowed areas in the urinary tract or biliary tract may be treated by percutaneous passage of a stent that can be left in situ to provide drainage through the narrowed area or dilated with balloon catheters.

The field of interventional radiology is a fertile one for the inventive and skilful radiologist, and one where Röntgen rays provide significant contribution to the treatment of disease as well as its diagnosis.

After 100 years, and the introduction of competing technologies, the rays discovered by Röntgen still provide the majority of imaging investigations and provide a major contribution to both diagnosis and treatment of disease.

Reference


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