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Medical Imaging: Concept, Precepts and Potentials

By

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INTRODUCTION

Medical imaging was born when Conrad Wilhelm Roentgen, a German physicist serendipitously discovered x-rays on the 8th of November 1895, while working in his laboratory. In his publication to announce the discovery, he called the radiation “x-rays,” because the phenomenon was hitherto unknown. One big surprise during the experiment, was that the “new rays” were able to blacken photographic plates in a darkened room, hence the changes noticed in the photographic plate. could not have been due to visible light.

The following month on 22th December 1895, Conrad Roentgen exposed the hand of his wife, Bertha Roentgen to the “x-rays,” and this showed the metacarpal bones and phalanges of her hand, as well the two rings she wore on her fourth finger. This was the first radiograph of the human body. Hence Conrad Roentgen can rightly be referred to as the “Father” of Medical Imaging.

CONCEPT OF MEDICAL IMAGING

X-ray Examination

From its humble beginnings as plain radiographic examinations, medical imaging has grown exponentially in the last 130 years, and now includes imaging modalities that do not use x-rays such ultrasound imaging and magnetic resonance imaging. Also radionuclide (radioisotope) imaging uses gamma rays from radioactive decay instead of x-rays.

X-ray imaging itself has evolved from plain radiographs to special x-ray examinations that are termed contrast studies such as intravenous urography and barium meal.

Computed Tomography

The next major advance in x-ray imaging took place in 1972, when a British physicist, Godfrey Hounsfield invented the computed tomography (CT) scanner. This invention revolutionized x-ray imaging because it eliminated the challenge of superimposition of anatomical structures encountered with plain radiographs. It heralded cross-sectional imaging, and acquired information at every stage about the human anatomy, as

x-rays traverse the human body along the path of the beam. In particular, CT scanning introduced the use of computer technology to perform mathematical calculations for data retrieval, transformation and three-dimensional image display on the monitor. Importantly, CT technology, for the first time provided the opportunity for acquired images to be archived on magnetic tapes or optical discs in addition to production of the traditional hard copies. The modern day CT scanners enable copying of images on compact disc (CD) and digital video disc (DVD) as well as printing of hard copies using laser jet printers.

A significant impact of CT scanning was in the examination of intracranial soft tissue, because for the first time, it became possible to visualize the brain, which had previously been rendered inaccessible by the adult skull. CT imaging has continued to be improved upon and has resulted in the development of newer generation of scanners; which have progressed from conventional CT scanners to spiral CT and now multislice scanners, that are capable of whole body image acquisition at very rapid speed. Multislice CT technology permits the application of techniques such as computed tomographic angiography (CTA) to outline blood vessels.

Radionuclide Imaging

Compared to x-ray imaging, radionuclide imaging uses gamma rays from radioactive decay to acquire images. However both x-ray and gamma are described as sources of ionizing radiation, which have deleterious effects on the tissues in the human body, when used in high doses, usually beyond the range for normal diagnostic radiology.

In radionuclide imaging, a radioactive material, termed radiopharmaceutical, is coupled to a carrier molecule, and introduced into the human body, either through injection into the bloodstream or inhalation in the caseof pulmonary ventilation studies. Inside the body, the radioactive substance emits photons from radioactive decay in the target organ, which is then detected using gamma camera and using computer analysis, the

information acquired is converted to an image displayed on the monitor.

The basic difference between x-ray imaging and radionuclide image is that, photons in x-ray imaging originate from the machine outside the body, and have to penetrate the body to acquire an image. On the contrary, photons from radionuclide imaging originate from the radioisotope material, inside the patient's body, and then come out to fall on the gamma camera scintillators.

Development of radionuclide imaging has produced more advanced 3-dimensional tomography techniques, which provide information on both anatomical structure and physiological function, such as single photo emission computed tomography (SPECT) and positron emission tomography (PET), unlike the conventional radionuclide imaging.

Ultrasound Imaging

In ultrasound imaging, high frequency sound waves are generated by piezo-electric crystals inside the transducer of the machine probe which enter into the body. The sound waves can be transmitted, deflected, reflected or absorbed. However, the most aspect for ultrasound imaging are the reflected sound waves, known as echoes, which return to the probe. On reaching the probe transducer, echoes interact with the piezo-electric crystals and generate electrical impulses which travel along the cable to the main frame of the machine, where they undergo computer analysis, are converted to digital image and displayed on the monitor.

Since ultrasonography uses sound waves for imaging, it is non-hazardous, unlike x-rays, hence it can be used repeatedly, even in pregnant women without any harmful effect on the unborn baby. It is also preferred for imaging of neonates and young children whose growing tissues are more prone to damage by ionizing radiation, which may result in the development of cancer later in life.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) uses radio frequency (RF) waves to acquire images of the human body. By nature, radio waves transmit electrical impulses without the need for a cable. Hence some of its practical non-medical uses are in the transmission of signals for mobile (cell) phones, broadcast transmission for FM radio stations and sending of data between computerized devices using bluetooth.

Apart from its safety due to absence of ionizing radiation, MRI is versatile because it is capable of acquiring images in three orthogonal planes of axial, sagittal and coronal without changing the patient's position.

This imaging modality has progressed from basic techniques of conventional MRI to more sophisticated applications such as magnetic resonance angiography (MRA), functional magnetic resonance imaging (fMRI) and magnetic resonance elastography (MRE).

Interventional Radiology

In interventional radiology (IR), medical imaging is employed to achieve a therapeutic effect in some disease conditions. Examples of these are: balloon catheter angioplasty to improve blood flow in arteries whose lumen has become narrowed by arteriosclerosis; fibroid mass shrinkage by injection of sclerosing agent into the uterine artery; and ablation of malignant renal tumour by injection of coils or sclerosing agent into the renal artery.

PRECEPTS OF MEDICAL IMAGING

Various medical imaging modalities are available in the radiology armamentarium for examination of the human body. The particular modality that is employed is dependent upon a combination of factors such as: the information required to make a diagnosis; age of the patient; cost-benefit to the patient; and availability of an imaging modality in the locality.

SPECIAL X-RAY EXAMINATIONS

The urinary system:

- Intravenous urography (I.V.U.) is used for evaluation of the kidneys, ureters and urinary bladder for diseases like infections, obstructive uropathy and tumours.
- Micturating cystourethrogram; when done under fluoroscopy, is used to dynamically assess the urinary bladder and urethra during voiding for conditions like vesico-ureteric reflux and posterior urethral valves.
- Retrograde urethrogram to assess the urethra for conditions like strictures.
- Retrograde pyeloureterography to demonstrate the site and lower limit of an obstructive lesion in the ureter e.g calculus.

Gastrointestinal Tract:

- Barium swallow for oesophageal lesions like achalasia and carcinoma.
- Barium meal for gastric and duodenal ulcer; gastric outlet obstruction; gastric tumours; and duodenal obstruction.
- Barium follow-through to demonstrate jejunal and ileal lesions e.g malabsorption in conditions like Crohn's disease, scleroderma and chronic pancreatitis. Ascaris worms can also be demonstrated with follow-through examination.
- Small bowel enema provides better visualization of the jejunum and ileum because barium is introduced by intubation directly into the jejunum, usually employed when follow-through study is equivocal.
- Barium enema for colonic lesions like intussusception; Hirschsprung's disease in children and rectal or colonic carcinoma.
- Hepato-Biliary Tract and Pancreas:
- Intravenous cholangiography (IVC) to demonstrate ductal lesions e.g. calculi, cholangiocarcinoma.
- Operative cholangiography done during cholecystectomy or bile duct surgery by injection of contrast into a cannulated cystic duct to avoid surgical exploration of the common bile duct.
- Post-operative (T-tube) cholangiography done to exclude

biliary tract calculi.

- Endoscopic retrograde cholangiopancreaticography (ERCP) for demonstration of biliary tract and pancreatic duct; and biopsy of ampullary lesions.
- Percutaneous transhepatic cholangiography (PTC) to confirm or exclude extra hepatic bile duct obstruction.
- Magnetic resonance cholangiopancreatography (MRCP) to demonstrate diseases of the biliary and pancreatic ducts.

The Cardiovascular System:

- Angiocardiography is performed simultaneously with cardiac catheterization such that pressures and oximetry are measured in the cardiac chambers and vessels under investigations. Indications include: congenital heart disease, valvular disease, myocardial disease and ventricular function.
- Arteriography to study arborization of arteries in various organs for conditions like aneurysm, arteriosclerosis, arteriovenous malformation.
- Venography to demonstrate diseases in the veins like varicosity and thrombosis.
- Bones and Joints:
- Double contrast knee arthrography using low osmolar contrast medium (LOCM) to demonstrate cartilage injuries, loose bodies and popliteal cyst.
- Hip arthrography for congenital hip dislocation, loose bodies, Perthe's disease and trauma.
- CT arthrography.
- MRI studies have essentially replaced conventional arthrography in the radiological examination of joints.
- Ultrasound for congenital hip dislocation and joint effusion.

Central Nervous System:

- Conventional myelography using LOCM (e.g. Iohexol or Iopamidol) injected into the subarachnoid space to demonstrate spinal cord or other intraspinal abnormalities.
- Radiculography using LOCM (e.g. Iohexol or Iopamidol) to demonstrate nerve root abnormality.
- Computed Tomographic (CT) myelography has the advantage

of superior sensitivity of CT to conventional myelography thus allowing detection of very dilute contrast medium beyond a spinal blockage.

- MRI is superior to CT and contrast myelography and preferred for examination of the spine, spinal cord and nerve roots..

ULTRASOUND IMAGING

- 2-D Grey Scale Imaging:
- Can be used to examine any part of the body except the lungs, bone and brain after closure of the anterior fontanelle.
- Applied repeatedly in pregnancy because it is non-hazardous to the unborn fetus unlike x-rays and this has made it an invaluable tool in obstetrics.
- Has a wide range of applications in diseases of the liver, pancreas, spleen, kidneys, thyroid, prostate and infant brain.
- Particularly useful in ophthalmology for evaluation of posterior segment diseases like retinal detachment when an opaque lens from cataract makes this impossible by ophthalmoscopy.
- Useful for assessment of effusion in joints and congenital hip dislocation.
- Endoluminal probes permit transvaginal examinations in obstetrics and gynaecology; transrectal evaluation of the rectum and prostate for carcinoma; and transoesophageal assessment of the oesophagus and stomach for staging of primary malignant disease and biopsy of primary tumours or nodal disease.
- Colour Doppler Ultrasound:
- The modern colour Doppler machine is a triplex scanner, which combines display of real time, grey-scale images with spectral velocity wave form and colour coded direction of blood flow in a vessel, contemporaneously on the image monitor.
- Useful to detect thrombosis in a vein, arteriosclerosis, aneurysm and other occlusive vascular diseases.

COMPUTED TOMOGRAPHY

- Conventional Computed Tomography:
- Produces cross-sectional images and particularly useful for intracranial and intraspinal lesions.

- With the aid of i.v. contrast enhancement, soft tissue lesions are outlined more clearly.
- Useful for the staging of malignancies of structures e.g. the kidneys, pancreas, bowel and prostate.
- With the aid of oral or rectal contrast, the GIT is outlined either as part of a routine abdomino-pelvic scanning or for evaluation of tumours.
- High Resolution Computed Tomography (HRCT) is important in the diagnosis of bronchiectasis.
- Spiral or Helical Computed Tomography:
- Spiral CT permits volumetric acquisition of spatial information in a composite manner.
- Useful for viewing of bones, vessels and geographical calcifications from a variety of angles.
- Images of spiral CT enable a surgeon to have 3-dimensional view of an organ or structure to allow for proper planning of surgery.
- Multi Slice Computed Tomography (MSCT):
- An improvement on the technique of single slice spiral CT.
- MSCT scanner is capable of making two gantry revolutions per second compared with just one for conventional single-slice CT scanners.
- Can produce images at stupendous speed that is eight times faster than the single slice system.
- Capable of producing slices as thin as 1mm.
- Able to detect tumours that are too small to be demonstrated by standard CT machines.
- Computed Tomographic Angiography (CTA):
- CTA is used to demonstrate or map out blood vessels in MSCT.
- Large number of slices in the range of 400-800 slices are usually required which is a major drawback because of high radiation dose to the patient.

Computed Tomographic Colonography (CT Colonography):

- CT colonography is useful to demonstrate the mucosal lining of the colon.
- Used to demonstrate colonic lesions such as polyps.

RADIONUCLIDE IMAGING

Standard Radionuclide Imaging Techniques:

- Radioisotope material termed radiopharmaceutical, coupled to a carrier molecule is introduced into a patient's body by injection into the blood stream, inhalation or ingestion. 99Tc is the most frequently used radionuclide.
- Photons emitted from the target organ are then detected using a gamma camera and displayed on a monitor with the aid of computer analysis.
- Radionuclide imaging has a wide range of applications examples of which include: lung ventilation/perfusion (V/Q) scans for suspected pulmonary embolism; bone scan for assessment of primary and secondary bone tumours.
- Static renal scan for assessment of “non-functioning kidney” as seen on i.v.u.
- Dynamic renal scan for diagnosis of an obstructed versus non-obstructed dilated upper tract; detection of gastrointestinal bleeding of unknown origin.
- Single Photon Emission Computed Tomography (SPECT)
- Photons emitted from the target organ e.g. brain or heart are detected using a conventional gamma camera.
- Perfusion imaging of the brain is done using hexamethylpropylene-amide oxime (HMPAO).
- The gamma camera is rotated around a patient during scanning.
- After computer analysis the image is displayed on a monitor.
- Advantages include: i. Image acquired gives information on both anatomical structure and function. ii. Provides useful data on the physiological processes of a tissue or organ.
- Disadvantages include: i. High cost of machine acquisition. ii. Patients are exposed to ionizing radiation. iii. Poor spatial resolution of images.

Position Emission Tomography (PET)

- It is also a 3-dimensional tomographic radionuclide imaging technique but it requires specialized positron camera to record images hence it is more complex than SPECT.
- It requires siting of a cyclotron machine near the imaging

facility.
- Gives improved information on functional activity and biochemistry of a region of interest in the brain.
- Useful for diagnosis and monitoring of treatment in brain tumours, infarctions, epilepsy and metabolic disorders.

MAGNETIC RESONANCE IMAGING

- Conventional Magnetic Resonance Imaging (MRI):
- Does not use ionizing radiation hence it is not known to have any deleterious effect when used at recommended magnetic field strength levels.
- Can acquire images in the 3 orthogonal planes namely: axial, coronal and sagittal without changing patient's position in the gantry.
- Useful for demonstration of white matter lesions such as multiple sclerosis and brain tumours.
- Contrast enhancement with gadolinium – DTPA demonstrates lesions more clearly.
- Now plays an important role in the management of sports related injuries especially those affecting the knee because it is able to demonstrate intra-articular structures like menisci and cruciate ligaments; as well as joint effusion.
- Useful for investigation of the spine because it enables demonstration of long segments of the spine and spinal cord.
- Magnetic Resonance Angiography (MRA):
- Employed to demonstrate blood vessels without the need for catheterization.
- Blood vessels may be demonstrated with or without injection of contrast medium.
- Has been used for assessment of blood vessels for stenosis from arteriosclerosis.
- Can also be used to evaluate aneurysms and arteriovenous malformations (AVMs).
- Magnetic Resonance Cholangio Pancreatography (MRCP):
- Outlines the biliary and pancreatic ducts without using contrast medium.
- Because it is non-invasive, it is now replacing ERCP.
- Functional Magnetic Resonance Imaging (fMRI)

- fMRI is used to acquire cerebral images during brain activity and compares them with images at rest. Areas which show high signal correspond to areas of activity.
- A practical application is the pre-operative use of fMRI to determine areas that should be spared during neurosurgical excision of brain tumour in order to preserve some brain abilities such as speech.

INTERVENTIONAL RADIOLOGY

- Employed in different situations to achieve a therapeutic effect examples of which include:
- Hydrostatic pressure reduction of intussusception during barium enema examination.
- Percutaneous nephrostomy for catheter drainage of dilated renal collecting system.
- Percutaneous nephrolithotomy for either removal of a single renal calculus or following disintegration of a larger calculus after lithotripsy.
- Transcutaneous intrahepatic porto systemic stent shunt (TIPSS) between the portal vein and a hepatic vein or inferior vena cava to decompress high pressure in portal hypertension.
- Balloon catheter angioplasty to recanalise an arteriosclerotic vessel.
- Injection of sclerosing agent into a blood vessel to control bleeding or for tumour ablation

POTENTIALS OF MEDICAL IMAGING

Potential Medical Uses of Imaging:

- Ultrasound Elastography (EUS) uses shear wave for imaging of the liver, breast, testis and ovary to determine increased stiffness of tissues that have been hardened by diseases such as fibrosis and malignancy and avoid unnecessary biopsy.
- Magnetic Resonance Elastography (MRE) also uses shear wave to detect increased stiffness in the liver, breast, muscle and brain in fibrosis and malignancy.
- Functional Magnetic Resonance Imaging (fMRI) to study physiological function of the brain without use of ionizing

radiation.

Tactile Imaging:

- A medical imaging modality that converts the sense of touch to a digital image.
- It works by translating pressure on soft tissue surface under applied deformation into an image.
- It closely mimics manual palpation because the examination probe of the machine is fitted with a pressure sensor array that is mounted on its surface and in a similar manner to human fingers, during clinical examination to detect changes in pressure pattern.

Uses include:

1. Imaging of the breast and prostate.
2. Elasticity assessment of the vagina and pelvic floor and supporting structures.
3. Muscle functional imaging of the female pelvic floor.

Potential Non-Medical Uses of Imaging

- X-ray is used to detect cracks in oil pipelines for petroleum exploration.
- X-ray is used to do security check and fluoroscopic screening of checked in luggage and cabin hand luggage to detect unauthorized metal objects such as knives, guns, ammunition and bomb that can endanger the lives of air crew and passengers.
- MRI was recently introduced at airports in the United States to scan passengers for ferromagnetic objects such as knives, guns, ammunition and bomb that may threaten the safety of air crew and passengers.

CONCLUSION

- Medical imaging techniques in the radiological toolbox encompass modalities that include use of ionizing and non-ionizing radiation.
- Careful selection of the appropriate imaging modality provides a cost-effective way of investigating disease conditions and treating cancer patients.
- Expenditure on state-of-the-art equipment for radiodiagnosis is a good investment for patient care and training of personnel.
- It is important to make adequate provision for after sales service and maintenance during equipment purchase.
- The potentials of medical imaging are enormous for both medical and non-medical uses and these should be fully harnessed.

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