Reviews—Technology and Medicine

High-Tech Imaging: Impact on Clinical Medicine

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INTRODUCTION
Since the pioneering discovery of X-rays by Roentgen more than a century ago, radiology has grown into a major clinical discipline. Perhaps no other specialty of modern medicine has been so profoundly affected by the technological developments of the last two decades. There has been a change from 'diagnosis by inference' using standard X-rays, to direct visualization using ultrasound (US), computed tomography (CT) and magnetic resonance imaging (MRI). This change has led to early diagnosis and staging of disease. Radiology has literally and metaphorically emerged from the basement of hospitals to a centre stage location, and presently touches the lives of everyone receiving medical care.

Since the enormous diversity and scope of imaging will not allow a discussion of all the areas where imaging has made an impact, we will highlight the important entities from a long and ever-increasing list, and will confine our discussion to diagnostic radiology alone. Looking back at the past reveals that in the rapidly progressing field of radiology, what seems impossible today becomes a reality tomorrow. Gazing at the crystal ball of radiology is a visionary task, but the possibilities of the future can be mentioned.

ULTRASONOGRAPHY
Ultrasoundography (US) is a widely available, inexpensive, and non-invasive modality which does not use ionizing radiation and has no known side-effects. Its versatility, portability, low cost and efficacy have made it an indispensable tool in patient care. The indications of sonography in the developing countries are many more than those in the West, due to economic reasons and the not-so-easy availability of computed tomography (CT). It finds application in imaging virtually all body parts including the abdomen, vascular system, orbit, brain, breast, musculoskeletal system and foetal evaluation. It is the first imaging modality to be used in evaluating abdominal masses, surgical obstructive jaundice, gallbladder pathology, pancreatitis and haematuria. It is widely used in the antenatal detection of congenital anomalies, assessment of foetal well-being and a host of gynaecological diseases. It is also used to perform guided biopsies and procedures such as percutaneous nephrostomy and abscess drainage.

The advent of transvaginal sonography (TVS) has further enhanced the applications of sonography in both gynaecological and obstetric practice. Since high frequency probes can be used due to close proximity of the region of interest, the resolution of TVS scans is much better and the inconvenience of having a full bladder is obviated. TVS provides invaluable information in the assessment of adnexal masses—both inflammatory and neoplastic,—uterine pathology, first trimester of pregnancy and infertility. Similarly, transrectal US (TRUS) plays a vital role in the diagnosis of suspected prostatic carcinoma. It is a sensitive technique that can detect impalpable malignancies and is useful in taking guided biopsies from suspicious areas. Endosonography of the anorectal canal is a relatively new technique and has a high accuracy in staging rectal cancers. It is also useful for evaluation of the external anal sphincter.

In recent years, the capability of US has been further enhanced by the development of colour and power doppler, intraoperative scanning, intracavitary and endoscopic US, ultrasound contrast media and harmonic imaging. Colour doppler has made it possible to non-invasively diagnose carotid artery stenosis, aortic pathology, peripheral arterial disease, and deep venous thrombosis with ease and rapidity, and sometimes even at the bedside in an intensive care unit setting. Early diagnosis of deep venous thrombosis and prompt institution of anticoagulant therapy has helped in the prevention of catastrophic episodes of pulmonary embolism.

Power doppler (PD) is a step further in colour doppler imaging. It is based on the integrated power spectrum of the standard doppler signal and is independent of the angle of insonation. It results in an approximately three-fold increase in flow sensitivity. PD is superior for detecting slow flow, early canalization of thrombus and non-occlusive thrombus. 3-D power doppler imaging has the potential to replace X-ray angiography in some applications. Study of tissue perfusion using PD is also currently an area of significant medical interest.

Endoscopic US (EUS) is a rapidly developing technique which has been used in evaluating the gastrointestinal tract, pancreas and even 'laparoscopic' US. Very high accuracy has been reported in the literature for EUS staging of oesophageal carcinoma. It has also been used for detecting subtle pancreatic mass lesions. Intraoperative sonography is very useful in guiding segmental resections of the liver, detecting small metastatic liver lesions and islet cell tumours in the pancreas. Intravascular US (IVUS) is providing new insights into vascular pathology. It can potentially detect disease earlier than angiography, provide information on plaques, thrombi and dissection. Its use is currently restricted due to its high cost and the indications for its use are still evolving.

Tissue harmonic imaging is another promising new extension of 'conventional' US which improves image quality and provides additional diagnostic information. It allows better lesion detection and characterization of focal hepatic and renal anomalies due...
to improved lesion conspicuity and reduced artifacts, and also helps in evaluating obese patients.

**COMPUTED TOMOGRAPHY**

The development of CT is widely considered to be the most important advance in X-ray imaging since the discovery of X-rays. It has expanded horizons and added new dimensions to the diagnosis of intracranial, chest and abdominal pathology by providing cross-sectional images. The advent of CT revealed that computers could reconstruct images of the human body and opened up tremendous possibilities, the full extent of which has not yet been realized. CT has provided new insight into the understanding and management of many diseases. Examples include functional endoscopic sinus surgery (FESS) based on coronal CT of the paranasal sinuses, segmental resection of the liver based on CT anatomy, and understanding the pathophysiology of interstitial lung disease based on high-resolution CT of the thorax.

Recent developments in hardware and software have made it possible for present day scanners to acquire data in continuous helical or spiral fashion, shortening acquisition time and reducing artifacts caused by patient motion. Helical CT is capable of generating volumetric data in a very short time, making 'breathhold imaging' a reality. It reduces respiratory misregistration artifacts, and allows three-dimensional reconstructions of structures under review. In recent times, the use of helical CT has revolutionized the diagnosis and management of acute flank pain, appendicitis and intestinal obstruction. Three-dimensional CT finds wide applications in the field of musculoskeletal imaging, especially in the setting of trauma.

Using intravenous contrast media, vascular structures can be imaged and CT angiography has become a common clinical procedure. It is a robust non-invasive modality to evaluate the vascular tree, and has been used to evaluate aortic aneurysms, carotid stenosis, aneurysms of the circle of Willis, mesenteric vasculature and a host of other applications. CT angiography can provide all the information required for the preoperative planning of abdominal aortic aneurysms. Unlike conventional angiography, CT angiography can accurately identify the presence of thrombi and define the size of the residual lumen. It may also be an acceptable alternative to catheter angiography in imaging suspected dissections and aortic trauma. High accuracy rates have been reported using 3-D CT for the detection of haemodynamically important renal artery stenosis. Other uses of CT angiography include detection of pulmonary thromboembolism, mesenteric ischaemia, peripheral vascular disease and non-specific aortoarteritis.

Recent advances in computer-assisted virtual reality data post-processing techniques have led to the development of novel techniques including virtual colonoscopy, bronchoscopy and cystoscopy. Using these techniques, it is possible to 'fly through' the region of interest and the lumen size, presence of obstructing lesions and extramural lesions can be well assessed. However, the current limitation of these techniques is their inability to detect subtle mucosal alterations.

A CT technique called ultrafast CT or electron beam CT was developed by Boyd in the early 1980s in an effort to achieve sub-second imaging times. Ultrafast CT has been found to be very useful in the qualitative and quantitative evaluation of cardiac function.

Another technical innovation is the development of multi-slice helical CT. This CT scanner has several detector rows and is showing a lot of promise in superior 3-D visualization and sub-second scanning with improved temporal resolution of CT images. CT fluoroscopy is also an exciting new application which will broaden the scope of CT-guided interventional procedures. This technique permits real-time evaluation of CT images, simplifying the targeting of lesions during interventional procedures.

**MAGNETIC RESONANCE IMAGING**

From the time of Lauterbur's seminal paper in *Nature*, MRI has come a long way. Over the last two decades, MRI has shown promise of being the most versatile imaging technique. Its indications in clinical medicine have expanded from cranio-spinal and musculoskeletal imaging to evaluation of the abdomen and pelvis, cardiovascular system and even foetal imaging. It has virtually replaced older techniques such as myelography and conventional arteriography. The availability of MRI has made a significant impact on the management of spinal tumours, disc disease, bone and soft tissue tumours and a variety of joint abnormalities, particularly sports injuries. Improved performance of the hardware and new software for image acquisition and reconstruction have dramatically shortened scan times, increasing the robustness and cost-effectiveness of this technique. A recent trend in MRI research is a shift towards 'functional' as opposed to 'morphological' imaging.

Echo-planar imaging (EP) is an ultrafast imaging application requiring high speed and high performance gradients. Modifications of this technique include diffusion imaging, perfusion imaging and cerebral activation techniques. Application of diffusion imaging includes early detection of cerebral ischaemia and differentiating solid from cystic lesions. Perfusion imaging is a useful tool for quantifying regional cerebral blood volume in stroke. Integration of these two techniques is certain to pave the way for effective cytoprotective and thrombolytic therapy in acute stroke. Cerebral activation studies are proving useful in pre-operative delineation of important cortical structures and will be invaluable for minimally invasive procedures such as proton beam therapy. The recent availability of open magnets has made intraoperative MRI a useful instrument in neurosurgery. The applications of this technique include brain biopsies, minimally invasive surgery for tumour resection and MRI-guided endoscopic sinus surgery.

Another exciting arena for the application of MRI is cardiovascular imaging. Non-invasive vascular imaging using MR angiography has made substantial contributions to clinical care. The role of MRI in imaging aortic aneurysms and dissections, and pericardial pathology is already well established. MRI also has the potential to detect proximal coronary artery stenosis non-invasively, although further work is required before it comes into clinical use. The most common indication of MR angiography is suspected cerebral ischaemia due to atherosclerotic disease. It is also useful in the evaluation of vascular malformations, intracranial aneurysms and venous occlusive disease. MR angiography with gadolinium has improved the diagnostic capability of this technique in the evaluation of renal artery stenosis and peripheral vascular disease.

Improvement in pulse design and availability of faster sequences have increased the abdominal applications of MRI. It is widely used as problem-solving technique for characterizing liver lesions and adrenal masses. Magnetic resonance cholangiopancreatography (MRCP) is an excellent technique for non-invasive evaluation of the biliary tree and pancreatic duct in the setting of obstructive jaundice and has almost replaced the more
invasive technique of ERCP, which is now reserved for performing endoscopic interventions.

MRI has the ability to distinguish several chemical substrates on the basis of their spectroscopic signatures. MR spectroscopy has been applied to a wide variety of disorders including encephalopathies, cerebral ischaemia, psychiatric disorders and brain tumours.  

NUCLEAR MEDICINE

Radionuclide imaging is a robust method of studying functional abnormalities and is an established modality for studying renal functional status, renovascular hypertension, skeletal metastases, thyroid and parathyroid disorders, and a host of other diseases. The advent of SPECT imaging and, in recent years, of positron emission tomography (PET) scanning have greatly enhanced the potential of this field.  

Imaging of glucose metabolism by using 2-fluoro-2 deoxy glucose and PET is being increasingly used in grading the malignancy of brain tumours, evaluation of pulmonary nodules, staging of non-small cell lung cancer, detection of recurrent colorectal cancer, etc. Other promising new applications of this technique include staging of breast cancer, lymphoma and detection of hepatic secondaries.  

The current research in nuclear medicine centres around improvement in collimators, better computer algorithms and targeted radiopharmaceuticals. Exciting new possibilities for the future include the development of agents that will localize in tissues undergoing apoptosis, localization of arterial and venous thrombi, and evaluation of the extent of inflammation using agents such as radio-labelled liposomes and immunoglobulins.  

PICTURE ARCHIVING AND COMMUNICATION

A picture archiving and communication system (PACS) increases the speed and reliability with which images can be stored, retrieved from storage, displayed and moved from and to different locations. A digital image can be stored in a compact memory device, from which it can be quickly retrieved and transmitted to clinicians and manipulated electronically. View boxes are replaced by computer terminals and radiology departments can become film-less. The speed and efficiency of PACS will lead to greater clinical accuracy, better health care and be more cost-effective in the long run. An extension of this is tele-radiology which allows transfer of images over long distances through telephone and satellite networks, to get specialist opinion on images obtained at remote locations.

Imaging is advancing at a pace faster than our ability to comprehend and the possibilities for the future are endless. The impact of ‘high-tech’ imaging modalities on modern clinical practice is so great that they will increasingly be seen as a strategic solution of delivering cost-effective health care rather than a resource-intensive burden. In developing countries such as India, this enthusiasm is tempered by limited resources. However, appropriate and judicious use of these modern techniques will, in the long run, help in providing more efficient and cost-effective medical care.

REFERENCES


