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A Review of Medical Imaging Innovations that Impacted Patient Care in Recent Decades as Link to Future Trends

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ABSTRACT

Background: Medical Imaging has witnessed a revolution in technological advancement, being in the forefront among other disciplines in the health sector. Most of the earlier modalities that were largely analogue and mechanical have been replaced by automated and digitized technology.

Objective: To track the developments and innovations in certain aspects of medical imaging that have impacted positively on patient care.

Methods: Relevant literature were searched physically and online for both old and modern technological innovations in medical imaging and patient care.

Results: There have been new technologies such as computed tomography, magnetic resonance imaging and the various ramifications of ultrasonography. Innovations in imaging modalities have brought increased diagnostic accuracy, much as examination time has been drastically shortened and radiation dose levels minimized or completely dispensed with. Manufacturing of portable equipment means that technology can now be taken to the patient and more time is dedicated to patient care. Introduction of digital radiography and Picture Archiving and Communication Systems have further impacted positively on efficiency and effectiveness of service delivery. Graduate degree programmes have invigorated radiographers' drive for the discovery of new and better ways of diagnosis and treatment through research.

Conclusion: Innovations in technology have led to miniaturization of equipment making it possible to take services to the critically ill patients, thereby improving patients' accessibility to medical care. Also patients' exposure to ionizing radiation has reduced due to improvement in research and development of new modalities using radiant energies other than ionizing radiation.

Key words: Medical Imaging, Modality Innovations, Patient Care, Trends

Introduction

The introduction of B-Mode ultrasound (US) in the 1960s, computed tomography (CT) in the early 1970s, and magnetic resonance imaging (MRI) in late 1970s have transformed medical imaging. These diagnostic tools have expanded further to include positron emission tomography (PET), single photon emission CT, and additional innovations in ultrasound such as M-mode and Doppler imaging [1]. In some obsolete imaging procedures and modalities, patient experience was gruesome, time of study was measured in multiples of hours and radiation exposure was significantly high [2].

The last couple of decades have witnessed enormous changes in modality and scope of

imaging technology. From the invasive borehole air encephalography introduced in 1919 [3] and percutaneous transhepatic cholangiography that debuted in 1937 [4, 5] to bronchography with all its discomfort to the patient, medical imaging has seen great improvements in technology, techniques [6] and manpower development. Remarkable improvements have resulted in reduced image processing times, improved spatial resolution and, where applicable, reduced radiation dose [1, 7].

These developments have enabled radiographers to improve patient outcomes, increasing productivity while also achieving better safety, accuracy and cost effectiveness.

Significant progress has been made in automatic film processors during the last 50 years, including reduction in film processing times from 90 seconds in the 1960s, to 30 seconds in the 1980s. Newer technology designs of processors evade liquid components in their processing cycle. These are no mean feats considering the fact that the first automatic film processor designed to replace manual processing, required about 40 minutes processing time [8].

It was noted that in mammography in the past, mean glandular dose per exposure for a sample size greater than a hundred ($n > 100$) was about 20 mGy. Following improvement in technology and technique, such as the use of fast film-screen systems, optimized radiation qualities and modern automatic exposure control units, this value has now decreased to about 1 mGy. Further reductions in dose appear feasible by the introduction of digital mammography [9].

Multidetector CT for CT coronary angiography is one more example of technological innovation driving clinical advancements. The addition of more rings of detectors and sections per revolution, have reduced the time required for this examination from about 7 seconds to as little as 1.0 second or less, with corresponding radiation dose reduction [10].

The fields of diagnostic neuroradiography, pneumoencephalography, myelography, lymphangiography, conventional tomography and arthrography, radionuclide brain scanning, and bronchography benefited immensely from the introduction of cross-sectional imaging, especially computed tomography (CT) and magnetic resonance imaging (MRI). Computed tomography and ultrasound have replaced Cholecystography and retroperitoneal air insufflation [2]. Lower limb angiography has successfully been replaced by Doppler ultrasound with the advantages of not just being real time but offers manipulations that improve diagnosis, such as compression, respiratory phasicity, Valsalva manoeuvre, augmentation [11], and estimation of degree and

length of arterial stenosis. This eliminates the debilitating effects of the invasive lower limb angiography.

The development of “special use” devices and miniaturization of electronics have encouraged the manufacture of portable medical devices. This means that it is now possible to “move technology to the patient” as in point of care ultrasonography (POCUS), thereby delivering care in more patient-centered ways [1]. It is safer and more efficient to provide portable services in an intensive care unit than to move a critically ill patient to a centralized imaging location. More recently computer-aided diagnosis (CAD) has been introduced to assist in interpreting abnormalities such as breast lesions on mammograms. However, modern medical imaging includes not only image production, but also image processing, image display, image recording and storage, and image transmission, most of which are included in a picture archiving and communication system (PACS) [12].

Methods

Relevant literature were searched both physically and online for old modalities and modern technological innovations in medical imaging and patient care. PubMed, PubMed Central, SPIE Digital Library, ResearchGate and Medline were searched using combinations of the following search terms: innovations in medical imaging, modern medical imaging and patient care, impact of new imaging modalities on patient care, innovations in radiology, radiography education, telemedicine and teleradiology. Primary and secondary sources were screened for relevance by title and abstract contents. Potential sources were then downloaded and their contents were scrutinized for relevance.

Digital imaging and networking

The central component of the analogue radiographic imaging system is the film-screen system (FSS), which was first employed soon after the discovery of x-rays in 1895 and is still widely used in many countries [13].

Its major disadvantage however, is that radiographs cannot be post-processed. This means that if a film is under- or overexposed, an additional exposure to the patient is inevitable to effect a correction. Digital images on the other hand provide increased latitude and wider dynamic range thereby reducing repeats. Several versions of the image can be produced and displayed on high quality screens as soft copy or transmitted and accessed simultaneously at any workstation and viewing stations set up at any location [14].

This revolution was accompanied by the adoption of picture archiving and communication systems (PACS), which provide electronic storage, retrieval, distribution, and presentation of images from imaging department. Digital imaging is associated with a number of important economic and clinical benefits [12, 15], chiefly, instant access to radio-diagnostic investigations regardless of location and without duplication or the necessity for physical transportation of films, with inherent risks of loss of films [16].

Radiographers can now handle more patients each day, and fewer rooms may be needed to handle the same number of investigations, allowing increased patient throughput without adding staff and expanding facilities, or freeing resources for other, activities that are more profitable. Facilities can now eliminate the costs of films and chemicals by adopting soft copy reporting, and redeploying personnel who previously handled film processing, storage, retrieval, and re-filing [15, 16]. Maintaining digital film archives free up film storage space for more productive uses, such as the acquisition of new advance modality.

Teleradiology

In developing countries and remote environments of developed countries where radiologists are scarce, teleradiology, allows images to be obtained in a location convenient to the patient and electronically transmitted for reporting at a main hospital or centre far away. A teleradiology system requires image gateways and specialized

communications capabilities, as well as diagnostic-quality workstations. Film digitizers can be mounted at such a remote place to transmit different kinds of images to experts for reporting and consultation. This way, clinicians and patients in rural communities can access vital radiology services without necessarily transporting hard copy images or very ill patients to tertiary health facilities in urban centres [17].

New modalities and future trends

Digital breast tomosynthesis (DBT)

Also called 3-D mammography, DBT is a state-of-the-art digital breast imaging technology. It represents a new standard in breast imaging due to its dramatic improvement in lesion visibility and its ability to detect cancer at its earliest, most treatable stage. With DBT a series of tomographic cuts are made in any chosen projection instead of each breast having images of two projections [18]. The procedure reduces the masking effect of overlapping fibro-glandular tissue, especially in dense breasts, thus improving breast cancer detection. This 3-D mammography offers all the benefits of a conventional 2-D digital mammogram (still the gold standard in early detection of breast lesions) while still offering the additional benefits of clearer view of abnormalities that could hide in overlapping images of breast tissues of different depths in a 2-D mammogram. It is postulated that DBT might replace conventional 2D mammography in clinical practice [19].

Non-Contact LASER Ultrasound

This is also called LASER-stimulated ultrasound (LSU) where a remote optical method, derived from industrial LASER ultrasonic, is used to detect ultrasound in tissues. The optical detection scheme used in industrial LASER ultrasound (LU) is adapted to the safe detection of ultrasound in biological tissue. The exposure leads to a slight warming of exposed cells, which then give off an acoustic signal. When this ultrasound wave is reflected back to the surface, the resulting vibrations can be detected with a second LASER system.

The use of a fixed optical source reduces potential operator variability in noncontact LASER ultrasound. The detection of ultrasound in photoacoustic tomography (PAT) usually relies on ultrasonic transducers in contact with the biological tissue through a coupling medium. This is a major drawback for important potential applications such as surgery, open wounds, burns, trauma, etc. However, in non-contact PAT, the use of the probe is dispensed with, thus eliminating the need for sterilization, coupling gels, or skin preparation [20, 21].

3D ultrasonic holography

Holography is a technique for recording and then reconstructing the amplitude and phase distribution of a coherent wave distribution, used to produce three dimensional (3-D) images or holograms. Unlike conventional 3-D ultrasound that uses LASER reconstruction, thus losing 3-D resolution, direct 3-D ultrasonic holographic imaging uses transmissive ultrasound with a scanning needle hydrophone and digital reconstruction. In a conventional LASER ultrasonic hologram, no useful depth information is detected. Although the information is still there, it is so collapsed that the TV camera sees it as a flat image. The digital process in 3-D ultrasonic holography has the ability to insert the proper ultrasonic wavelength and thus avoid the problem of demagnification associated with conventional 3-D ultrasound. The resolution of generated images is high in comparison to those of a normal ultrasound. Holography is potentially the most powerful method for high spatial resolution real time 3D ultrasound imaging and diagnostics. Furthermore, the images are easily reproducible and allow automated computer-based data interpretation [22].

Elastography

This is a medical imaging modality that maps out elastic properties of various soft tissues. Elastography imaging technique is based on the change of soft tissue elasticity in various pathologies which yield quantitative and qualitative information used for diagnosis.

Elasticity of tissue is affected by pathology which can be assessed using ultrasound or MRI. The stress - strain data of soft tissues are acquired by insonation or exposure to radiofrequency (RF) under magnetic waves. Elastography employs tactile imaging, also called mechanical imaging or computerized palpitation. Palpitation here can be induced by pushing, deforming, or vibrating a surface with ultrasonic probe. Elastography translates sense of touch into a digital image formed from reflected ultrasound beam [23]. Commercial types of ultrasound elastography in current use include: transient elastography, acoustic radiation force impulse imaging, supersonic shear-wave imaging and real time tissue elastography [24, 25]. Elastography is very useful in estimating prognosis and course of treatment for cases of chronic liver diseases of various etiologies. It is very suitable in grading the degree of liver fibrosis through measurement of the liver tissue stiffness. Newer applications are in breast imaging, thyroid, prostate, kidneys and lymph nodes [23].

Data mining

The rapid innovations in digital imaging and expansion in modalities have resulted in hundreds of millions of patients' data and reports domiciled online at different institutions all over the world. This is called the era of "big data". Researchers are now more able than before to access such data through "data mining", thus raising the prospect for new information and knowledge about the patients. With "big data" there will not just be more than enough data for research but there will also be enough information to drive administrative decisions and enhance scientific knowledge towards automated reporting in the near future. This will enhance quality of patient care through evidence-based practice [26, 27].

Manpower development in radiography

This review will not be complete without factoring in the manpower component that drives and coordinates the advancement in technology and modality innovations.

Establishment of graduate radiography programmes has brought a shift in the educational focus from knowledge-based to evidence-based. Interestingly, research in radiography has become a requirement rather than an option. The engagement of radiographers in research is emphasized as a priority that has brought the profession to the limelight and helped to maintain high standards of patient care. Awareness and commitment to research efforts is on the increase, judging by the increasing number of radiographers receiving Ph.D award and the number of fresh Ph.D enrolments [13].

Conclusion

Medical Imaging has witnessed rapid developments in digital technology, electronic miniaturization, modality innovations and manpower development. These developments have combined to reduce harmful practices, reduced waiting time and radiation dose levels, improved patient care and experience and enhance the effectiveness of imaging outcome. The availability of trained manpower means that the radiography profession can keep pace with innovative developments and the expanding demand for radiography expertise.

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