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Current concepts

DIGITAL IMAGING IN TRAUMA AND ORTHOPAEDIC SURGERY
IS IT WORTH IT?

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A rich array of visual images and radiographs is a vital component of the practice of trauma and orthopaedics. Advances in digital imaging now make it possible to include these as part of the integrated patient record. If there are sufficient sites within the hospital which allow convenient and high-quality retrieval, the traditional packet of films will no longer be required. It is now possible to run a system whereby an image can be stored and retrieved almost spontaneously for viewing anywhere in the world. The digital image format allows pictures to be sent by e-mail or placed on a page of the World Wide Web. The image can be reproduced indefinitely without losing colour or detail. The exciting concept of a 'film-less' hospital has many benefits for patient care including decreased exposure to radiation, no loss of images and lower rates of rejection[1-3] (Table I). Digital imaging may not initially realise cost benefits,[4,5] but advances in technology will rapidly facilitate this.

The picture archiving and communication system (PACS) allows the viewing of pictures at diagnostic, consultation and remote computer workstations and the archiving of images on to magnetic or optical media using short- or long-term storage devices. The PACS should offer the interfaces and gateways to healthcare facilities and information systems necessary to give an integrated system to the user. Using PACS it will be possible to develop an integrated electronic patient record (EPR). Successful digital imaging will only be possible, however, if the technology is introduced in a carefully controlled manner and is responsive to the needs of the end user. Filmless radiology decreases the need for consultation in the radiology department hence freeing time for clinical work.[6] Immediate access to digital media raises legal issues which must be overcome to allay the fears of the clinician that this may ultimately jeopardise the quality and confidentiality of patient care.[7]

What is digital imaging?

Digital imaging[8,9] entails the use of a computer to modify existing or to create new graphical images. A digital camera, like a standard film camera, uses a lens to focus the image on a focal plane. While the traditional camera relies on a film to capture the image, the digital camera uses a sensor which is either a light-sensitive chip, such as a charged coupled device, or a complementary metal oxide semiconductor. As light strikes the array of picture elements called pixels which make up the sensor it is converted to an electric current. The pixel is the smallest part of a digital image sensor and the digital image, or bitmap, is a conglomeration of pixels, like a mosaic. The electric current is then passed to an analogue-to-digital converter. This converts the analogue signal originating from the image sensor to a digital picture which is stored as a computer data file. The size of such a file can be very large. The larger the number of pixels the higher is the resolution of the image and, in turn, the larger the size of the data digitally representing that image. The size of the image file is also dependent on the depth of the bitmap, which is the amount of digital storage space used to record information about the colour of an individual pixel. The way in which the data representing an image are electronically written, either in a computer memory or on a disk, is the image file format. Different formats exist. Many use compression techniques to reduce the storage space required by image data. Different methods of compression are classified by whether or not they remove detail and colour from the image. 'Loss-Less' techniques compress image data with-

Table I. The clinical benefits of PACS

Reduction of foot traffic between clinical wards and the radiology department
Significant increase in availability of investigations
Increase in the speed of availability
Virtual elimination of lost studies
Decrease in radiation dosage
Reduction in wasted films
Reduction in retrieval times

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out removing detail, while 'Lossy' methods entail removing detail or depth of colour. The most common personal computer standard of compression for use with digital cameras is the joint photographic experts group (JPEG) format. Previously, compression of stored data was an important factor influencing the cost and viability of a PACS, but storage media are now relatively cheap.

In the hospital all digital images must be 'digital imaging and communications in medicine' (DICOM) compatible. The DICOM standards allow medical images to be exchanged between instruments, computers and hospitals, and have evolved over many years through a series of discussions between software engineers and computer companies (representing the National Electronic Manufacturer's Association, NEMA) and surgeons. It is important that any DICOM conversion is made before transmission of image media since this will otherwise create potential conversion difficulties and slow the system. Radiology information systems (RIS) and hospital information systems (HIS) must allow for bidirectional communication with any PACS system. DICOM minimises the risk of conflicts during the development and upgrading of systems.

Requirements of a digital imaging system

When a digital imaging system is introduced its exact aims must be clearly defined and a programme of implementation established. Clinicians, information technology staff and hospital managers must be clear as to what is required from their system and then define how it may be implemented. There must be an ongoing dialogue to continue the development and to maintain the system. Flexibility must also be built in to respond to emerging, upgradeable technologies and to ensure that the data gathered remain in a format which allows integration with established information technology projects locally, nationally and internationally. The rate of transfer of data for relatively large images is important, as this is potentially time-consuming. An orthopaedic 'electronic utopia' would be a digital system which integrates the patient's electronic notes, radiology, hospital laboratory data and clinical photography where appropriate. Central storage of data has the advantage that it can be accessed simply from any remote site, with appropriate security clearance.

Digital image input

The rapid development of the personal computer has led many surgeons to become familiar with the use of digitising equipment in orthopaedic practice. The cost of high-quality digital equipment is rapidly declining and medical digital imaging of high resolution is now affordable. The quality of the image must be such as not to cause loss of potential diagnostic information or require unnecessarily large image files.[8] With digital imaging there is no requirement for large stacks of stored radiographs and it is therefore possible to store larger numbers of images and to retain them indefinitely if required. If an image is to be digitised then the earlier the better, since labour-intensive steps can be removed and the information made available immediately to clinicians synchronously at different sites.

Conventional computed radiology

Computed radiography (CR) is the digitisation of images by means of a stimulated phosphor plate. The film plate is scanned by a laser beam and then into a reader to generate a digital output. It is contained within a cassette similar to that for conventional radiographs and can be used with existing radiographic equipment. CR can therefore be a useful intermediate step, as digital radiology (DR) will not always be easily integrated with current equipment. CR does, however, still involve the manipulation and chemical preparation of cassettes, which is not required with a DR system.

Teleradiology and digital radiology

Teleradiology is the process of sending radiological images from one point to another and is now becoming an essential part of HIS/RIS systems. The process of digital radiology does not always require a separate plate reader apparatus and can be performed by either direct or indirect plate systems. The direct system plate has an amorphous selenium photoconductive layer which directly converts x-ray photons to electrical energy. The indirect system has a caesium iodide layer which first converts the x-ray energy to light, which is then changed to digitised data. The direct system offers superior quality, since there is no scattering of light at the detector layer. Both systems have a broad dynamic range allowing a certain degree of under- or overexposure. They also allow for a lower dose of radiation to the patient because of the superior sensitivity of the plate. Although these systems are currently costly, their price will fall and the initial expenditure can be offset against long-term savings in x-ray film, chemicals, processors and staff time. It is important to realise that PACS and teleradiology are not just about new technology, but are a different approach to the way in which we work.

Digital archive and backup

In order to manage the large volume of data which is developed by a digital image system it is necessary to create a multilevel archive system. A typical chest radiograph can be 10 Megabytes (Mb) and each slice of a CT or MR image can be about 1 Mb. A large radiology department can produce around 120 Gigabytes (Gb) per day[5] and could be required to store many terabytes (1000 Gb). The small numbers of images which would be in current use or required immediately can be stored in a fast access system. Images which would normally have been filed away in the

film store can then be placed in a higher capacity and less expensive storage medium, such as a tape drive or optical drive. This enables great savings in cost although access times for the long-term archive material will rise. The PACS archive should be located in a secure environment with planned automatic back-up for fire, flood, electrical failure and theft, and security protection. The archive must be registered for data protection. The system software should provide a safe audit trail with permanent marking of images and measures to prevent accidental deletion. The network cabling within the hospital should be capable of a bandwidth of 100 Mb/s with the capability for expansion. The digital archive system should be built in a RAID (redundant array of inexpensive discs) with disc drives and power supplies which can be maintained without requiring the system to be shut down. It is vital that surgeons are confident of back-up and emergency procedures in gaining acceptance of any PACS project.

Digital image output and image access

The retrieval of data in a digital system will be accomplished by the use of an Internet browser to locate the data in central storage on the server. Access can be allowed from multiple sites and to multiple users. The central storage of patient information with, potentially, very large numbers of peripheral access points, jeopardises patient confidentiality and security of access to the data must be stringently controlled to prevent unauthorised entry. It is likely that the Internet browser will be used over secure connections with encryption and digital signatures. Access will be limited to specific areas rather than the entire database as part of the security strategy. An activities log would also allow further monitoring of access. One of the major benefits of digital storage is that the number of outlets for viewing is unlimited. Efficient management of data allows peripheral output of image files for viewing, manipulation or production of hard copy almost instantaneously. Viewing stations must be of a suitable quality to ensure that the interpretation of the image is not compromised by the resolution of the monitor but its this may be varied depending on the specific requirements of the user and the environment.[6]

Specific applications in orthopaedics and trauma

In orthopaedics and trauma, clinical photographs and video are likely to be used more often as they become easier both to produce and store. The complete image portfolio of a patient can be made available at the physician's workstation. In the ideal situation, distributed digital media would be in every ward and department, but in practice there will still be the need to produce a hard copy. Currently, film printing will be required for 10% to 20% of all investigations.[4-6] Within the hospital there can be a local area network (LAN) of either copper or fibre-optic cables for speed and capacity. Outside the hospital there can be a wide area network (WAN), or use of the Internet, to link many sites by a digital telephone line such as the integrated service digital network (ISDN) or satellite. On the wards or in the surgeon's office, the PACS system would be a LAN linked to a local laser imager which can produce hard-copy films for use outside the department. These printable downloadable films can be used for preoperative planning. Orthopaedic and trauma units which have developed large-scale PACS have required the surgeons and radiologists to have ongoing evaluation of the systems.[10,11]

Implementation strategy

The high cost of the hardware involved in implementation means that most hospitals require a phased programme of introduction. With more widespread use, 'off-the-shelf' packages of equipment will become available and will be much cheaper. In the short term, the introduction will be limited to the radiology department, with initial digital printing of images when required outside there. This can be followed by the introduction of peripheral viewing stations which will gradually replace the film-printing service. In some settings with low requirements for radiology it may be more efficient to maintain a film-printing service in the medium to long term, and this may be retained for emergency use. A training programme would be needed for continuous upgrading of staff knowledge. A successful digital imaging system needs to be supported by the whole hospital and integrated[12] fully into the PACS, HIS, RIS and eventually the EPR. Collection, retention and transmission of any clinical information must conform to the latest guidelines on security and confidentiality.

It has been suggested that it is negligent to consider installing a conventional radiology department rather than a PACS.[13] Building a system *de novo* has several potential benefits as the financially inefficient intermediate steps along the road to digital radiography are eliminated. Setting up a new department offers the ideal window to allow the transition to a 'filmless' hospital.[14-16] Orthopaedic imaging is entering the new millennium with a solid record of recent advances in digital, cross-sectional, and interventional radiology. Advances in radiology have been invaluable in orthopaedics and trauma surgery, but careful thought will be needed to solve the many problems which will arise in the future.[17]

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