Teleradiology: present and future

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Synopsis

- Teleradiology is the transmission of images electronically by a variety of media.
- Teleradiology allows provision of specialist radiology services to remote or small communities previously denied these services.
- Although initial capital costs are high, there are significant savings in materials and manpower.
- Teleradiology is most effective as part of a larger telemedicine network.
- Telemedicine should in the future be integrated within the ADF computer network with the ultimate goal of a paperless personnel system.

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TELERADIOLOGY — the electronic transmission of radiographic images over short or long distances — allows the provision of rapid and cost effective specialist radiology services to small and remote centres of population where these services were previously not available.[1-5] It now forms an integral part of current radiology practice in both the public and private sector of Australian radiology as well as within the armed forces of many overseas countries, most notably the USA. I first used this technology while attached to the National Naval Medical Center (NNMC) in Bethesda, Maryland, USA, and I now use it routinely in my private practice in Sydney.

Modes of transmission

DICOM (Digital Imaging and Communications in Medicine) is the industry standard for transferral of radiologic images and other medical information between computers. Patterned after the Open System Interconnection of the International Standards Organization, DICOM enables digital communication between diagnostic and therapeutic equipment and systems from various manufacturers. The DICOM standard is now at version 3.[6]

There are many ways that medical images can be transmitted, the choice depending on the volume and complexity of images, the cost effectiveness of the different types of transmission and the availability of those transmission modes.

Public switched telephone network (PSTN): PSTN is the standard local telephone system, designed to carry analog (sound) data. PSTN has the advantage of being freely available and cheap, but is the slowest form of electronic transmission (up to 56 kbps — 56 000 bits per second — but generally less). PSTN has difficulty in transmitting large numbers or very complex images and is little used these days because of these limitations. Although images are sent using the Internet on PSTN lines, such applications are effectively restricted to small images and compressed data formats (eg, JPEG, discussed below).

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Integrated services digital network (ISDN): ISDN offers increased rates of transmission (64 kbps, or 128 kbps in a dual channel system) and thus greater efficiency, and is more frequently used than PSTN.

Local area network (LAN): LANs set up and owned by single organisations are generally limited in size to a single building or group of buildings, but can provide cable connections within this local area at speeds of 4–100 Mbps (4 000 000–100 000 000 bits per second), depending on the cabling and transmission protocols used. The frame relay protocol is a fast option for transmitting digital images over a LAN or WAN.

Wide area network (WAN): The big brother of the LAN, WANs may connect several organisations in a private network. Operating over larger distances, WANs can supply secure transmissions between members.

Satellite communications

USS ENTERPRISE with satellite antenna seen on the port side of the flight deck at the bow. (Photographs courtesy US Navy.)

Fibreoptic cables: These offer high transmission rates (100 Mbps when using fibre distributed data interface protocols [FDDI]) and high transmission quality, but are often not available to remote areas. Laying fibreoptic cable is expensive.

Microwave or satellite transmission: For many situations, particularly within the Defence Forces, a cable connection between the imaging site and the image interpretation centre is not possible, and hence microwave technology and satellites are the preferred methods of transmission. These have the fastest transmission times, but are extremely expensive to operate, even on a shared basis. Costs for a satellite link vary, but are about $25 000 per month. These methods also have limitations: microwaves are limited by ground topography, as a direct line of sight between transmitter and receiver is required. Frequent repeater stations are required to boost or deflect the signals. Satellite transmissions can be disrupted by orbital paths and severe weather conditions.

Digitisation

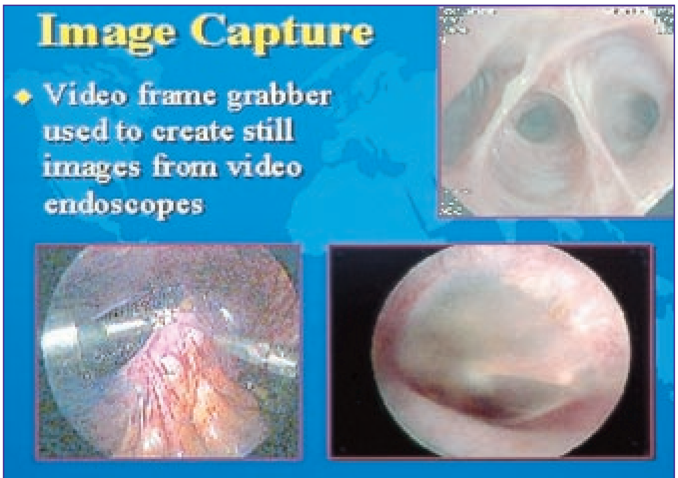
Before the images can be transmitted, the images must be in digital rather than analog (hard copy) format. Many of the current radiology machines provide a direct digital output for their imaging. All magnetic resonance imaging machines are digital in their output, as are many computed tomography scanners, the more sophisticated ultrasound machines and angiography catheter laboratories. However, most plain radiography machines produce analog (film) output. These images must be digitised before they can be transmitted. There are a variety of digitising machines, ranging in sophistication from machines which require the radiographer to insert each x-ray film individually to those that automatically process a stack of x-ray films. With increasing sophistication comes an increasing cost: digitisers range in price from $80 000 to $160 000.

After the image has been digitised, it is advisable to crop it as much as possible to remove unwanted space from around the diagnostically important area of the image. This saves transmission time and, if the image is to be stored on a picture archiving and communication system (PACS), considerable storage space and retrieval time is also saved.

Using "frame grab" technology, images can also be digitised from the video display screens typically used with endoscopes and fluoroscopy machines.

Compressing images

Before digital images are transmitted, they are usually compressed to minimise their size, which reduces the time and costs of transmission. Compression is essential if complex



(Slide courtesy US Navy.)

Picture archiving and retrieval systems (PACS)

A full hospital PACS will support all the imaging activities within a hospital (plain x-ray, ultrasound, computed tomography, magnetic resonance). All images are centrally stored and can be electronically distributed to all wards and client departments, together with reports.

Reporting of images is usually done directly from monitors. Hard copies of all images can be produced (usually by laser printers) for distribution to referring practitioners not connected to the PACS.

A PACS is easily connected to a teleradiology system to provide storage and transmission of images for remote viewing.

Most PACS have two levels of storage: an online, rapid access system (for images of current patients) and a much larger, generally slower, archive.

studies (eg, ultrasound or computed tomography) are to be transmitted.

Lossless compression: Techniques to reduce the size of a digital image without removing data can compress an image to 50% or perhaps 33% of its original size. Lossless compression algorithms store the same data using fewer bits. In practice, lossless compression is not sufficiently compact for a high volume of image transmissions.

Lossy compression: Lossy compression techniques select part of the digital output to be transmitted without significantly affecting the quality of the image as visualised at the other end. These compression techniques are very complex and are continually improving in sophistication and quality. It is beyond the scope of this article to go into these techniques (which include JPEG, MPEG and wavelet technology) in any detail.

The JPEG technique (a standard developed by the Joint Photographic Experts Group) compresses images by removing data about subtle changes in colour. This exploits the limitations of the human eye, which is relatively insensitive to small colour changes, but quite sensitive to changes in brightness.[7] The amount of JPEG compression can be adjusted from low data loss to high data loss to suit the requirements of transmission and interpretation. A typical compression ratio for these images is 20 to 1, which involves a noticeable decrease in the quality of the image at the receiving station when compared with the initial image. Yet most medical images can still be interpreted correctly at this level of compression without compromising the accuracy of reporting.[8,9]

One exception is mammography. The fine microcalcifications typically seen with ductal carcinoma in situ may be completely lost, or their morphology may become blurred as a result of compression techniques, thus rendering the accurate differentiation of microcalcifications, and hence the diagnosis of ductal carcinoma in situ, extremely difficult. For this reason, the Surgeon General of the United States, on the advice of the American College of Radiology, has banned the diagnosis of mammography images using teleradiology.[10] The Royal Australian and New Zealand College of Radiologists also endorses this policy.[11]

Advances in compression techniques (eg, wavelet technology) continue to improve the quality of the transmitted image, while maintaining high transmission rates. It is quite possible that in the future the present problems in relation to mammography may be overcome.

The resolution of medical images is critical for diagnostic confidence. A digitally acquired film on a 35 x 43 cm format has a line-pair resolution of 4 line pairs per millimetre (4 lp/mm). An analog image has a resolution of 8–10 lp/mm. Although there is obviously reduced resolution in the digital image, post-processing techniques allow manipulation of this image. The ability to alter the contrast and density and the use of magnification and inversion techniques more than compensate for the reduced resolution. Digital technology, however, is not an excuse for poor radiography. The better the quality of the original image, the better the transmitted image.

A 35 x 43 cm DICOM chest X-ray has a file size of 8 Mb (8 000 000 bytes, or 64 000 000 bits). Transmitting this image without compression over a normal PSTN telephone line would take at least 19 minutes (at 56 kbps) and longer if the network is busy. Compression can reduce image size, and hence transmission time, by a factor of 20.

Digitally acquired images may be smaller in the first instance, but are often gathered in series, making the total size of the transmission quite large. Thus, compression remains important for digitally acquired images.

Receiving station

Receiving digitised images does not require special computer technology, but, if large numbers of images are being transferred, the receiving computer does require plenty of random access memory (RAM) and a fast transfer system to a hard disk drive. Received images can be transferred to a personal computer, a PACS, or an optical disc (CD), depending on how the images are then to be stored and displayed.

PACS can be interfaced with a radiology information system (RIS). The RIS stores all written information relating to the patient, such as old reports and requests as well as billing information. When a patient presents to a radiology unit running such an integrated system, the radiological history and previous images can be made available for display with the current examination. This can all be initiated by a single swipe of an identifying bar code unique to each patient. This is truly a paperless system. Such a system is currently operating in the radiology department at Westmead Hospital in Sydney.

Display technology

The images are usually displayed on cathode ray tube monitors. The quality of these monitors varies enormously, but they usually display more line pairs than television or computer monitors, giving better image resolution. Most current systems use a dual monitor system, with a typical price for each monitor being $15 000–$20 000. Two monitors are used so that two full-sized images can be displayed at once (eg, anteroposterior and lateral projections for a chest x-ray), or to increase the ability to display multiple small images (eg, an MRI study often includes more than 60 images).

As already discussed, there is a loss of quality of the image once it is digitised, compressed and transmitted, but this is offset to a degree by the enormous flexibility that is available once the information is in digital form. The image can be displayed in "portrait" or "landscape" presentation, inverted or rotated, and measurements of distances and angles between any points on the image can be readily obtained. Contrast, brightness and magnification are easily controlled. It is also possible to annotate the images for the information of referring doctors.

Images can be displayed singly, sequentially or side-by-side, and dynamic images such as fluoroscopies, ultrasound and MRI can be viewed and looped.

If a printed image is required for a referring doctor, the image can be printed from the system using a variety of techniques, including laser dry view technology and thermal paper.

Costs

As already noted, the costs of this technology are substantial. These costs are falling as technology becomes more available and the research and development costs are recovered. The trends in teleradiology are in keeping with the experiences of the computer industry as a whole.

Currently, the costs of a digitiser range from $80 000 to $160 000. The costs of computed radiography plates for digital radiography range from $10 000 to $520 000. High resolution monitors cost about $25 000 each. A personal computer with suitable capability for receiving and holding images would be about $5000, and a spooler (used in archiving images) would cost about $2000. Software licences for digitising, transmitting and managing the images may cost up to $30 000. If the images are to be stored on a PACS, then the costs escalate considerably. A simple PACS (hardware and software) costs about $400 000, ranging up to $2 000 000 for the more sophisticated systems.

Although these costs are substantial, they are offset by significant savings when compared with conventional cut film technology. These savings include the cost and storage of films, and the labour involved in filing and retrieving patient studies. PACS, combined with a local or wide area network, can make images available to multiple users and referrers to the radiology service, with low transmission cost and no risk of lost or damaged images. There is far greater ease of availability of data for research and epidemiological studies. Finally, teleradiology can help provide services to remote areas where either the location or the numbers of studies involved make it impractical for a radiologist to visit.

These systems require careful attention to patient confidentiality, but this is well protected in modern systems, which use encrypted transmission of images and access codes to restrict access to data.[12]

Teleradiology plus

While teleradiology as a stand-alone technique now has a proven place in modern medicine, its cost effectiveness is considerably enhanced when it is associated with other facets of telemedicine. The United States Navy commenced its Multimedia Integrated Distributed Network [MIDN], a telemedicine initiative, in early 1996. This program is based at the National Naval Medical Center (NNMC) and the founding director is Captain Richard S Bakalar, MC, USN.[13]

I was fortunate during my attachment to the NNMC to be able to participate in this program. On a daily basis I was reporting x-ray films transmitted via satellite from four US carrier battle groups. These consist of an aircraft carrier in company with several destroyers or frigates, a landing or troop ship and a nuclear submarine. The groups were the USS YORKTOWN, USS ENTERPRISE, USS GEORGE WASHINGTON and USS STENIS, scattered throughout the Pacific and Atlantic oceans.

Not only did these carrier battle groups transmit their radiological images, they also transmitted pathological images and data, electrocardiograms, medical documentation and personal documents using the same technology. Also available on each

National Naval Medical Center, Bethesda, Maryland, USA

The NNMC is the hub of the US Navy telemedicine program. (Photograph courtesy US Navy.)

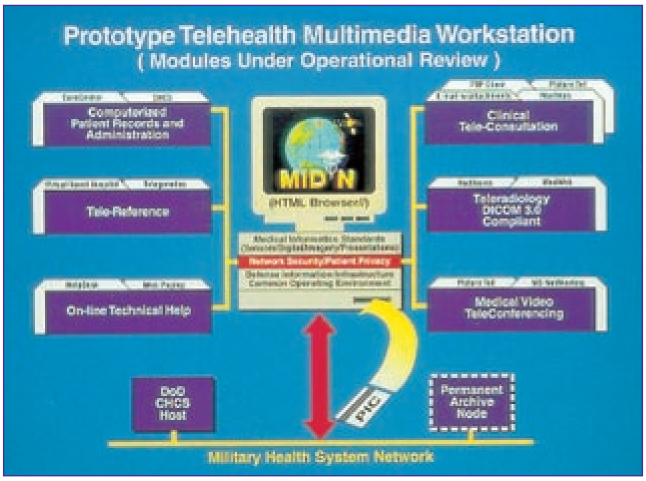
of these ships were digital cameras, which were particularly useful for diagnosing dermatological conditions. The images are of high quality and allowed the dermatologists at the NNMC to make accurate diagnoses of these conditions.

A videoconferencing facility was also available. This was most commonly used in the diagnosis of psychiatric conditions, particularly in the assessment of whether a sailor was sufficiently disturbed to require medical evacuation. The psychiatrist at NNMC could sit in an interview room and talk one-on-one with the sailor via video link and make accurate assessments of his or her psychological status. Video cameras were also fitted in the operating theatres and dental surgeries of each of the aircraft carriers. This was supposed to enable the transmission of images during complicated dental or surgical procedures, so that remote specialists could assist the surgeon or dentist on board with the performance of these procedures. Speaking to the surgeons at the NNMC and aboard the aircraft carriers, it was my impression that this capability was little used and may be removed as the system continues to evolve.

The system is also linked to the US hospital ship USNS COMFORT, and to smaller fleet units ranging from nuclear submarines to destroyers. These smaller fleet units usually only have digital data links and do not have videoconferencing facilities because of the large size of the antenna required (3 m diameter) and its associated weight (about 1200 kg). Teleconferencing also requires a higher frequency band for transmission, incurring greater costs.

The Americans have recently used their telemedicine facilities during their involvement in the Balkans war, with results being transmitted to larger base hospitals in Germany for expert assessment. The Royal Australian Navy has also trialled teleradiology during the Rim of the Pacific 2000 (RIMPAC) exercises, with images transmitted back to a receiving station at HMAS PENGUIN.

Multimedia Integrated Digital Network

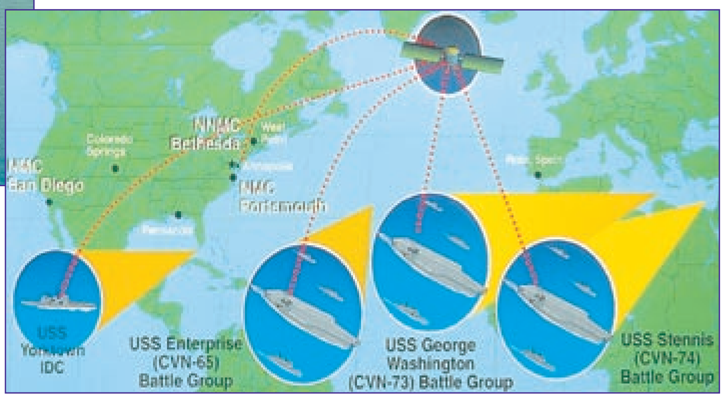


The MIDN carries a suite of telemedical services. (Image courtesy US Navy.)

Virtual Naval Hospital

One of the most frequently used aspects of the US MIDN system is the Virtual Naval Hospital (www.vnh.org). This Internet-based information system is a comprehensive reference resource with detailed information on almost any medical, dental or nursing problem. It also contains detailed information in relation to the administration of the US Navy Medical Department. It is freely used in the training and continuing medical education of the entire department from sailors through to officers.

In the first month of its installation in March 1997, there were only 197 hits on the website and 1000 pages of information were available. In March 1998, the website was accessed 60 000 times from nearly 12 000 different sources,



US Navy carrier battle group

The group shown has two aircraft carriers, rather than the usual one, but is otherwise typical. Carrier battle groups are connected to the NNMC by satellite links which provide, among other things, a growing range of sophisticated telemedical services. (Images courtesy US Navy.)

Diagnosis at a distance

A digital camera image of a suspicious lesion was transmitted from a US Navy vessel to the NNMC, where an accurate diagnosis was rapidly made. (Image courtesy US Navy.)

accessing nearly 57 000 pages of information. Of the users, 44% were in the US military, 50% were US civilians and 6% were international users, of which 40% were Australians.

The easy availability and the comprehensive nature of the information in the Virtual Naval Hospital will quickly make reference libraries irrelevant, providing a considerable saving in cost, space and time. The information can be easily and continually updated as new techniques are developed.

The future

As the costs of electronic information technologies continue to fall, and their speed and accuracy continue to increase, then the prospects for the future are indeed exciting. Australia is a large continent with a sparsely spread population, and these technologies have the potential to provide a wide range of specialist services to communities which were previously denied this level of sophistication. This has implications for the ADF as well as for civilian communities.

The United States Armed Forces are already pursuing the computerisation of all health and personnel records. Smartcard technology is available which might in future allow individual service members to carry a complete personnel and health record on a card the size of a conventional credit card. This would avoid the need to transfer bulky and heavy personnel and health documents from establishment to establishment. This smart card could be updated as the person's health and personal situation changes. The implications for units where space and weight is a priority are very exciting. In particular, ships and deployed army units would benefit greatly. Imagine the amount of space and weight that could be saved if all the health, personnel and administrative documents on board a destroyer were totally computerised.

If we are to go down this pathway, there will be a huge initial capital outlay, but the savings in terms of manpower and space are equally enormous. With the ADF increasingly functioning in a triservice format, it is vital that all three services have the same information technology system so that interchange of personnel occurs easily. The defence health computer system will also need to be compatible with other computer information systems used in the ADF. The fact that systems are DICOM 3.0 compatible does not mean that they are interchangeable, and it is crucial that the same operating system is used throughout all three services. In the US the services have individually developed their own systems and unification is now a very expensive if not impossible task.

An exciting and at the same time daunting future lies ahead for the ADF as it tries to find the best means of using computer technology to improve service life. The ultimate goal should be a totally paperless personnel records system integrated within a computerised administration system.

Acknowledgement

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