Digital storage and retrieval: the future in echocardiography

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It seems we have been on the threshold of the digital revolution in echocardiography for some time and yet the vast majority of echocardiographic studies are still stored and reviewed from videotape. Why should this be? Several large echocardiography laboratories have had digital storage for over a decade now, and the capability for sophisticated all digital storage and retrieval is being offered by several vendors. Nevertheless, there is an “energy of activation” that most laboratories have not been able to muster to make the leap into the digital era of echocardiography. This review article outlines the state of the art in digital echocardiography, covering formatting standards, compression choices, and advances in computer instrumentation. It is hoped that this will provide a practical guide to the choices that we as echocardiographers have to make as we move into the era of digital echocardiography.

Advantages of digital echocardiography

First, one must ask the question “why convert to digital echocardiography at all?” There are several major advantages to digital storage and retrieval. First, digital echocardiography studies can be reviewed much more easily than videotaped ones. It is possible to organize the study by views and modalities and thus move very quickly from parasternal to apical views without tedious searching on the VCR. This advantage is more obvious when comparing with previous studies. Despite the obvious need for side-by-side comparison of serial studies, this is rarely done with analogue storage, and yet it is extremely easy when studies are stored digitally. The second major advantage is improved delivery of echocardiograms. Too rarely do referring physicians review the actual echocardiographic data on studies they have ordered. With digital storage, echocardiograms can be viewed, at least in abbreviated form, anywhere in the hospital. Third, digital storage preserves quality in echocardiograms better than analogue storage. The videotape process produces significant distortions in both the spatial resolution and colour fidelity of images. This problem is compounded when videotapes are copied. With successive copying, image degradation is profound, while digital copies can be made repeatedly with no degradation. Even without successive copying, videotape images degrade over time, as the magnetic particles on the tape lose their alignment. The improved quality of digital echocardiograms is also manifest in their quantitative potential, as calibration data can be stored for distances, times, and velocities. This allows improved off line computer analysis and image processing. Finally, digital storage greatly facilitates tele diagnosis. When echocardiograms are transmitted digitally, either via network or disk, the referral hospital has access to all the primary data on the patient and need not repeat these studies. Thus, there are abundant reasons to push for digital echocardiography. Now we must figure out how to get there.

State of the art

FORMATTING STANDARDS

A few years ago the echocardiographic community was in a state of chaos with regard to formatting standards. The major echocardiography vendors had each adopted unique and incompatible file formats and none of these was compatible with the current standard for storage in radiology—ACR-NEMA (American College of Radiology-National Electrical Manufacturers Association) 2.0. That situation has completely changed as all major echocardiography vendors and off line storage companies have cooperated to formulate and adopt the DICOM (Digital Imaging and Communications in Medicine) 3.0 standard, developed as a successor to ACR-NEMA 2.0. The end user need not be concerned with the details of the DICOM Standard, it is simply a set of rules that specify how echocardiography images are to be transmitted over a network or stored on disk, together with identifying information such as patient name and image calibration. Although DICOM was initially formulated as a networking standard for radiographic instruments, it has seen its initial application in echocardiography in disk storage of images. The currently approved storage media for echocardiograms are: 144 MB floppy disks, 3½ and 5½ magneto-optical disks, and CD-R writable compact disks. The floppy disks are useful for storage of isolated images or very small studies, while the magneto-optical devices allow storage of multiple studies and have rewritable capability, allowing them to be used as a transfer medium between echocardiography machine and a larger network. The CD-R can only be written to once, and thus provides permanent storage for echocardiograms and is compatible with the storage standard for x ray angiography. It should be emphasised that the DICOM Standard specifies how images should be exchanged between users and does not in any
way dictate how images should be archived within a given laboratory. Indeed, high capacity digital tape may be the most efficient long term archival medium for echocardiograms, although this is not specified within DICOM.

**COMPUTER PROGRESS**

Moore’s Law hypothesises that the price performance ratio of computer technology doubles approximately every 18 months, a phenomenon that has been observed with remarkable consistency since the 1950s. Indeed, if the automobile industry had shown the same degree of progress in the past 30 years, the price of a new car today would be less than one penny. Considering only the past four years, using advertisements for high end personal computers in a major computer magazine, we note the following: the processor has advanced two generations from the Intel 80486 to the Pentium Pro; the processor speed has increased from 33 MHz to 180 MHz; standard memory has increased from 8 to 32 MB; standard hard disk storage has increased from 340 to 3000 MB; video graphics sophistication has doubled in memory; standard software has progressed tremendously; and common peripheral features include high speed CD-ROM readers. Despite this profound improvement in performance, the advertised price of these systems has actually dropped from £2337 to £1565. It is clear that Moore’s Law is still alive and well!

**COMPRESSION**

A topic of intense interest in the echocardiographic community is the acceptability of digital compression of echocardiographic images. To understand the need for compression, one must recognise that full colour, full screen echocardiograms (30 frames per second) require close to 30 MB of storage per second, or close to 20 GB of storage for a 10 minute study. Clearly, there must be careful editing of the clinical content of these studies, and selective storage of single cardiac cycle loops—especially in quad screen format—for storage need never exceed 100-fold. Additionally, digital compression of the files will gain a further significant increment in storage capacity and transmission speed. Digital compression may be either lossless or lossy, and both types are acceptable within DICOM Standard. For lossless compression, there is no concern about image quality, as the original image can be reconstructed on a pixel by pixel basis without any loss of data. The DICOM Standard specifies a run length encoding algorithm called Packbits, whereby repeated pixels with the same value are encoded very efficiently. This is especially effective for the large areas of blank space around the echo sector on the image and can result in compression ratios of 2 or 3:1.

To gain more significant compression, lossy algorithms must be used and DICOM currently specifies only the JPEG (Joint Photographic Expert Group) algorithm for lossy compression of echocardiograms. The JPEG algorithm divides each image into a series of 8 x 8 pixel blocks and then performs a discrete cosine transformation on each block (similar to a Fourier transformation converting spatial intensity data into spatial frequency data). The compression is achieved by discarding the high frequency components of each pixel block and then run length encoding the resulting data for even greater compression. By varying the frequency cut-off point the compression ratio can be varied from about 7:1 to close to 100:1. Several recent studies have demonstrated that JPEG compression of echocardiograms at 20:1 does not impact their clinical interpretation. This has been shown in quantitative assessment of image quality, in the recovery of quantitative velocity data from colour maps, and in a randomised trial of 179 observers in the 1994 American Society of Echocardiography meeting. In that study, observers were presented with identical echo loops playing side by side on a computer, one derived from digitised videotape the other from direct data, directly digitised from the echocardiography machine. Viewers overwhelmingly selected the original digital images over the videotape images both for image quality and clinical content, and this preference was not impacted in any way by JPEG compression at 20:1. JPEG has also been shown to be acceptable in clinical trials of other high resolution imaging modalities such as nuclear and ultrasound imaging.

There are a number of other compression algorithms that may be very attractive for application in echocardiography, although they have not yet made it into the DICOM Standard. Because echocardiography consists of moving images with relatively little change on successive frames, compression algorithms that exploit redundancy between video frames would be expected to have superior performance compared with single frame algorithms such as JPEG. Among the multiframe compression standards are the video conferencing standard H.261 and the Motion Picture Expert Group (MPEG) algorithms, MPEG and MPEG-2. The original MPEG standard was based around the data transfer rate of a 1 x CD-ROM reader (150 KB per second) and thus provides close to 200:1 compression compared with full storage video. Where higher transmission speeds are required, the MPEG-2 algorithm provides significantly higher quality images but with a reduced compression ratio. It should be noted that the clinical acceptability of MPEG compression of echocardiograms has not been demonstrated in any published study to date, although a pilot study has reported encouraging results. Also, it is not currently an acceptable transfer syntax within the DICOM Standard, although efforts are underway to have it included in an amendment to DICOM.

Among other compression algorithms worth considering in echocardiography are wavelets, fractals, and the lapped orthogonal transformation. The lapped orthogonal transformation avoids the problems of JPEG (which may have visible artefact from the pixel blocks) by overlapping the individual compression blocks. Wavelets are similarly based upon
reducing an image to its component frequencies, but have the advantage that images may be sent at multiple resolutions, with the initial data providing an overall image and later data improving the detail resolution. This compression technique has been shown to be clinically acceptable for radiographic images. Finally, fractals are based on reducing the image to a group of self-similar features that are replicated throughout the image. The ultimate role of any of these algorithms in echocardiography remains to be seen.

**Practical aspects of digital echocardiography**

While many formatting and compression issues remain to be clarified, these are largely the domain of researchers and international standards organisations. However, there are a number of practical issues that each echocardiography laboratory will have to face as it converts to digital storage. The following discussion may assist users in their discussions with vendors in seeking a digital storage solution for their laboratory.

**CHOICES IN ECHO EXPORT**

One of the major hindrances to converting to digital storage is the presence of legacy systems within a laboratory that do not have digital storage capability. The only way to integrate these into a digital laboratory is with video frame grabbing, and several vendors offer off line digitisation equipment that converts video images into DICOM compatible files. More advanced digital storage is currently offered by writing echocardiography data directly onto magneto-optical disks. While many vendors still store these data in the proprietary standards of 1992, most are in the process of converting to DICOM compatible storage. With this type of output, it is possible to move echocardiograms from the machine to a computer network using the magneto-optical disk as a “sneaker net”. The ideal future situation for digital echocardiography would be a direct network connection from the echocardiography machine to a hospital based archival system. The DICOM Standard provides a robust set of network protocol tools to allow the remote reading and writing of DICOM images over a network. While no echocardiography vendor has fully implemented such a network based storage solution, most are in the process of developing one.

**CHOICES IN FILE STORAGE**

To balance the need for rapid access to clinically relevant data with the requirement for high capacity, low cost, long term storage, a hierarchical storage solution will be necessary for most laboratories. This may be considered as a pyramid of storage (fig) with very rapid access but relatively expensive video RAM (random access memory) and hard disk storage at the top of the pyramid, and relatively slow but very cost effective digital tape at the bottom. An effective strategy for assuring access to data when it is needed would be to search for all patients scheduled for echocardiographic examination the following day. They would have all prior echocardiography studies uploaded from the tape archive onto hard disk storage and be thus available for review with their current study. Similarly, whenever a patient was admitted to the hospital, all prior data could be uploaded from archive to short term storage.

**WHAT TO STORE?**

A fundamental choice to be made in digital echocardiography is whether to follow the paradigm of the VCR by providing long recordings of echocardiography data played from a video server or to limit storage to a single or a few cardiac cycles played over and over in a loop. While there are a few circumstances where prolonged segments may be necessary (sweeps in congenital heart disease and some transoesophageal echocardiography studies), for the most part echocardiography studies are efficiently summarised by several well selected cardiac cycles from all standard echocardiographic windows. With such a strategy and a fairly modest degree of JPEG compression, a very thorough study with complex pathology could be stored in fewer than 30 MB of data. With a high speed hospital network (100 megabits per second), such a study could be transmitted in two to three seconds. Furthermore, with the price of hard disk storage falling progressively, it is not unreasonable to maintain on line access to 30 GB of data (or more), permitting up to 1000 studies to be within immediate access. For longer term storage, digital tape cartridges with a capacity of 50 to 100 GB are available at an average cost of £12, implying that each echocardiography study could be archived for less than one cent. Several small video server companies have demonstrated playing MPEG echo images in real time over a network, but these in general have not been single loops, but rather long sequences that may require excessive storage space and be more difficult to review rapidly. While MPEG is a very attractive compression
standard, its use should not preclude storage of isolated cardiac loops, which bring tremendous benefit in their own right in data compression and ease of review.

CHOICES IN TELECOMMUNICATIONS

The networking standard for most hospitals remains the Ethernet, which nominally has a maximum transfer speed of 10 megabits per second, though in reality the transfer speeds are often significantly less than this. For digital review over a network, it is essential that higher speed links are available, such as fibre-optic cabling, or high speed copper cabling, with transfer speeds of 100 megabits per second. Increasingly, hospitals will convert to even higher speed networking using Asynchronous Transfer Mode (ATM) protocols with speeds up to 622 megabits per second.

For transmission between institutions, the revolution in telecommunications will insure that echocardiography transmission will become increasingly cheaper in the next few years. Currently, most digital access would be via modem to a standard telephone service, allowing transfer speeds up to 33.6 kilobits per second, requiring several hours to transfer a 30 MB study. Speeds up to 128 kilobits per second can be obtained by ISDN, which is available in most communities for slightly more than the cost of a standard telephone line. The fastest standard telephone link is via a T1 line, providing 1.54 megabits per second of bandwidth and permitting real time transfer of compressed video images. Unfortunately, T1 lines have traditionally been available only as full time leased lines, costing about £500 a month. It is anticipated that this cost will fall considerably over the next few years. The Internet provides a very attractive possibility for image transmission, with very low costs and relatively fast transmission speeds, provided the hospital provides a high speed access onto the Internet trunk. Even connections to residential areas should be improved by several orders of magnitude with the widespread implementation of cable modems, which allows Internet access via cable TV connections at speeds up to 30 megabits per second. There are several concerns about Internet transmission of medical data, primarily in the security realm. As Internet data passes through a number of servers on its way from one point to another, it is possible that confidential medical data could be intercepted at some point in the transmission process. Thus, strategies for encryption of data will need to be perfected before this can be used in common practice. Nevertheless, the paradigm of the world wide web is very attractive for delivering echocardiography images. One can issue echocardiography reports in HTML (Hyper Text Mark-up Language), containing both the textual interpretation along with links to selected images of the examination. These could be conveniently reviewed by the referring physician using any web browser.

Conclusions

So what should a laboratory do when approaching digital echocardiography. The hallmark should be adherence to standards and the use of open architecture. The DICOM Standard provides a clear reference to which vendors should be held. It is essential that each component of a digital echocardiography laboratory provides DICOM input and output, so that the user is allowed to mix and match various echocardiographic instruments with selected network review strategies. The use of standard computer equipment is also important, as this provides the most cost effective approach and allows the flexibility to switch to new architectures as they come along. Clearly, if one were able to begin an echocardiography laboratory from scratch, there are a variety of ways that digital storage can be implemented. The challenge is to evolve into a digital laboratory while utilising the analogue equipment that is already present. To use this equipment effectively while growing towards an all digital laboratory requires careful collaboration with vendors and the information services department of the hospital. Once established, however, it should be possible to achieve the goal of digital storage of all echocardiograms within a few years.

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