Gerard R. Manecke, Jr, MD
Marco Ranucci, MD
Section Editors

Electronic Storage of Echocardiographic Images: From Clips to Bits

Ronald A. Kahn, MD

WHILE THE DEVELOPMENT and implementation of echocardiography have advanced rapidly over the last few decades, the storage of these images also has evolved substantially. Early images were stored using static photographic techniques, which limited the representation of dynamic images. With the increased availability of video technology, videocassette recording (VCR) became the prevalent method of image storage. However, this technology is limited by its sequential nature (limiting random access of images both within as well as among studies), physical storage requirements, and propensity for degradation of images over time. The increased affordability of both digital computing hardware and software has allowed the digital storage of echocardiographic images. In this review, the advantages of digital storage of images, the validation of digital storage in the interpretation of echocardiographic examinations, the concepts and language of echocardiographic image storage, and the necessary components for the establishment and operation of a digital echocardiographic storage system are discussed. This review is meant to provide the clinician with the basic concepts and terminology for effective communication with both potential vendors and members of his/her information technology department during the acquisition, development, and operation of a digital storage solution; it is not meant to be a comprehensive review of the subject.

THE ADVANTAGES OF DIGITAL STORAGE OF ECHOCARDIOGRAPHIC EXAMINATIONS

Although the digital storage of echocardiographic images has increased the complexity of study storage, The American Society of Echocardiography (ASE) and others have suggested that digital storage has advantages over other modalities (Table 1).[1,2] They include the following:

1. More efficient reading: with the use of VCR tapes, the echocardiographer needs to review the entire 10 to 30 minutes of the study, which includes both important as well as redundant information. Using digital storage, the echocardiographer can direct his/her attention to specific clips, data may be accessed randomly, and the noncontributory segments of the study need not be viewed.
2. Because the studies are stored on a central server, the echocardiographer may read studies at any location that contains a workstation. When the storage system is properly configured, studies may be read on campus via institutional intranet connections or even may be read off-site.
3. Because of study centralization, indexing, and archiving in digital storage systems, previous studies may be accessed rapidly for comparison to a current study. The need to rummage through racks of old videotapes and search for a specific study is eliminated. This centralization of studies decreases the inefficient use of clinical staff time retrieving and loading physical media such as VCR tapes or digital media. Because these older studies are more easily available, there is a decrease in unnecessary duplication of procedures and more optimal patient care.
4. Because the Digital Imaging and Communications in Medicine (DICOM) file header contains information about the acquisition of the study, spatial, temporal, and velocity calibration are included with each image, quantification may be accomplished rapidly within the analysis program without special tools.
5. More convenient communication with the referring physician may be facilitated, because the study images may be included easily with the report.
6. The standard resolution of video home system (VHS) images is equivalent to 480 × 320 pixels, whereas the standard resolution of super VHS (sVHS) is equivalent to 560 × 480 pixels. Digital images provide an improved resolution of 640 × 480 pixels or greater, which are exactly as they are recorded by the ultrasound machine. There is no degradation in the transfer of images from the ultrasound machine to the digital storage systems as will occur with videotape transfer.
7. Over time, videotape degrades. There is magnetic realignment of the VCR tape with resultant degradation of image quality. Digital echocardiographic storage provides a more stable image quality.

From the Department of Anesthesiology, The Mount Sinai Medical Center, New York, NY.
Address reprint requests to Ronald A. Kahn, MD, Department of Anesthesiology, Box 1010, Mount Sinai Medical Center, One Gustave L. Levy Place, New York, NY 10029. E-mail: ron.kahn@mssm.edu

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Table 1. Advantages of Digital Echocardiographic Storage[1,2]

1.	More efficient reading
2.	The ability to read studies in a variety of locations
3.	Easy comparison with previous studies
4.	Easier quantification
5.	Ability to include images with reports to referring physicians
6.	Higher image quality
7.	No image degradation over time
8.	Lower physical space requirements compared with VCR tapes
9.	Integration of the images and reports within the hospital's electronic medical record
10.	More robust research
11.	Easy implementation of a clinical performance improvement program
12.	Improved accuracy and reproducibility overall
13.	Greater facilitation of medical education
14.	Decreases in medicolegal risk

8. The physical storage of a VCR requires significant space, which is usually a premium in either a hospital or office environment.
9. The echocardiographic reports may be incorporated within the hospital's electronic medical record.
10. Because the highest quality images are available, more robust research may be performed. Communication with core laboratories is simplified.
11. A clinical quality-assurance program easily may be implemented, whereby echocardiograms can be re-reviewed randomly on a regular basis. If consultation is necessary, sharing studies with colleagues both within and outside of the institution easily can be accomplished over digital networks.
12. Because physicians may be directed to the important aspects of the echocardiographic examination, there is improved accuracy and reproducibility of echocardiographic examinations.
13. Because moving images easily can be incorporated into presentations, there is greater facilitation of medical education.
14. Because studies may be retrieved easily and reliably, medicolegal risk is reduced.

The increased efficiency of digital reading of echocardiographic studies has been shown by Mathewson et al,[3] who timed study acquisition and analysis during approximately 750 pediatric echocardiograms. As a group, the digitally captured images contained more hemodynamic measurements and, hence, required more time for acquisition. The average times for study acquisition were 26.0 $\pm$ 8.9 minutes for videotape and 28.4 $\pm$ 11.5 minutes for the single-beat digital method. In contrast, interpretation of these studies was more rapid using digital methods with an average interpretation time of 6.5 $\pm$ 3.7 minutes for the videotape compared with 4.6 $\pm$ 3.9 minutes for the digital method.

IMAGE TERMINOLOGY

Image Creation

The basic digital representation of data is the bit, which represents an "on" or "off" state. These bits are grouped into units of 8 binary characters, which is termed a "byte" and can represent numbers from 0 to 255 (2^8). A bit is usually represented by the lower case "b," whereas a byte is usually represented by the upper case "B." A kilobyte (KB) is 1,024 (2^{10}) bytes and not exactly 1,000 bytes. A megabyte (MB) is 1,024 kilobytes, a gigabyte is 1,024 megabytes, and a terabyte (TB) is 1,024 gigabytes. A single static echocardiographic image is rendered by a number of dots or pixels on a screen. The image resolution is defined by the number of columns and rows of pixels displayed, which are typically 640 and 480, respectively, for medical ultrasound. Each pixel of the image is described by its red, green, and blue component, which is represented by 3 bytes of data; each of these bytes contains a number from 0 to 255, which represents the level of the pixels' primary colors. If there are 256 possible levels for each of these 3 primary colors, a total of 16.8 million colors (256^3) may be represented. A video clip consists of a series of sequentially displayed static images. Most echocardiographic video clips have approximately 30 frames per second. If no methods of compression are used, the storage requirements for digital storage of echocardiographic clips become huge. A single image would require 921,600 bytes of data (640 columns $\times$ 480 rows $\times$ 3 bytes per pixel). If a 30 frame per second temporal resolution is used, an uncompressed 10-minute examination would require 16,588,800,000 bytes or 15.4 gigabytes of storage.

Clinical Compression

Because of these space requirements, clinical examinations must be subject to compression. There are 2 major categories of compression: clinical and digital. During the performance of echocardiographic examinations, many cardiac cycles may be obtained during image acquisition. During standard analog storage of examinations using VCR technologies, the tape is allowed to run continuously, capturing the entire examination. With clinical compression, short clips are stored to represent each relevant echocardiographic view. Typically, either several seconds or several cardiac cycles are recorded, which may be played back in a loop when displayed for interpretation.

Does clinical compression affect the interpretation of echocardiographic examinations? Haluska et al[4] reported high concordance between video and digital echocardiographic interpretations of adult echocardiographic examinations. Most observed discordances were minor, with lesser values being reported with the digital method. For example, degrees of mitral regurgitation were reported to be milder by digital compared with video presentation. Most major discordances were cases of assessment of aortic and mitral valve thickening and the degree of mitral regurgitation; the authors hypothesized that the major discordances were caused by undersampling and not image quality. The routine acquisition of longer video clips may not necessarily increase the accuracy of digital echocardiogram readings. Shah et al[5] evaluated 102 patients with regurgitant valvular disease, recording findings on videotape as well as digitally using 1, 2, and 3 cardiac cycles. They observed substantial agreement when the video and 1-cycle digital presentations were compared. There were no increases in agreement when 2 or 3 cardiac cycles were presented digitally.