Feasibility and clinical value of "intelligent" compression and digital storage of transthoracic echocardiograms in day-to-day practice

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Background. **The aim of this study was to assess the clinical concordance of expert cardiologists' interpretation of echocardiographic studies recorded on Super-VHS videotape or stored in magneto-optical disk, as well as the feasibility and clinical value of intelligent compression and digital storage of echocardiographic data as cine-loops and still-frames for interpretation of transthoracic echocardiographic images in clinical practice.**

Methods. **All clinical cardiologists experienced in echocardiography in our department (n = 10) reported on a standardized worksheet checklist the echocardiographic data of 7 consecutive patients (140 reports), and recorded them on videotape or magneto-optical disks to compare the interpretation of videotaped studies, acquired in the usual way, with clinically compressed studies stored to magneto-optical disks using a standard (Italian Society of Echocardiography) image acquisition protocol.**

Results. **The time interval between analog and digital study readings was 50 ± 15 days. Except for tricuspid valve regurgitation grading (k = 0.28) and for left ventricular global hypokinesia (k = 0.32), the intraobserver agreement in the interpretation of the 3290 cardiovascular morphological and functional findings found on analog and digitally stored images was good (k value ranging from 0.66 to 1.00). The wall motion score index was 1.56 ± 0.53 when interpreting analog studies, and 1.52 ± 0.54 on digital studies (p = 0.35). Conversely, the interobserver variability of the wall motion score index (Gini index ranging from 0 to 0.80) was significantly lower when interpreting studies stored digitally than when analog ones were examined (0.48 ± 0.021 and 0.52 ± 0.023 respectively, p = 0.006). In comparison to videotape recordings, digital storage of echocardiographic studies significantly shortened the time to image access for study review (327 ± 62 and 30 ± 4 s, respectively, p < 0.0001) and the reading time (600 ± 300 and 540 ± 300 s respectively, p = 0.034), rendered study accessibility easier (difficult or good: 73 vs 43% of observers, fast or optimal: 27 vs 57% of observers respectively, p = 0.0011) and improved the recorded image quality perception (poor: 25 vs 10% of observers, sufficient or good: 75 vs 90% of observers respectively, p = 0.022), without loss of study completeness (insufficient: 18 vs 17% of observers, adequate or complete: 82 vs 83% of observers, respectively; p = NS). Finally, from September 1, 1999, digital storage has become routine practice for patients admitted to our Department. By December 31, 1999, 411 echo studies had been stored: 7 ± 3 cine-loop/study, 32 ± 18 frames/cine-loop, and 3 ± 2 still-frames/study. The average amount of memory needed for storage was 18.6 ± 11.9 MB/study.**

Conclusions. **Clinical compression of echocardiographic studies seems to be an accurate summary of the complete examination recorded to videotape for the assessment of patients admitted in the coronary care unit. In addition, digitally stored studies allow a significant improvement in the interobserver reproducibility of wall motion score assessment.**

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Recent years have witnessed a dramatic innovation in the computer technology related to the management of the echocardiographic laboratory. New generation digital echocardiography machines and review workstations have become commercially available and a standard image format has been established[1]. Besides, the price/performance ratio for computer technology has improved more than 10-fold. All these innovations have put the digital storage solution within the reach of daily routine in the echo-lab.

A major limitation to the widespread use of digital media for the storage and retrieval of echocardiographic studies is the objective difficulty encountered when managing the amount of memory space required for storage of standard echocardiographic sequences. Full-motion, full-color echocardiography generates an incredible amount of data and it is estimated that 20 GB are required for a standard 10 min study.

To circumvent storage and network constraints two image management approaches can be used with the aim of minimizing the amount of data stored whilst retaining all important information: clinical and digital image compression. Clinical or intelligent image compression refers to the elimination of redundant or unnecessary data by using the acquisition of single loops for each view rather than semi-continuous videotaping in which multiple cardiac cycles are acquired for every view as well as for the transition between views. Digital image compression involves an alteration of the digital coding of the images by eliminating redundant data and image noise. Several studies have demonstrated that digital image compression at compression ratios up to 20:1 using JPEG[2-4] and 200:1 using MPEG[5,6] induce less image distortion than high-quality Super-VHS videotape, and does not affect the interpretative accuracy. However, some echocardiographers have questioned whether the selection of the representative beats to be saved as cine-loops and still-frames by the operator, as necessary when performing clinical image compression, retains the same diagnostic accuracy as that of complete videotape studies which currently constitute the gold standard. Several investigators addressed this concern and found that experienced sonographers can select representative echocardiographic cine-loops and still-frames whilst still maintaining the same diagnostic accuracy as fully Super-VHS videotape studies[6-12]. However, in these studies echocardiographic study review was performed by a few well-trained and highly motivated echocardiographers while, in the clinical arena, the clinical accuracy of digitally stored as compared to analog recorded echocardiographic studies remains to be addressed.

To address this issue, we designed this prospective study with the aim of determining whether digital storage and review of routine echocardiographic studies of patients admitted in a cardiology unit is feasible and whether it maintains its diagnostic accuracy when read by experienced clinical cardiologists too.

Table I. Standard protocol of echocardiographic digital image acquisition used in our echocardiographic laboratory.

Cine-loops (1 cardiac cycle if sinus rhythm/3-5 cardiac cycles if significant arrhythmia)
Parasternal views: long-axis, basal level short-axis, papillary muscle level short-axis
Apical views: 4-chamber, 2-chamber, long-axis
Subcostal 4-chamber view
Valve regurgitant jets
Still-frames
Aorta and left ventricular M-mode tracings
Mitral valve flow Doppler tracing
Any other clinically significant cine-loop or still-frame

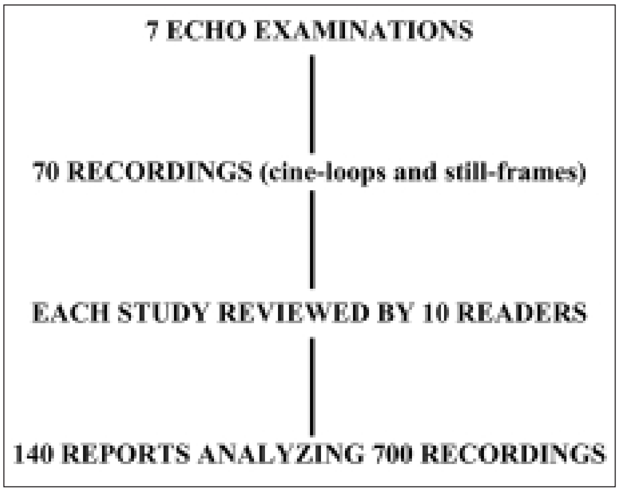

Figure 1. *Flow-chart of the study.*

Methods

Our study was planned in two phases: 1) the evaluation of the diagnostic accuracy of digitally stored echocardiographic studies acquired using a minimum acquisition protocol (Table I, Fig. 1); 2) the evaluation of the feasibility of digital storage and retrieval of routine echocardiographic studies obtained from patients admitted to our coronary and stepward care units.

Diagnostic accuracy of digitally stored transthoracic echocardiograms. To address the specific issue of the diagnostic accuracy of digitally stored echocardiographic studies when read by clinical cardiologists, complete echocardiographic studies obtained from 7 consecutive patients and simultaneously recorded both digitally as well as on videotape were reviewed by all the clinical cardiologists experienced in echocardiography in our Department (n = 10) with the exclusion of the two of us who were directly involved in the implementation of the digital echo lab (LPB, MW). The average echocardiographic reading experience of the reviewer after specialization was 12 ± 7 years (range 3-22 years). Echocardiographic studies were obtained using an Agilent Technologies Sonos 2000 Imaging System (Agilent Technologies Co., Andover, MA, USA) equipped with multifrequency 2.5 and 3.5 MHz phased array transducers. They were directly stored onto a 1.2 GB magneto-optical disc (EDM-1200B Sony, Tokyo, Japan) in a file format (HP Sonos DSR format, an extended tagged imaged file format-TIFF) commonly used in clinical practice, and proprietary to Agilent Technologies. Digital loops of single or multiple frames were acquired on line by one of us (LPB) and using a minimal acquisition protocol derived from a standard (Italian Society of Echocardiography) image acquisition protocol[13] (Table I). In addition to images acquired according to the protocol described in table I, we were free to acquire any additional normal findings only if they were significant for that specific echocardiographic examination. All loops consisted of 1 cardiac cycle for patients in sinus rhythm, and of 3 to 5 cardiac cycles for patients with significant cardiac arrhythmia. Images were stored in lossless format using a run length-encoding scheme called "pack-bits" and commonly used in TIFF. The capability for storage saving of this fully reversible type of compression is 2:1 to 3:1[1]. Simultaneous one half-inch Super-VHS videotape recordings were obtained from the same patients in a standard fashion using a Panasonic Super-VHS videocassette recorder (model AG-MD830). The reviewers were blinded to the patients' identities and to all clinical data, except for the indication to echocardiography. The loops and the tapes were read separately in random order and over a period of weeks in order to minimize observer recall. The digitally captured loops were played over and over, as long as it was necessary for the reviewer to make a diagnosis on a personal computer (HP Vectra Pentium 266 MHz, 1.4 GB hard drive, 64 MB of RAM, SCSI adaptec + magneto-optical disk drive, SureStore Optical 5200ex) with a Super-VGA monitor. The software used to visualize native digital echocardiographic images (512 × 512 pixels with 256 gray levels) was DSR (Digital Storage and Retrieval, Agilent Technologies). The analog tapes were reviewed in the usual manner and could be cued back and forth as required. The results of the echocardiographic study reviews were reported on a standardized worksheet checklist. Segmental wall motion was analyzed according to the scoring system of the American Society of Echocardiography that divides the left ventricle into 16 segments[14]. The wall motion in each segment was graded as either normal, hypokinetic, akinetic, dyskinetic, or aneurysmal. A wall motion score index reflecting the extent and severity of the dyssynergy was also calculated. Valvular disease was evaluated using two-dimensional and Doppler echocardiographic data. For the purpose of this study, echo reviewers were not asked to determine the exact degree of a valvular stenosis, but to determine a given patient's triage on the basis of the presence or absence of valvular stenosis. Aortic, mitral and tricuspid regurgitation were qualitatively assessed with spectral Doppler and color flow imaging. When reporting the results of the echocardiographic study examination, in addition to the checklist the reviewers were also asked to complete a questionnaire regarding the relative study accessibility, stored image quality and study completeness of digitally stored and analog videotaped echocardiographic examinations (Table II).

Table II. Relative study accessibility, stored image quality, and study completeness of videotape recorded and digitally stored echocardiographic studies.

	Super-VHS videotape (n=70)	Magneto-optical disk (n=70)	p
Study accessibility			
Difficult	16	2	< 0.0001
Good	33	27	
Fast	19	31	
Optimal	1	7	
Recorded image quality			
Poor	17	7	0.022
Sufficient	37	40	
Good	13	21	
Study completeness			
Insufficient	12	12	NS
Adequate	40	41	
Complete	16	16	

Feasibility of routine digital storage of transthoracic echocardiograms. Having determined that the diagnostic accuracy of our minimal image acquisition protocol for digitally stored echo studies was sufficient for routine clinical practice, we assessed the day-to-day feasibility of digital storage of routine clinical transthoracic echocardiograms. To address this issue, all patients admitted to our coronary care unit and/or semi-intensive care unit between October 1st and December 31st, 1999, who underwent routine echocardiographic examination were enrolled in the study.

Data analysis. Reports were databased and matched. Computerized reports were analyzed by comparing individual findings. Data were analyzed according to the anatomical structure. Findings that were explicitly recorded in one report but not mentioned in the matching report were not considered in the analysis of data. The intra-reader agreement for digital and videotape findings was assessed with a weighted k statistics and graded as follows: 0 to 0.2 = poor to slight; 0.21 to 0.4 = fair; 0.41 to 0.6 = moderate; 0.61 to 0.8 = substantial; 0.81 to 1.0 = nearly perfect[15]. The inter-reader concordance for segmental wall motion analysis was assessed by using the Gini's heterogeneity index[16]:

$$S = 1 - [(N_1/N)^2 + (N_2/N)^2 + (N_3/N)^2 + (N_4/N)^2 + (N_5/N)^2]$$

where $N_{1\rightarrow5}$ is the number of interpreters assigning a score which can be 1, 2, 3, 4, or 5 for a given left ventricular wall segment, and N is the number of interpreters evaluating that particular left ventricular wall segment. In case of 5 possible scores for wall motion analysis[14], the value of S may range from 0 (minimal heterogeneity, i.e. perfect agreement between interpreters) to 0.80 (maximal heterogeneity, i.e. no agreement at all between observers).

Statistical analysis was performed using the statistical software package SPSS V6.1 (SPSS, Inc. Chicago, IL, USA). Continuous variables were reported as mean value ± SD and analyzed using one-way analysis of variance. Dichotomous or qualitative variables were reported as percentage and analyzed using the uncorrected McNemars test. Values ≤ 0.05 were considered as statistically significant.

Results

Comparison of digital acquisition with videotape recordings. Digital storage of the seven echocardiographic studies averaged 7 ± 3 cine-loops (each loop being composed of 32 ± 18 frames), and 3 ± 2 still-frames, and required 18.6 ± 11.9 MB per exam. The average length of each videotape recording was 7 ± 2 min. Five patients had impaired left ventricular regional wall motion, and 2 patients had valvular heart disease. The time interval between digital and videotape study readings was 50 ± 15 days. Therefore, it would seem that any training effect was excluded. The average time for image retrieval and display was 30 ± 4 s for digital, and 327 ± 62 s for videotape studies ($p < 0.0001$). The average time for thorough review of the echo studies for final diagnosis was 540 ± 300 s for digital. and 600 ± 300 s for videotape studies ($p = 0.034$). The relative study accessibility, stored image quality, and study completeness of digitally stored and videotape recorded echocardiographic studies given by all 10 clinical cardiologists for all two-dimensional and color Doppler echocardiographic images are summarized in table II. The access to images was easier, and the image quality was better for echocardiographic studies stored on magneto-optical disc than for those recorded on Super-VHS videotape. In addition, the effect of the clinical compression of the echocardiographic studies in single cardiac cycle cine-loops and still-frames on the study completeness was similar to that of traditional videotape recordings (Table II).

There was a total of 3920 findings recorded in the 140 study reports paired by reader, giving an average of 28 findings per study. An average of 6 findings per study were abnormal, and in no study did the clinical cardiologist observe completely normal findings. Tables III and IV display the intra-reader agreement (weighted k values) comparing the two-dimensional findings for Super-VHS videotape recordings and for magneto-optical disk stored studies given by all 10 clinical cardiologists for all two-dimensional and color Doppler echocardiographic images. For most of the morpho-functional findings tested, the agreement between videotape and magneto-optical disk was substantial or nearly perfect. The only two findings where the agreement between videotape and digital images was rated fair were the degree of tricuspid regurgitation and the presence of diffuse hypokinesia of the left ventricle ($k = 0.28$ and $k = 0.32$, respectively). The average left ventricular wall motion score index was similar regardless of whether the images examined on videotape or on magneto-optical disk (1.56 ± 0.53 and 1.52 ± 0.54, respectively, $p = 0.35$). However, when we evaluated the interobserver agreement regarding the wall motion score for all 1120 left ventricular segments examined (7 studies × 16 segments × 10 observers) using the Gini index, we found a significantly improved agreement between the 10 observers when they examined images stored on magneto-optical disk than when they viewed the videotape (Gini index 0.48 ± 0.021 and 0.52 ± 0.023, respectively, $p = 0.006$).

Table III. Comparison of valvular abnormalities as interpreted using videotape and digital recordings.

	Super-VHS videotape	Magneto-optical disk	k
Mitral valve			
Stenosis	1	1	1.00
Regurgitation			0.73
Mild (1+)	19	13	
Moderate (2+)	15	23	
Severe (3+)	0	0	
Prolapse	1	1	1.00
Thickening	17	18	0.67
Calcified	5	6	0.92
Aortic valve			
Stenosis	4	7	1.00
Regurgitation			0.66
Mild (1+)	26	22	
Moderate (2+)	5	4	
Severe (3+)	0	0	
Thickening	32	28	0.50
Calcified	8	9	0.66
Tricuspid valve			
Stenosis	0	0	1.00
Regurgitation			0.28
Mild (1+)	11	9	
Moderate (2+)	9	6	
Severe (3+)	3	0	
Thickening	1	1	1.00

Table IV. Comparison of morpho-functional findings as interpreted using videotape and digital recordings.

	Super-VHS videotape	Magneto-optical disk	k
Left atrium			
Dilated	39	38	0.73
Left ventricle			
Dilated	12	18	0.69
Rounded	7	6	0.74
Hypokinetic	7	4	0.32
Wall motion abnormalities	41	43	0.85
Right ventricle			
Dilated	7	6	0.81
Hypokinetic	1	1	1.00
Wall motion abnormalities	1	1	1.00

Use of digital storage of transthoracic echocardiographic studies in daily clinical routine. From September 1st to December 31st, 1999, all echocardiographic studies performed on 411 in-patients admitted to our coronary or stepward care units were stored on magneto-optical disks. The clinical indications for the performance of the echocardiographic examination are listed in table V. On average, each study was composed

Table V. Clinical indications for echocardiographic examinations performed. In-patients evaluated between September 1st and December 31st, 1999.

Acute myocardial infarction	53
Coronary artery disease	257
Congestive heart failure	63
Cardiomyopathies	9
Endocarditis	2
Valvular heart disease	15
Evaluation of prosthetic valves	7
Pericardial effusion/tamponade	3
Cardiac tumor/masses	2

of 9 ± 3 cine-loops and 3 ± 2 still-frames. In comparison to the standard protocol of echocardiographic digital image acquisition used in our echo-lab which recommends the storage of at least 7 cine-loops and 3 still-frames, we stored < 7 cine-loops/examination in 46% of our 411 in-patients, and > 7 cine-loops/examination in 38% of our study patients. In no case did the patient's clinician or the consulting cardiac surgeon judge the images insufficient and require that the echo study be repeated. The computer memory occupied per exam stored was 14.8 ± 7.2 MB. Therefore, each magneto-optical disk can store 85 ± 6 echo studies at a cost of € 0.393/echo study. For comparison, we examined the use of videotape for the recording of studies of patients evaluated in the previous 6-month period. On average, each 180 min Super-VHS videotape could store recordings from 45 ± 4 echo studies at a cost of € 0.131/echo study.

Discussion

The results of this study show that clinical compression and digital storage of echocardiographic studies are feasible and that they allow efficient storage and retrieval of data. Besides, the diagnostic accuracy so obtainable is comparable to that of standard Super-VHS videotape recordings, even in the clinical arena. The latter statement is based on the substantial agreement observed between analog and digital study interpretations performed by a panel of clinical cardiologists experienced in echocardiography. Furthermore, according to this panel, digital storage of echocardiographic images significantly shortened the time to image access for study review, significantly decreased the reading time, made study accessibility easier and improved recorded image quality perception without loss of study completeness. In addition, digital reviewing of echocardiographic studies stored on magneto-optical disks allows a significantly improved interobserver reproducibility of important functional parameters such as the left ventricular wall motion score.

Digital storage of echocardiographic studies. Videotape recording of echocardiographic studies is the standard image storage method used in most echocardiographic laboratories today. However, recent innovations in computer technology and the consequent dramatic increase in their digital storage capacity and chip data processing speed, coupled with a continuous fall in costs, and the establishment of a standard image format have rendered the digital storage solution feasible for daily routine in the echocardiographic laboratory. Generalized routine use of digital acquisition and storage of echocardiographic studies would have a tremendous utility in the practice of cardiology. In fact, it would allow immediate and random access to any echocardiographic study, the facilitation of side-by-side or quad-screen comparison, the fast transfer of echocardiographic data to remote sites and straightforward interfacing with computers for off-line image post-processing and analysis, long-term data integrity, and duplication of echocardiograms without degradation of the images[17]. However, the feasibility and clinical value of intelligent compression and digital storage of echocardiographic data as cine-loops and still-frames for the interpretation of routine echocardiographic studies has not yet been sufficiently documented in the clinical arena. Our study is the first trial designed to compare analog and digital recording modalities in a simulation of the real-world clinical situation.

Clinical compression of echocardiographic images. Despite the advantages outlined above, digital storage of images is hampered by the fact that in a digital echocardiography study the large amount of data necessitates large storage capacities. Complete digital storage of the data of a single 5-min two-dimensional echocardiography (640 × 480 pixels at 30 Hz) would occupy 2.5 GB of space without color and 4.2 GB at 24 bit color resolution. An echocardiography laboratory performing 5000 examinations per year would require more or less 40 terabytes of storage capacity annually. The use of higher frame rates or of a higher image resolution would increase these storage requirements substantially. Therefore, the need for image compression to facilitate digital echocardiography is obvious.

Given the fact that spatial JPEG is the only compression protocol accepted by the American Society of Echocardiography under the DICOM standard, and that its maximal clinically accepted compression ratio is 20:1, compressed echocardiographic studies are generally limited to selected single cardiac cycle loops (clinical or "intelligent" compression), in order to achieve a manageable overall echocardiographic study size (20 to 60 MB). In the near future, with further progress in computer technology and as the clinical validation of compression protocols able to eliminate both spatial and temporal redundancies (i.e. MPEG protocols) will be considered acceptable, direct compression of streaming video in a continuous format more familiar to echocardiographers will become a reality. MPEG protocols have been validated for both the qualitative and quantitative analysis of echocardiographic recordings and are considered comparable to Super-VHS[6,11].

Image compression protocols can be divided into "lossless" and "lossy" depending on whether the original image can be completely and reliably recreated from the compressed image. In our study, we used a form of lossy compression, that is "clinical compression", associated with a lossless digital compression using a run length-encoding algorithm[1] for further reduction in the size of echocardiographic studies by a factor of 2:1 to 3:1. Clinical compression is a form of lossy compression that reduces image data through digital storage of the selected loops and still-frames representative of the clinical information contained in a particular view, thus eliminating redundant or unnecessary data. As shown in our study, by storing only a single cardiac cycle from a given view rather than recording for 30 s, one can immediately achieve a 30:1 data reduction, and a 7 min videotape recording can be stored in 7 single beat-loops and 3 still-frames lasting only a few seconds.

Several studies have shown that clinical compression can be effectively used to accurately represent the clinical information contained in a complete videotaped study, the current gold standard[5-7,9,18]. Although some echocardiographers have questioned whether such clinical "intelligent" compression, proven to be effective for the storage of a routine echocardiography study, could retain its diagnostic accuracy even in complex examinations, there are data which show its clinical accuracy when transesophageal[10], pediatric[19], and acquired valvular heart disease[12] echo studies are stored. However, in these studies, echocardiographic image review was performed by a few, well-trained and highly motivated echocardiographers. The clinical effectiveness of this technology in day-to-day clinical practice remains to be addressed. Our results show that even in the clinical arena, using a predefined, practical acquisition protocol, clinical compression and digital storage of echocardiographic studies is feasible and that it allows efficient storage and retrieval of data with a diagnostic accuracy comparable to that achievable with standard Super-VHS videotape recordings. According to our protocol, a normal study typically consists of 7 cine-loops and 3 M-mode and spectral Doppler still-frame images requiring 19 MB of computer memory for storage. If cardiovascular abnormalities are encountered, additional cine-loops and still-frames are stored until the appropriate anatomy and physiology are documented.

Analog versus digital image quality. On visual assessment, clinical cardiologists involved in our study judged the image quality to be significantly better when the same image was stored digitally to magneto-optical disk than when it was recorded on analog Super-VHS videotape. This subjective perception mirrors the fact that the quality of digitally acquired images is actually superior to that of the corresponding analog images. The resolution of any ultrasound image recorded on Super-VHS videotape is limited by the peak luminance (black, white, and gray) and chrominance (color) bandwidths which are 4.2 and 1.2 MHz respectively[20,21]. The luminance of VHS videotape is lower at 2.4 MHz and the chrominance is the same as that of Super-VHS videotape[20]. The horizontal resolution of Super-VHS and VHS videotapes depends on their bandwidth and equals 224 and 128 vertical line pairs respectively[21]. The vertical resolution is a function of the number of visible horizontal scanned lines. Analog images are produced by scanning 525 horizontal lines/s and the 262.5 odd lines are interlaced with the 262.5 even lines every 1/30 s to prevent perceived image flicker[22]. Since 22.5 lines at the top and bottom of each frame are required for vertical retrace, only 480 horizontal lines are actually visible and the vertical resolution of analog images is thus only 240 lines[20,23].

Digital echocardiographic images consist of rectangular pixels of light and dark set in a standard matrix of 512 horizontal $\times$ 512 vertical pixels/frame. Since 2 pixels are required to define one line of resolution, the horizontal and vertical resolutions equal 256 line pairs. Because each pixel is assigned up to 8 bits, 2^8 (256) shades of gray are possible. For color images, 24 bits will result in a display of up to 2^{24} (16.8 million) colors.

Modern ultrasound systems create images on their monitor up to 60 frames/s in digital format. To record on videotape, these high-resolution digital images must be downscanned to the analog-interlaced television format. Motion artifacts and image degradation result.

Videotape versus magneto-optical disk storage costs. The 411 echocardiographic studies performed between September and December 1999 were stored to 5 magneto-optical disks. Maintaining the recording protocol used during the 6-month period prior to the study, the corresponding number of 180-min Super-VHS videotapes necessary in order to record the same number of exams was > 9. Although the archival cost per exam when data were stored on magneto-optical disks was 3 times greater than for Super-VHS videotape, it was still very low. In addition, the true cost of archiving should also include the costs of storing and retrieval of videotapes that, compared to magneto-optical disks, are inconvenient and relatively bulky. The volume of one 1.2 GB magneto-optical disk is 248 cm^3, < 50% of the volume of a standard videotape which is 513 cm^3. Since the exam content of a 1.2 GB magneto-optical disk is twice that of a 180 min videotape, the space required to store echocardiographic studies can be reduced by 75% using this storage facility. 2.3 GB magneto-optical disks are presently available on the market. Using 2.3 GB disks, which occupy the same volume as the 1.2 GB disks, the cost for study storage will be € 0.255 (1.9 times the cost of Super-VHS recordings), and the storage space thus gained will be 87%. Furthermore, each digitally acquired echocardiographic study may be viewed by means of random access to the ultrasound machine or on an off-line review station 11 times faster than when searching on videotape. Hence, using digital images, even including "sneaker net" technology, serial study comparisons are greatly enhanced.

Study limitations. The agreement in interpreting the anatomical and functional findings derived from echocardiographic images was subjective. Besides, observers were not blinded to the archival media used and the study was limited to patients admitted to our cardiovascular department. However, our study was not intended to evaluate the effects of digital storage on the quantitative assessment of echocardiographic images, which had been assessed previously, but to evaluate the value of an echocardiographic image when a clinical cardiologist had to determine whether a cardiovascular abnormality was present or absent. Finally, this study was intended as a pilot study, and its applicability was purposely restricted to hospitalized patients, in order to repeat the study without any trouble for patients if it was found to be incomplete. Additional trials are warranted to assess the feasibility and clinical value of digital storage of routine echocardiography studies in outpatients.

Conclusions. With the progressive improvement in computer processing speed, the increasingly cost-effective storage of large amounts of digital data and the establishment of a standard image format, the digital storage solution for echocardiographic images has become a reality. Our study shows that it is feasible, using currently available technology, to acquire and store representative loops from every study performed in patients admitted to a cardiovascular department. In addition, these loops seem to be an accurate summary of the complete echocardiographic study recorded on videotape thus allowing accurate and convenient interpretation of routine echocardiograms. Our study provides support for the transition from videotape to digital recording of routine echocardiograms.

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