Understanding the Need and Use of Digital Echocardiography

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This year marks the 50th anniversary of the introduction of echocardiography into the spectrum of cardiac care. From what began as a primitive technology – one that was able to provide only limited information on what would now be considered advanced pathology – echocardiography has developed into a modality that can rapidly provide anatomic and physiologic data of ever-increasing sophistication. It remains a technology that is predominately noninvasive, with no biologic risk, that is practical to apply in a variety of clinical settings. These characteristics have propelled its clinical use. Even with the emergence of newer techniques, such as cardiac MRI and CT, by virtue of its utility and applicability, the clinical role for echocardiography seems secure for the foreseeable future.

With the parallel advances in both signal processing and computer capabilities, the volume and complexity of information that can be derived from echocardiographic systems continues to increase. Thus, it is not only reasonable but also practical to expect that the echocardiographic systems of the future will continue to provide even further clinical information of greater complexity and subtlety. Looking forward, one of the greatest challenges facing echocardiographers will be how to absorb, analyze, and process this data in an environment that, in all likelihood, will be supported with ever-diminishing resources. Recognizing this, leaders in the field have asserted that digital information management techniques (which we will call ‘digital echo’) will be vital in the clinical use of echocardiography as the field advances. It is the aim of this paper to explain precisely why digital echo is needed, and how it can be applied in the clinical setting.

What is a “Digital Echo Lab”?

It first must be recognized that the term “digital echo lab” can mean different things in different contexts. Perhaps the most common definition for a digital echo lab is one that possesses the capability to supply digitized loops of echo images for review on a computer monitor, as opposed to the conventional approach of reviewing videotaped images on a VCR/TV monitor system. Some of these computer-based image review systems may have online analytic capabilities, such as digital calipers for making measurements on images, and the echo images may be linked to a larger image database for review of prior studies.

Alternatively, a digital echo lab can be defined as having a computer database for all echo studies. This database would contain alpha numeric data, such as demographic and measurement information, and have the capability to view images. In this environment, echo reports are generated by the computer database program, with reports being populated with text statements extracted from preconstructed phrase files.The sophistication of the report in these cases is limited by the level of detail in the phrase file library. In this environment, numerical and text data from prior studies is readily available online, so comparisons can easily be made between studies.

Defined either way, a digital echo lab offers advantages over what is considered a "standard echo lab", i.e., one in which echo images are recorded onto videotape and viewed on a VCR/TV monitor, with the subsequent echo report dictated and transcribed. Digital echo labs with online image review allow readers to view images more quickly (we will discuss this concept later), while the digital labs with automated report generation can be expected to deliver the clinical information back to the patient care environment in more time-sensitive manner. As will be presented, digital image review and digital reporting capabilities are both equally essential for capitalizing on the inherent advantages of digital echo labs.

For our purposes, we will consider a digital echo lab to be one in which the following apply:

1) acquired echo images are exported digitally to a computer-based review system;
2) this review system also imports alphanumeric information from the echo machine, as well as from the hospital/office information system; and
3) the review system allows automated report generation, eliminating the need for dictation or transcription.

Before analyzing the value of each of these core components of a digital echo lab, let's begin by examining the steps involved in performing an echocardiogram and generating an echo report in a "standard echo lab."

Performing the Echocardiography in the Standard Lab

Figure I provides a workflow diagram of the steps involved in performing and interpreting an echocardiogram in the conventional environment. The process begins with a request for an echocardiogram that is forwarded to the lab. This may be via the lab's information system or through direct person-to-person contact using the lab's support staff. Once the necessary clinical and demographical information is obtained, it is condensed and relayed in some form to the sonographer, who then populates the data fields of the echo machine's report template with the essential data. The study is then performed and recorded onto videotape. In order to make measurements, the sonographer must stop acquiring images to perform "live" measurements or print out still-frame images for offline review. A third option that is increasingly available involves capturing a digitized "highlight" for immediate analysis after completing the study, so that the data can be recorded onto the videotape. Once the study is completed, the sonographer generates some form of preliminary report, manually transposing the quantitative data into report form. The sonographer then rewinds the tape for physician review.

The physician reviewing the study has the benefit of some form of preliminary report. Videotape review commences, and the physician sequentially reviews the images obtained in the order of the lab's protocol. Often, the physician will want to compare the findings on the present study with those of past studies. If so, provisions will need to have been made by the sonographer to "pull the old study" or at least find an old report. Once complete, a final report is dictated. The turnaround time from physician dictation to obtaining the final report (which still needs to be proofread) remains contingent on the transcription services for the hospital or office. (It is unusual for an echo lab to transcribe its own reports.) The final report is then forwarded either directly to the hospital chart, the referring physician or back to the echo lab for review and dissemination. In addition, the final report is sent to the billing office, where a compliance officer crosschecks the billing codes applied to the study against that which is documented in the report.

In this era of concern for cost containment in the delivery of medical services, it is easy to understand why the methods of the standard echo lab are suboptimal. In this type of lab, clinical data are obtained repeatedly and re-copied into some other form, either for the sonographer, the echo lab's archival system, or the physician. Numerous individuals, some of whom may not be in the direct employ of the lab (e.g., transcriptionists), play a small but critical role in the workflow process. It is not as simple as having the sonographer perform the study and the physician read it. If at any point one of these individuals fails to perform their required duties in a time-sensitive manner, the workflow process is delayed. Moreover, by being predicated on repeated transfer of information from one transient form to another (study request; sonographer work order; preliminary report; final but unproofed report), there are inherent impediments to optimal workflow. As resources supporting echo labs continue to diminish, this type of inefficiency in the delivery of care will not be acceptable.

We will now dissect the above workflow processes and identify process improvements that may be achieved by establishing a digital echo lab. We will break this down into the three cardinal areas of workflow:

1) management of clinical and demographical data;

2) acquisition and analysis of image data; and

3) report generation and integration with other information systems.

Management of Clinical and Demographical Information

In the digital echo lab, clinical data are either imported or primarily generated; they are never manually copied or retranscribed from an original source. Unlike in the previous example, in the digital echo lab the echo reporting system is linked to the "outside" hospital or office information system. (One typical interface is an HL-7 interface, which stands for Hospital Language 7, a common protocol for communicating patient demographical data between medical computer systems.) If the request for the echo study were to come to the lab by telephone, the echo lab staff goes online to extract the necessary demographical data from the larger outside information system. If this is an entirely new patient to the medical system, patient registration is performed once, and demographical data become a permanent part of the patient's echo record. With time, any changes in the patient's demographic/billing data would be updated in the echo lab's system through its interface with the external information system.

In this environment, the echo machines used by the sonographers are linked to the echo lab's digital network. Therefore, when initiating a study, the sonographer does not have to re-enter the patient's clinical information into the database. As soon as the sonographer begins typing the patient's name, the data fields for that patient become populated. Thus, in order to perform a study, all the sonographer needs know is the patient's name. All other background information already exists in the echo lab's information system. We will return to this aspect of information management after examining the image acquisition and review process.

Image Acquisition and Review

In a digital echo lab, the sonographer obtains images in the same manner as in a standard lab. However, rather than recording onto videotape, the sonographer captures a digital image loop at each stage of the lab's protocol. (Depending on the lab, the loop may vary from 1 to 10 cardiac cycles). This loop represents the optimal image that can be acquired from a particular standard view. The digital loop is then stored on the hard drive of the echo machine until the study is complete. Because the data is digitized and internally calibrated, analysis of the images for quantitative data, such as chamber measurements, Doppler gradients, etc., can be done at a later time. (This is true for most systems.) In a busy lab, this allows the machine to be used to gather images, which is a more efficient use of time. The sonographer can finish with the patient, and export the images into the echo lab's image review system for later analysis, allowing another sonographer to use that same machine on another patient. This reduces machine "idle time".

In the standard echo lab, the sonographer typically is responsible for generating a preliminary echo report. Sitting at a workstation, the sonographer opens up the patient study and completes whatever image analysis needs to be performed. (For completeness, it should be noted that this all could be done on the echo machine itself, but as echo machines cost a great deal more than computer workstations, it makes more financial sense to use the echo machines to acquire the data, and computer workstations to analyze it in a busy lab. In lower volume labs, all this can easily be done directly on the machine.)

As data are generated (again, such as chamber dimension measurements or Doppler gradients), they are transferred to populate data fields within the echo database. This occurs at the time of initial data analysis – the data never need to be recopied into the database. Using the online reporting system, the sonographer constructs a preliminary report. This report serves as the framework for the final report that will be generated by the physician. In terms of workflow, there are no wasted steps in data entry. The final report is built serially from the initial measurements and impressions of the sonographer.

Physician Involvement in the Digital Echo Lab

Compared to a standard echo lab TV/VCR arrangement, the physician working in the digital echo lab views the images on a computer monitor. Available digital echo review systems typically provide simultaneous viewing of 4 to 16 distinct cardiac loops. This is, perhaps, the fundamental advantage of a digital lab over a standard lab with respect to physician involvement in the review process. Recall that in terms of performing an echo exam, all accredited echo labs mandate that the sonographer acquire images by a set protocol. Thus the physician reading in a standard lab must read studies in series, i.e., one image after the next. While this is ideal with respect to image acquisition (so that exam comprehensiveness is assured), it is, in fact, detrimental to the review process. For example, if a pathologic finding were to be encountered in the initial parasternal views, the reviewing physician ideally would like to corroborate and further characterize the finding in another view, such as the apical views. However, on videotape, those images are not present until after viewing several minutes of videotape, while other standard requisite views are obtained.

In the digital echo lab, the physician has immediate access to multiple simultaneous digital loops. This allows the physician to rapidly move to other views to confirm or better understand an initial finding. The physician is thus reading in parallel, assessing multiple views almost simultaneously, which allows integration of the data in a time efficient manner. This reduces the overall amount of time spent reviewing the study, without compromising the quality of the review – perhaps even improving upon it.

As the physician is reading the study, the preliminary report is presented side-by-side with the images. Some physicians review this report "as they go," while others complete the image analysis and then turn to the report. Typically, if the lab employs experienced sonographers, most of the information from the preliminary report is accepted, and minor revisions are made. Instead of dictating a complete report, the physician modifies the existing test, perhaps adding more from the same phrase file library or typing select comments. This report is then electronically signed and prepared for distribution to the hospital/office information system, as well as the lab's billing system.

A final point on physician involvement in the reading process concerns drawing comparisons with previous studies. In the digital environment, old studies are already online. Numerical data, such as Doppler gradient values, can be viewed in graphical form, allowing for recognition of trends. Previous images can be readily uploaded, allowing for side-by-side comparison with the present study. From a workflow standpoint, the time savings in retrieval and preparation of an old study for comparison are self-evident in this environment. From a quality control point of view, it is reasonable to conclude that having ready access to old studies increases the likelihood that the reviewing physician will view and compare the new data with prior studies.

Report Generation and Integration with Hospital/Office Information Systems

After the physician electronically signs the report, it becomes a study of record. Subsequent changes can be made, but such a revised report would be so designated. At this point, the report is simultaneously forwarded to the external hospital/office data environment, as well as to the lab's billing department. With respect to the hospital/office system, the amount of data exported from the echo lab will be dependent upon the sophistication of the receiving information system. In simplest form, the echo report can be a simple text document, formatted with required measurements and text data. In an advanced system, text data and image loops can be exported or primarily stored on the hospital/office information system. This allows for integration of the echo data into a larger electronic medical record. In either case, the physicians providing care for the patient receive the echo data essentially as they are generated by the reading physician. By eliminating the need for dictation/transcription/dissemination turnaround, the timeline of patient care can be compressed. If done systematically, the inherent gains in the efficiency of patient care delivery, while difficult to quantify precisely, are legion.

Measuring the Benefits of the Digital Echo Lab

By identifying the shortcomings of the standard echo lab and outlining the advantages of the digital lab, it would seem axiomatic that all labs would soon convert to the digital environment. The simplification of workflow is illustrated in Figure 2. However, in clinical practice, there is often a gulf between theoretic idealized plans for care and actual clinical practice. "Real-world" data are often helpful in affecting transitions. To date, such data exist primarily in anecdotal form, culled from individual labs' experiences. Three busy clinical labs recently shared their experiences at the 2002 ASE meeting. What follows is a compilation of specific clinical dividends that these labs attained by converting to a digital environment. Annualized dividends/savings are based on a lab performing 2500 studies per year:

1) physician review time is decreased by 5 minutes per study: this translated to 25 full work days that are "given back" to the physician

2) transcription costs are eliminated: direct saving of $10 000 - $20 000

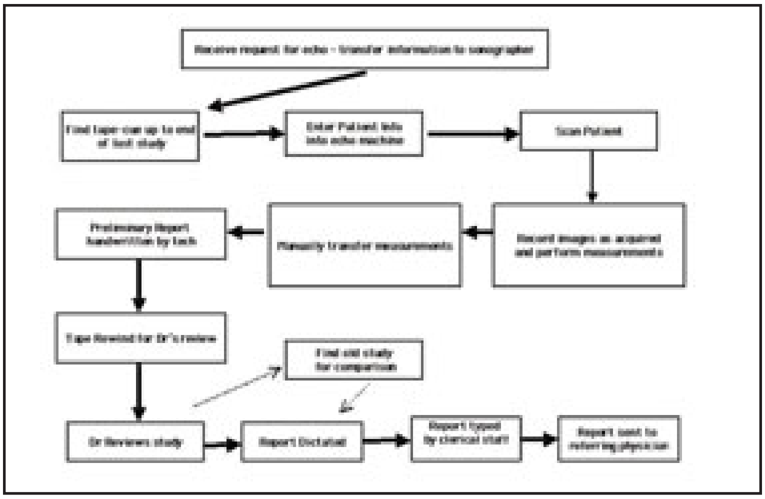

Figure 1.

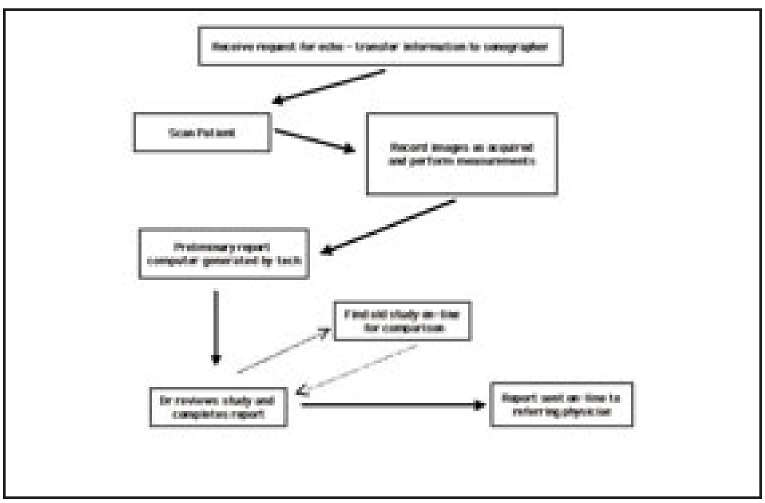

Figure 2.

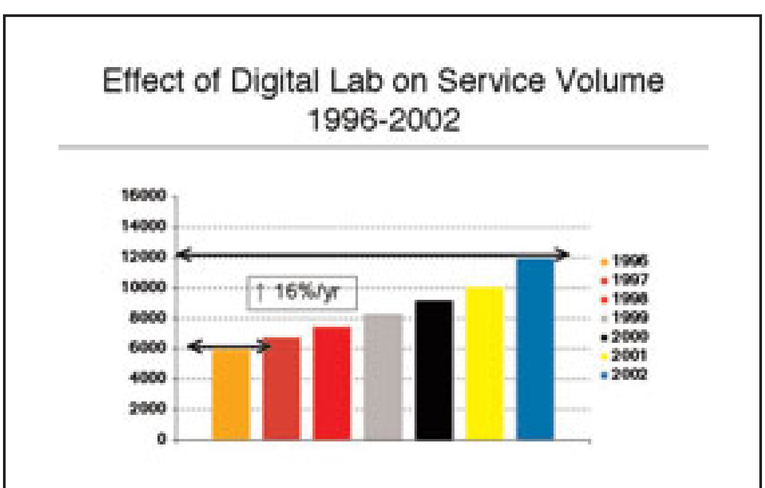

Figure 3.

3) decreased sonographer "downtime" spent performing administrative/secretarial duties: echo volume increased by 100% with ~50% increase in staff (Figure 3)

4) decreased echo machine "idle time": 100% increase in volume with 50% increase in number of echo machines

5) report formats and content now standardized, facilitating ICAEL accreditation

6) lab information system downtime <1%

The benefits of the digital echo lab are easiest to quantify when viewed somewhat parochially from the perspective of the echo lab administrator. It becomes more difficult when trying to measure how these benefits extend to the hospital or office at large. Figure 2 demonstrates the work-flow process in the digital echo lab. Note the number of steps eliminated (and thus time saved) as compared to Figure 1. How many patients will be discharged sooner because information has returned to the chart more quickly? How many clinical decisions are reached sooner by having access to echo information? How is clinical care improved in complex cases when echo images can be viewed side-by-side with catheterization or nuclear images? When the goal is the integration of care, it becomes quite difficult to tease out and qualify the specific contribution of each component of that care. What is substituted instead is the expectation that each piece of the healthcare system operate at optimal efficiency, and that this efficiency extend to the system at large. For the reasons outlined above, this efficiency requirement for healthcare delivery can not be met in the conventional echo lab, but only in a digital environment.

Future Needs and Further Considerations for the Digital Echo Lab

Figure 4 outlines the basic quantitative information one could obtain from an echocardiographic study over the past decade, and adds to that what, if not routinely reported now, will become standard measures in the near future. In short, given the advances in the technical capabilities of echocardiographic systems, videotape (an analog medium) will no longer be adequate for archival of this complex data. Moreover, as we continue to increase the sophistication of the data, physicians will likely be expected to perform more direct measurements and analysis from the image data. Since in most labs the physician is not with the patient at the time of image acquisition, the data obtained will need to be contained in a medium that is dynamic and easily accessible. This can only be accomplished in a digital echo lab.

In considering a digital echo lab, another point that should be emphasized: understanding the difference between primary digital data and digitized video. In the former, the raw digital signal returning to the echo machine from the patient is used to form the image and is stored with the image data. Thus, the image presented is multi-dimensional; it is not simply a two-dimensional picture of the heart. The corresponding data contained in the image can be queried offline by appropriate analytic tools. This is how we can analyze tissue Doppler velocity and derive regional tissue strain profiles today and how we will routinely quantify tissue perfusion by contrast echo in the future. In contrast, systems that export digitized video typically take the image data and compress it into a digitized format (e.g., JPEG). This provides for excellent images, and allows for all of the workflow advantages of the digital echo lab, as previously described. However, as systems become more advanced, we will no longer be able to simply look at an image and make a few caliper measurements and generate a state-of-the-art echo report, as we do now. We will need the capability to "interrogate" the image, teasing out the subtleties of the velocity and contrast profiles. This is not abstract conjecture; it is harsh reality if echocardiography is to contend with cardiac MRI as the noninvasive diagnostic modality of choice in the assessment of cardiovascular disease.

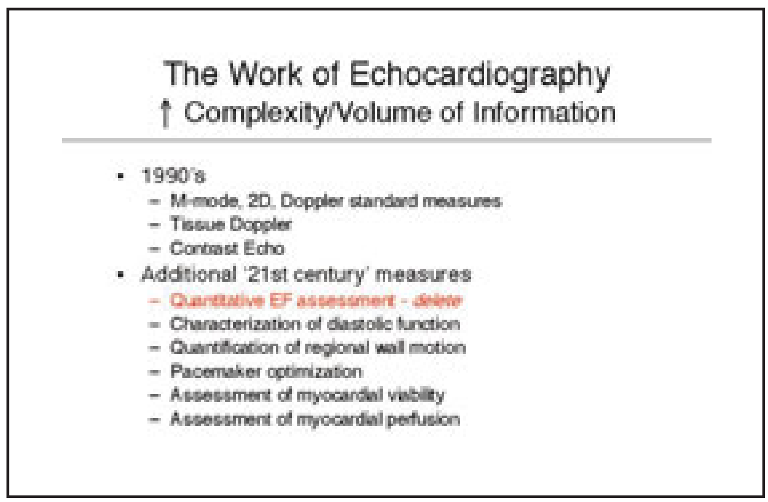

Figure 4.

Conclusions

Data derived from echocardiographic systems continue to increase in complexity. Today's conventional echo labs utilize videotape, an analog medium, offering a relatively inexpensive way to archive large volumes of data, such as the video data generated by echo machines. However, videotape is a static medium and must be viewed in serial fashion. The increased sophistication of the information available from echo machines today requires recording to a medium that is dynamic, so that offline measurements can be performed when indicated, and to allow for random image access so that the study can be viewed in an order that is particularly suited to the specific patient. Moving to a digital environment imparts other dividends (which have been presented) with respect to laboratory workflow – all of which combine to increase lab – and ultimately healthcare system – efficiencies.

While we have outlined why digital echo information management systems are superior to conventional systems, it also should be noted that the perfect digital echo lab does not yet exist. As recently as ASE 2002, <10% of all labs considered themselves "digital" labs, and encompassed within that distinction were the various definitions of "digital lab" as outlined. Some labs have wholeheartedly embraced digital review technology, only to then pick up the telephone to dictate an echo report and suffer the pitfalls of that process. Others have proceeded further but have not integrated their data with hospital networks to integrate their data with the larger medical record. Very few have yet to coordinate patient scheduling and patient billing interfaces with their echo reporting systems. Digital echo is therefore still very much in its infancy. However, it holds more promise – than anything else within the field of echocardiography – to allow practioners the ability to accomplish more and more with less and less. Unless there are dramatic changes in healthcare policies, that demand will be the expectation of our healthcare system for some time to come.

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