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Emergency Echocardiography Telemedicine: An Efficient Method to Provide 24-Hour Consultative Echocardiography

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Objectives. This study sought to assess the clinical utility of interpreting emergency echocardiograms after regular working hours through a telemedicine connection to on-call cardiologists.

Background. Physician interpretation of emergency echocardiograms is often delayed during weekends, evenings or night hours. This delay places undue responsibility on less qualified personnel to interpret echocardiograms of vital importance.

Methods. Digital quad-screen cine-loop format was transmitted over standard telephone lines. Clinical data and conventional and telemedicine interpretations were collected prospectively for 187 emergent or semiemergent tele-echocardiograms after regular working hours.

Results. Indications for the echocardiogram included assessment of left ventricular function, ischemia, pericardial effusion, valvular disease, heart donor status and arrhythmia. Three off-site echocardiographers received the standard echocardiogram and spectral, gray-scale and color flow Doppler images in cine-loop format using a laptop computer. Laptop interpretation showed 19 technically limited studies, 153 abnormal studies and 54% with wall motion abnormalities. Overall mean agreement rate between telemedicine laptop interpretation and conventional workstation interpretation performed in blinded manner for serious disorders with classic echocardiographic findings (pulmonary hypertension, left ventricular thrombus, aortic dissection, severe valvular insufficiency and large pericardial effusion) was 99.0% (95% confidence interval [CI] 96% to 99%). For serious wall motion abnormalities, the agreement rate was 96.3% (95% CI 92% to 99%). The following mean times elapsed after completion of the echocardiogram: to laptop fax report, 2.14 h (range 10 min to 8 h); to dictation of videotape, 11.74 h ($p < 0.001$); to transcription of videotape dictation, 56.6 h ($p < 0.0001$).

Conclusions. After-hours emergency echocardiography telemedicine using a laptop computer is more rapid than scheduled conventional interpretation from a videotape workstation, yet diagnostic accuracy is comparable.

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Echocardiography provides important information in a variety of cardiovascular emergencies. Assessment of chest pain, heart failure, valvular stenosis or insufficiency, shunt flow abnormalities, pericardial effusion and cardiac emboli are established indications for echocardiography in emergency situations (1–3). However, emergency echocardiography has not been utilized to its potential because of logistic challenges after regular weekday hours. Even when on-call ultrasonographers or resident physicians are used, review of emergency echocardiograms by an experienced cardiologist is often delayed. This places undue pressure on less qualified personnel to render an opinion in clinical emergencies, introducing the possibility of decreased diagnostic accuracy and increased medical-legal liability (4). We hypothesized that telemedicine might provide a solution.

Telemedicine applications link physicians to underserved areas in increasing numbers (5). In radiology and other specialties (6), telemedicine brings needed expert information to inaccessible locales. However in cardiology, there has been only limited use of telemedicine to transmit electrocardiograms and echocardiograms from rural locations to regional medical centers (7–9).

Computer manipulation of echocardiograms has become the norm for interpretation of stress echocardiography (10). Cine-loop digitizers ("frame grabbers") capture still cardiac images that are sequentially displayed to simulate cardiac motion. Digital cine-loop echocardiography also has been shown to yield diagnostic interpretations comparable to conventional videotape reading (11). Given the wide dissemination of digital cine-loop technology, the familiarity of ultrasonographers with this procedure, and experience using this technology in consultative pediatric echocardiography telemedicine (7), it seemed reasonable that this technology could be practically adapted for adult emergency echocardiography telemedicine during evenings, nights and weekends.

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Methods

Patient enrollment. Patients were enrolled after an unsolicited request for emergency tele-echocardiography by their

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physicians to answer diagnostic questions important to urgent clinical care. These consecutive tele-echocardiograms were performed at Methodist Hospital of Indiana after regular hours during weekends, on holidays or after 6 PM Monday through Friday. Ordering physicians requested interpretations to be immediate (or before 9 AM the following morning). Patient selection reflects adult emergency cardiovascular practice, with infrequent pediatric studies. The study protocol was approved by the Institutional Review Board of Methodist Hospital of Indiana.

Personnel. Six ultrasonographers routinely performed studies during regular business hours and early evenings; they were on call nights and weekends for emergencies. Three cardiologists concentrating in echocardiography maintained 24-h off-site availability for emergency echocardiography telemedicine interpretation.

Equipment. Equipment utilized for echocardiography telemedicine was standard digital cine-loop technology. Cine-loop echocardiograms were obtained on line with a digitizing system (TomTec Imaging Systems) integrated into the echocardiograph (Sonos 1000, Hewlett-Packard). The four echocardiographic views obtained from a quadrant of the original sector echo centered on the region of interest were acquired 50 ms apart and presented in quad-screen systolic eight-frame cineloops. Each overall quad screen bitmap frame was displayed at a density of 320 × 240 lines.

Echocardiography telemedicine. Transmission was performed from the patient's bedside or an echocardiographic workstation (TomTec Imaging Systems). Transmission speed was up to 14.4 kbaud (thousand bits per second) over standard residential copper wire telephone lines. Care was taken to avoid electronic interference from digital switchboards, call-waiting and household security systems that might interfere with digital transmission. Data were transmitted in a "lossless" proprietary format developed before DICOM standards (12).

Reception of images by a laptop computer resulted in minimal logistics. A single laptop computer was passed among the cardiologists for their nights on call, which required installation and maintenance of only one computer rather than multiple home units. Furthermore, the laptop computer receiving station permitted increased mobility by on-call cardiologists. The laptop computer (C4400, Toshiba) contained 20 MB RAM, a processor at 33 MHz (486DX, Intel), a 130-MB hard drive, a 9.5-in active color matrix screen and a v.32bis internal modem. Proprietary software (Review Software for Windows, TomTec Imaging Systems) displayed up to three simultaneous quad-screens in motion, accompanying electrocardiography rhythm strips and patient data (Fig. 1). As many as 25 previous studies could be recalled and displayed with accompanying patient data and echocardiograms. A preliminary report was created (Word, Microsoft) and faxed (Winfax Lite, Delrina) to the referring physician. The final interpretation, derived from conventional videotape and digitized images at an echocardiography workstation, was performed by a cardiologist unaware of the results of the preliminary laptop interpretation. The workstation dictation was dictated and later transcribed by secretarial staff.

Figure 1. Quad-screen format of the standard four echocardiographic views of the heart with electrocardiogram accompanying each view. Images of dilated cardiomyopathy with apical left ventricular mural thrombus seen in apical views (bottom).

Statistical analysis. Data were analyzed to determine qualitative left ventricular function, the degree of agreement between laptop computer versus conventional workstation-derived interpretations, time for report generation and effect of learning on response time and accuracy of interpretation.

Telemedicine laptop wall motion interpretation of the left ventricle was performed using visual estimates of the percentage of abnormal myocardium as well as wall motion scoring of major ventricular walls (anterior, inferior and lateral). Left ventricular wall motion score was obtained by dividing the sum total scores for each major wall by 3 (13). A normal wall score is 1. A modified model with 3 segments rather than the standard 16 segments was used to highlight the agreement in making a broad preliminary diagnosis rather than to emphasize minor differences between segmental wall motion, which may be of limited clinical applicability in emergency situations.

According to guidelines proposed by Grigsby et al. (14), telemedicine systems compared to conventional reading should assess results using an abnormality of relatively high incidence, with findings intended to challenge readers and system resolution, and having important consequences in patient care and outcome. Interpretations by staff cardiologists at a conventional echocardiogram workstation generally vary sufficiently to exclude these as reference standards. Therefore, comparisons between telemedicine laptop computer interpretation and conventional workstation interpretation were principally made using agreement rates. However, with the videotape digital workstation used as reference standard, sensitivity and specificity were offered for the telemedicine laptop interpretations. Overall agreement, sensitivity and specificity were calculated and expressed with 95% confidence intervals.

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Table 1. Indication for Emergency Echocardiography*

Left ventricular function	33%
Ischemia	29%
Pericardial effusion	17%
Valvular heart disease	7%
Arrhythmia	6%
Evaluation as a heart donor	2%
Preoperative assessment of cardiac structures	2%
Myocardial contusion	2%
Assessment of cardiac source of embolism	1%

*Major indications for ordering emergency echocardiography with telemedicine as a percent of total number of telemedicine studies.

Two-tailed paired *t* tests were used to determine if the time for telemedicine interpretation was significantly less than workstation dictation and secretarial transcription times. Significance levels of $p < 0.05$ were used to test these hypotheses as well as those listed below.

To compare the agreement of telemedicine interpretation with conventional workstation interpretation over time, the first 76 patients were compared to the following 111 patients. The Fisher exact test was used to compare percent agreements ± standard deviations in the two groups. A Student *t* test was used to compare the time after completion of the echocardiogram to telemedicine report ± standard deviations in the early and late patient groups.

Results

Patients. Echocardiography telemedicine was performed in 183 patients (91 men, 92 women; mean age 57.9 years; range 1 to 92), resulting in 187 separate transmissions from July 1993 until September 1994. Four patients had two emergency echocardiograms during the period. During this interval, a total of 5,848 two-dimensional echocardiograms were performed at Methodist Hospital; thus, 3.2% of echocardiograms were transmitted after hours for emergency telemedicine interpretation. Tests were performed in the general hospital units (33%), coronary care unit (26%), emergency medicine and trauma center (21%), adult intensive care unit (6%) or other areas (13%). The ordering physician listed the indication for emergency echocardiography (Table 1).

Emergency echocardiography results. Echocardiography was judged poor in quality (insufficient resolution for interpretation) in 12 (6%) of 187 transmissions from the conventional workstation and 19 (10%) of 187 from the telemedicine laptop computer, with concurrence in 8 (4%) of 187.

Most transmissions consisted of the four standard echocardiographic views on one quad-screen cine-loop ~0.5 MB in length. Further two-dimensional views, color images, Doppler scans and diastolic images added to file length. Transmissions (29 of 187) included Doppler studies after color Doppler telemedicine capability became available when there was significant valvular pathology. On studies with involved valvular pathologies, as many as four quad-screens of two-dimensional, M-mode and various Doppler images were required to adequately depict the cardiac pathology.

Table 2. Frequency of Abnormalities Recognized by Echocardiography Telemedicine Using a Laptop Computer

Diagnosis	No.*
Left ventricular wall motion abnormality	101
Isolated anterior wall motion abnormality	43
Isolated inferior wall motion abnormality	43
Isolated lateral wall motion abnormality	6
Generalized left ventricular hypokinesia	44
Left ventricular mural thrombus	6
Left ventricular hypertrophy	17
Pericardial effusion	25
Aortic enlargement	15
Mitral valve disease	38
Aortic valve disease	42
Mitral regurgitation	21
Aortic regurgitation	11
Tricuspid regurgitation	14
Pulmonary hypertension	6
Aortic stenosis	1
Aortic dissection	1
Mitral stenosis	1

*Number of abnormal findings/diagnosis as recognized by telemedicine laptop computer.

Most studies viewed on the laptop computer showed significant cardiac pathology. Interpretations were abnormal in 153 (82%) of 187 cases. A spectrum of abnormalities was recognized on the transmitted echocardiograms (Table 2). Significant abnormalities of left ventricular function were seen. Wall motion abnormalities were seen in 54% of studies. The overall average percentage of abnormal myocardium by visual estimate was 26%. The average wall motion score was 1.33; average anterior wall motion score was 1.43, inferior was 1.36 and lateral was 1.2.

Agreement rates for interpretations between laptop computer and workstation for individual diagnoses are listed (Table 3). For serious cardiovascular disorders with classic and pronounced echocardiographic findings (large pericardial effusion, severe valvular insufficiency, pulmonary hypertension, left ventricular mural thrombus, aortic root dissection), the overall agreement rate was 99.0% (95% confidence interval [CI] 96% to 99%). For serious wall motion abnormalities (dyskinesia, akinesia or hypokinesia of at least two major walls) of the left ventricle, the agreement rate was 96.3% (95% CI 92% to 99%) (Table 4).

Telemedicine results. Transmissions were sent mainly to cardiologists' homes (183), but a few transmissions were directed to other locations (e.g., conferences, friends' homes, churches). Emergency echocardiography telemedicine occurred mainly in the early evening hours and during weekend days; transmissions between 11 PM and 6 AM occurred infrequently (14 [7%] of 187).

Included in the time from physician request until the echocardiogram was completed were contacting the echocardiographic technician (at home after 9 PM and weekends),

Table 3. Agreement Rates Between Telemedicine and Conventional Diagnosis for Echocardiographic Abnormalities

Diagnosis	Agreement Rate*	No.†	95% CI
Large pericardial effusion	100%	8	98–100
Severe valvular insufficiency	100%	7	98–100
Aortic root dissection	100%	1	98–100
Aortic stenosis	100%	1	98–100
Pulmonary hypertension	98%	6	95–99
Left ventricular thrombus	97%	4	94–99
Serious left ventricular wall motion abnormality	96%	61	92–99
Isolated lateral wall motion abnormality	94%	6	90–97
Right ventricular enlargement	86%	29	81–91
Right atrial enlargement	85%	36	80–90
Isolated anterior wall motion abnormality	82%	43	78–88
Left atrial enlargement	82%	82	76–87
Isolated inferior wall motion abnormality	78%	43	72–84

*Overall agreement for normal and abnormal findings divided by the total number of studies. †Number of abnormal findings/diagnosis as recognized by telemedicine laptop computer. CI = confidence interval.

technician travel time, performance of the echocardiogram and cine-loop digitization. On average, time from request until completion was 2.6 h (median 1.33 h, range 20 min to 6.5 h). Echocardiography telemedicine (from completion of the study until the requesting physician received the fax report) included telemedicine transmission (~8.5 min/quad-screen cine loop), interpretation, report generation and fax time for report. Average telemedicine time was 2.14 h (median 1.33 h, range 12 min to 8 h). Compared with the time for conventional workstation dictation of 11.78 h, telemedicine interpretation was significantly faster ($p < 0.001$). In comparison to transcription time of conventional workstation dictation (58.8 h), echocardiography telemedicine interpretation and report generation was much faster ($p < 0.0001$).

Table 4. Agreement Rate for Echocardiographic Serious Left Ventricular Wall Motion Abnormalities*

Conventional Echocardiographic Findings	Telemedicine Echocardiographic Findings: Normal	Telemedicine Echocardiographic Findings: Abnormal
Normal	121	4
Abnormal	3	59

*Distribution of patients by conventional echocardiographic interpretation at a workstation versus echocardiographic telemedicine to a laptop computer. Serious abnormalities are defined as dyskinesia, akinesia or hypokinesia of two or more major (anterior, inferior or lateral) left ventricular walls. Agreement 96.3% (at 95% confidence interval [CI] 92% to 99%); sensitivity 95.2% (at 95% CI 87% to 99%); specificity = 96.8% (at 95% CI 92% to 99%), assuming conventional echocardiogram as reference standard for this diagnosis.

Table 5. Lack of Learning Curve in Emergency Echocardiography Telemedicine

	Agreement Rate*	Telemedicine Time (h)†
Patients 1–76	92.1%	1.85 ± 0.72
Patients 77–187	87.4%	2.35 ± 0.80

*For pericardial effusion between telemedicine laptop and conventional workstation interpretation. †Time for receipt of preliminary telemedicine fax report after completion of echocardiogram. p = NS for all comparisons.

Cost analysis. At this time, echocardiography telemedicine is not reimbursed by federal or state health programs or insurance coverage. The expense of installation or this system at a site with existing cine-loop digitizer amortized over 2 years with 250 telemedicine transmissions/year amounts to ~$20/study. At a site without a cine-loop digitizer, the cost would be ~$80/echocardiography telemedicine study.

Discussion

Staffing concerns. Performance of emergency echocardiography telemedicine requires a cooperative effort. Ultrasonographers must be proficient in echocardiography and digital cine-loop technology. The images transmitted are those chosen by the echocardiographic technician. Choosing the proper images requires a sophisticated knowledge of cardiac pathology and the ability to recognize abnormalities quickly. Thus, telemedicine logistics can make an emergency situation stressful for the novice ultrasonographer. Likewise, the cardiologist must be accomplished in echocardiography and interpretation from digital cine-loop images. Even so, there does not appear to be a learning curve in that the agreement rates and transmission times were not statistically significant from the first and second halves of this study (Table 5).

Telemedicine interpretation. Even though the time for telemedicine interpretation after completion of the echocardiogram averaged more than 2 h, the process could be expedited to 12 min for especially urgent situations. The longer times (32 of 187 studies >2.4 h) occurred in the following situations: when reports were requested semiurgently (e.g., before surgery), when several studies were sequentially performed and batch transmitted, when human errors occurred, and when technical difficulties happened, such as battery depletion and modem failures to connect. A more relaxed approach was taken by ultrasonographers and cardiologists alike when a report was requested simply before the start of the next business day.

The echocardiograms sent for emergency telemedicine interpretation demonstrated numerous cardiac abnormalities. Several clinical situations requiring prompt echocardiographic evaluation led to prompt therapy as a result of emergency echocardiography telemedicine.

Technical developments and limitations. An evolution in technology made this clinical service possible. Advancements in cine-loop technology, software for receiving telemedicine

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transmissions and laptop computer design allowed for practical emergency telemedicine. Anticipated developments in the near future include using faster transmission speeds, image compression and cellular transmission, all of which will further enhance emergency echocardiography telemedicine.

The technical factors involved in transmission, laptop computers and digitizing influence echocardiographic image quality. Even though our software transmitted data in a "lossless" format, images on the laptop screen were somewhat less distinct than those on the workstation monitor because of limitations of the portable liquid crystal laptop screen and the internal graphics support. Even so, the laptop computer images were of sufficient diagnostic quality to make interpretations comparable to those from a conventional echocardiographic workstation.

Because including color flow Doppler in cine-loops resulted in very large files, color was used only for demonstration purposes. In practice, we chose "gray-scale flow" Doppler cine-loops for their shorter transmission times. We found this representation to be unambiguous when accompanied by two-dimensional echocardiograms from the same orientation.

Physicians ordered emergency echocardiograms for their patients in intensive care and emergency units. A higher number of abnormalities were recorded in this series of studies than would be expected in an unselected population. Because abnormalities were not unexpected on emergency tele-echocardiography, interpretations may have been weighted toward these abnormalities as well. A high congruence between tele-echocardiography and workstation echo interpretations existed, so we suspect bias to have only a minor influence.

Cost justification. Even though echocardiography telemedicine is presently not reimbursable, we believe that the addition of this affordable telemedicine technology to existing cine-loop equipment is fiscally responsible. The minimal expenditure to decrease technician medical-legal liability, speed patient care and provide backup to on-call personnel seems justifiable. Current economics in echocardiography do not seem to justify elaborate telemedicine systems requiring considerable capital outlays.

Conclusions. Providing a more rapid physician report through emergency echocardiography telemedicine decreases the pressure for ultrasonographers to make an interpretation to eagerly awaiting clinicians. Echocardiography telemedicine using digitized cine-loop echocardiography is relatively simple and inexpensive, yet provides diagnostically interpretable images. Providing rapid 24-h consultative echocardiographic interpretation in emergencies speeds assessment and impacts many treatment decisions.

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References

1. Hauser AM. The emerging role of echocardiography in the emergency department. Ann Emerg Med 1989;18:1298–303.
2. Peels CH, Visser CA, Kupper AJ, Visser FC, Roos JP. Usefulness of two dimensional echocardiography for immediate detection of myocardial ischemia in the emergency room. Am J Cardiol 1990;65:687–91.
3. Oh JK, Meloy TD, Seward JB. Echocardiography in the emergency room: is it feasible, beneficial, and cost-effective? Echocardiography 1995;12:163–70.
4. Kisslo J, Adams DB. Reporting of preliminary data: time to take our ultrasonographers "off the hook." J Am Soc of Echocardiogr 1991;4:6–9.
5. McGee R, Tangalos EG. Delivery of health care to the underserved: potential contributions of telecommunications technology. Mayo Clin Proc 1994;69:1131–6.
6. Perednia DA, Allen A. Telemedicine technology and clinical applications. JAMA 1995;273:483–8.
7. Sobczyk WL, Solinger RE, Rees AH, Elbl F. Transtelephonic echocardiography: successful use in a tertiary pediatric referral center. J Pediatr 1993;122:S84–8.
8. Berdusis K, Fisher JB, Webb CL, Gidding SS, Alboliras ET. Successful preparation of Community Hospital ultrasonographers for transtelephonic transmission of infant echocardiographic studies [abstract]. J Am Soc Echocardiogr 1995;8:398.
9. Paterson J, Montgomery W, Compos W, Schwartz S, Pandian N. Live, on-line realtime tele-echocardiography: on-line review, control of study performance, interpretation, training, and consultation to remote sites with transtelephonic ultrasound data transmission and videoconferencing [abstract]. J Am Soc Echocardiogr 1995;8:405.
10. Armstrong W, O'Donnell J, Dillon J, McHenry P, Morris S, Feigenbaum H. Complementary value of two-dimensional exercise echocardiography to routine treadmill exercise testing. Ann Intern Med 1986;10:531–8.
11. Eichelberger JP, Schwarz KQ, Pomerantz R. Validation of cine-loop versus videotape review in exercise echocardiography interpretation [abstract]. J Am Soc Echocardiogr 1995;8:411.
12. Thomas JD. The DICOM image formatting standard: what it means for echocardiographers. J Am Soc Echocardiogr 1995;8:319–27.
13. Schiller NB, Shah PM, Crawford M, et al. Recommendations for quantitation of the left ventricle by two-dimensional echocardiography. J Am Soc Echocardiogr 1989;2:358–69.
14. Grigsby J, Schlenker RE, Kaehny MM, Schaughnessy PW, Sandberg EJ. Analytic framework for evaluation of telemedicine. Telemedicine J 1995;1:31–9.