Impact of Telemedicine on the Practice of Pediatric Cardiology in Community Hospitals

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ABSTRACT. *Background.* **Tele-echocardiography has the potential to bring real-time diagnoses to neonatal facilities without in-house pediatric cardiologists. Many neonates in rural areas, smaller cities, and community hospitals do not have immediate access to pediatric sonographers or echocardiogram interpretation by pediatric cardiologists. This can result in suboptimal echocardiogram quality, delay in initiation of medical intervention, unnecessary patient transport, and increased medical expenditures. Telemedicine has been used with increased frequency to improve efficiency of pediatric cardiology care in hospitals that are not served by pediatric cardiologists. Initial reports suggest that telecardiology is accurate, improves patient care, is cost-effective, enhances echocardiogram quality, and prevents unnecessary transports of neonates in locations that are not served by pediatric cardiologists.**

Objective. **We report the largest series to evaluate the impact of telemedicine on delivery of pediatric cardiac care in community hospitals. We hypothesized that live telemedicine guidance and interpretation of neonatal echocardiograms from community hospitals is accurate, improves patient care, enhances sonographer proficiency, allows for more efficient physician time management, increases patient referrals, and does not result in increased utilization of echocardiography.**

Methods. **Using desktop videoconferencing computers, pediatric cardiologists guided and interpreted pediatric echocardiograms from 2 community hospital nurseries 15 miles from a tertiary care center. Studies were transmitted in real-time using the H.320 videoconferencing protocol over 3 integrated services digital network lines (384 kilobits per second). This resulted in a frame rate of 23 to 30 frames per second. Sonographers who primarily scanned adult patients but had received additional training in echocardiography of infants performed the echocardiograms. Additional views were suggested as deemed necessary by the interpreting physician, and interpretations were made during the videoconference. The results of the echocardiogram and recommendations for patient care were communicated to the referring physician over the telemedicine system. Analyses of accuracy, patient treatment, echocardiogram quality, time to diagnosis, pediatric cardiologist practice time management, patient referral patterns, and echocardiography utilization were conducted prospectively.**

Results. **A total of 500 studies in 364 patients were transmitted during a 30-month period. The most common indication for echocardiography was to rule out congenital heart disease (208 of 500 studies). Signs and symptoms that prompted this concern included cyanosis, murmur, tachypnea, genetic syndrome, arrhythmia, abnormal fetal echocardiogram, and maternal diabetes. Other indications included suspected patent ductus arteriosus (PDA; 182 of 500 studies), intracardiac clot or catheter position, persistent pulmonary hypertension, and hemodynamic instability. Cardiac diagnoses included complex congenital heart disease ($n = 16$), noncritical heart disease ($n = 107$), and PDA ($n = 86$). Additional diagnoses included persistent pulmonary hypertension ($n = 12$), septal hypertrophy ($n = 18$), right atrial mass/clot/vegetation ($n = 11$), and decreased cardiac function ($n = 6$). An umbilical venous catheter was visualized in the left atrium in 9% (45 of 500) of all studies. No significant abnormalities were found in 244 studies. Major diagnoses were confirmed by subsequent review of videotape in all studies. Comparison of final videotape interpretation to initial telemedicine diagnosis resulted in 1 minor diagnostic change (membranous versus inlet ventricular septal defect). Echocardiograms were performed in subsequent visits in 264 patients. The diagnosis was altered in 3 patients. Telemedicine had an immediate impact on patient care in 151 transmissions. The most common interventions were indomethacin treatment for PDA ($n = 76$), retraction of umbilical venous catheters from the left atrium ($n = 45$), inotropic or anticongestive therapy ($n = 19$), anticoagulation ($n = 8$), and prostaglandin infusion ($n = 8$). Nineteen patients were transported to our hospital because of the telemedicine diagnosis. Inpatient or outpatient cardiology follow-up was recommended in an additional 131 studies and did not result in any change in the initial management. The most common diagnoses in these patients were ventricular septal defect ($n = 56$), atrial septal defect ($n = 21$), septal hypertrophy ($n = 9$), intracardiac thrombosis ($n = 8$), and pulmonary valve stenosis ($n = 4$). We speculate that the immediate availability of an echocardiographic diagnosis likely prevented unnecessary transport in 14 cases. Recommendations for additional views or adjustment of echocardiography machine settings were made in 95% of transmissions. Real-time guidance was especially helpful in suprasternal notch and subcostal sagittal imaging. Depth, color Doppler sector size, and color Doppler scale were frequently adjusted from routine adult settings during the teleconference. The average time from request for echocardiogram to completion of the videoconference was 28 ± 14 minutes. This was significantly shorter than the waiting time (12 ± 16 hours) for the videotape to be**

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delivered by courier. Telemedicine eliminated the need for consultation in 194 cases and allowed the cardiologist to delay the visit until the end of the day in an additional 26 cases. This resulted in average time savings of 4.2 person-hours/wk based on travel and consultation time. Utilization of echocardiography was similar before (35 of 1000 births) and after (33 of 1000 to 43 of 1000) telemedicine installation. The percentage of neonatal echocardiograms that were interpreted by our practice increased from 63% to 81% at 1 hospital and from 0% to 100% at the other hospital.

Conclusion. **Real-time transmission of neonatal echocardiograms from community hospitals over 3 integrated services digital network lines is accurate and has the potential to improve patient care, enhance echocardiogram quality, aid sonographer education, and have a positive impact on referral patterns and time management without increasing the utilization of echocardiography. *Pediatrics* 2002;109(1). URL: http://www.pediatrics.org/cgi/content/full/109/1/e3; *telemedicine, echocardiography, congenital heart disease, neonatology, patent ductus arteriosus.***

ABBREVIATIONS ISDN, integrated services digital network; Kbps, kilobits per second.

Echocardiography is used for definitive diagnosis or exclusion of congenital heart disease in newborns.[1,2] Many neonates in rural areas or smaller cities do not have immediate access to local pediatric sonographers or echocardiogram interpretation by pediatric cardiologists. This can result in suboptimal echocardiogram quality,[3] delay in initiation of medical intervention, unnecessary patient transport, and increased medical expenditures. In community hospitals served by pediatric cardiology consultants, there can also be considerable delay in diagnosis secondary to limitations in the cardiologist's schedule or time for courier delivery of an echocardiogram to a tertiary care center.

Telemedicine has been used with increased frequency to improve efficiency of pediatric cardiology care in hospitals that are not served by pediatric cardiologists. Initial reports suggest that telecardiology is accurate, improves patient care, is cost-effective, enhances echocardiogram quality, and prevents unnecessary transports of neonates in locations that are not served by pediatric cardiologists.[4–12]

Pediatric tele-echocardiography is also being used in community hospitals in larger metropolitan areas. We report the largest series to evaluate the impact of telemedicine on delivery of pediatric cardiac care in this setting. The aim of this study was to evaluate the accuracy of real-time pediatric tele-echocardiography and the impact of this technology in a community hospital on patient care, quality of echocardiography, utilization of echocardiography, referral patterns, and pediatric cardiologist time management.

METHODS

Desktop videoconferencing computers (ViTel Net Inc, McLean, VA) and 3 integrated services digital network [ISDN] telephone lines were installed in 2 community hospitals (Silver Spring and Cheverly, MD) and a tertiary care pediatric echocardiography laboratory (Washington, DC). The community hospitals were 15 miles (30–45 minutes driving time) from the tertiary care center. Before telemedicine, echocardiograms were sent to the tertiary care center by courier or interpreted on-site by consulting pediatric cardiologists who traveled to the community hospital. Telemedicine was available for all patients in the neonatal intensive care unit, well-infant nursery, and pediatric ward undergoing echocardiography. The service was available at night and on weekends at the discretion of the sonographer and cardiologist on call. The investigational review board of Children's National Medical Center sanctions the practice of telecardiology.

Echocardiograms were performed on the SONOS 2500 or 5500 (Agilent Technology, Andover, MA) or Sequoia C256 (Acuson, Mountain View, CA) with high-frequency neonatal transducers. Patients were imaged from standard pediatric windows (parasternal long and short axis, apical four-chamber, subcostal coronal and sagittal, and suprasternal coronal and sagittal). Studies were transmitted in real-time using the H.320 videoconferencing protocol over 3 ISDN lines (384 kilobits per second [Kbps]). This resulted in a frame rate of 23 to 30 frames per second. The S-VHS output of the echocardiography machine and video camera signal served as alternative video inputs into the telemedicine unit along with continuous audio communication. Each end had the option of viewing the S-VHS picture or video camera signal. Studies were transmitted from neonatal intensive care units and well-infant nurseries.

Sonographers who primarily scanned adult patients but had received additional training in echocardiography of infants performed the echocardiograms. One of 7 pediatric cardiologists licensed in both the District of Columbia and Maryland provided continuous audio feedback to the sonographers while viewing the studies live. Additional views were suggested as deemed necessary by the interpreting physician, and interpretations were made during the videoconference. The results of the echocardiogram and recommendations for patient care were communicated to the referring physician over the telemedicine system. In a small number of cases, studies were recorded before telemedicine transmission, and the videotape playback was transmitted over the telemedicine system. Studies were also recorded on videotape and sent by courier.

The final reading was compared with the initial telemedicine interpretation. The physician who was covering the echocardiography laboratory when the tape arrived made the final interpretation (not necessarily the same physician who participated in the teleconference). Follow-up diagnostic studies were also reviewed to uncover any diagnostic errors in the initial telemedicine transmission. The decisions to refer patients for follow-up care and perform echocardiograms during these follow-up visits were at the discretion of the individual physicians.

Data were collected prospectively on each transmission, including patient location, age, and weight; indication for echocardiogram; diagnosis; management recommendations; sonographers guidance; and time utilization. Each study was classified as echocardiogram only, echocardiogram with consultation, or avoided consultation on the basis of the service requested by the referring neonatologist or pediatrician. The average time required for an on-site consultation was assumed to be 3 hours. This includes round-trip travel time, patient examination, on-site review of any diagnostic testing, and discussion of the findings with the family. Time savings for pediatric cardiologists were calculated on the basis of videoconference time and number of avoided consultations and expressed as person-hours per week.

The impact of telemedicine on utilization of echocardiography was evaluated by comparing the number of echocardiograms per 1000 births performed during the 12 months before telemedicine to the 30 months after installation of telemedicine. The impact on referral patterns was assessed by comparing the percentage of all pediatric echocardiograms referred to our practice from each hospital during the 12 months before telemedicine to the first 12 months of telemedicine. Statistical analysis was performed using χ^2 testing with statistical significance assumed at $P < .05$.[13]

RESULTS

There were 500 telemedicine transmissions in 364 patients between April 1998 and October 2000. All 500 studies are included in the analysis. Echocardiograms were performed in the neonatal intensive care

unit in 380 cases (76%), in normal newborn nursery in 116 cases (23%), and on the pediatric floor in 4 cases (1%). Echocardiograms were transmitted in real time in 95% (473 of 500) of cases. The mean weight and age were 2.2 ± 1.3 kg (149 studies in patients <1 kg) and 8.9 ± 15 days (range: 2 hours to 4 years), respectively. Seven studies were performed on Saturday or Sunday, and 2 were performed after 7 PM.

The most common indication (Table 1) for echocardiography was to rule out congenital heart disease (208 of 500 studies). Signs and symptoms that prompted this concern included cyanosis, murmur, tachypnea, genetic syndrome, arrhythmia, abnormal fetal echocardiogram, and maternal diabetes. Other indications included suspected patent ductus arteriosus (PDA; 182 of 500 studies), intracardiac clot or catheter position, persistent pulmonary hypertension, and hemodynamic instability.

Diagnoses are shown in Table 2. A cardiac diagnosis was identified in 209 studies (42%). Cardiac diagnoses included complex heart disease (n = 16), uncomplicated heart disease (n = 107), and PDA (n = 86). Additional diagnoses included persistent pulmonary hypertension (n = 12), septal hypertrophy (n = 18), right atrial mass/clot/vegetation (n = 11), and decreased cardiac function (n = 6). An umbilical venous catheter was visualized in the left atrium in 9% (45 of 500) of all studies. No abnormalities were found in 244 studies. Patients with physiologic pulmonary branch stenosis (peak velocity <2 m/sec) or a patent foramen ovale and full-term infants who were <72 hours old and had a PDA were considered to be normal.

Comparison of final videotape interpretation to initial telemedicine diagnosis resulted in 1 minor diagnostic change. One patient who was believed to have a small membranous ventricular septal defect with tricuspid valve aneurysm tissue partially closing the hole by telemedicine was found to have a transitional atrioventricular septal defect with a small atrial component after videotape review.

Echocardiograms were performed in subsequent visits in 264 patients. The diagnosis was altered in 3 patients. A patient with an initial diagnosis of 2 small muscular ventricular septal defects at 2 days of life was found to have 1 ventricular septal defect and a small coronary to right ventricular fistula at 1 month of life. Careful pulsed-wave Doppler interrogation with attention to timing in the cardiac cycle during the live transmission might have prevented this error.

Two patients who received a diagnosis of mild physiologic pulmonary branch stenosis at 1 and 9 days of life were found to have moderate to severe obstruction at 1 month (1 patient with valvar pulmonary stenosis and 1 with pulmonary artery branch stenosis). Follow-up was recommended in both cases, but the site of obstruction was not correctly diagnosed in the patient with pulmonary valve stenosis. In all 3 cases, telemedicine echocardiograms were performed while the pulmonary vascular resistance was still elevated. This affects the interpretation regardless of how the echocardiogram was performed. Patient care was not adversely affected in any of these cases.

The telemedicine encounter altered immediate patient management in 151 studies. The most common interventions were indomethacin treatment for PDA (n = 76), retraction of umbilical venous catheters from the left atrium (n = 45), inotropic or anticongestive therapy (n = 19), anticoagulation (n = 8), and prostaglandin infusion (n = 8). Nineteen patients were transported to our hospital because of the telemedicine diagnosis (Table 3).

Inpatient or outpatient cardiology follow-up was recommended in an additional 131 studies and did not result in any change in the initial management. The most common diagnoses in these patients were ventricular septal defect (n = 56), atrial septal defect (n = 21), septal hypertrophy (n = 9), intracardiac thrombosis (n = 8), and pulmonary valve stenosis (n = 4). Follow-up was recommended in some patients with physiologic pulmonary branch stenosis and in some full-term infants with a PDA at the

TABLE 1. Indications for Echocardiography

Indication	Studies
Suspected congenital heart disease	208
Cyanosis	23
Tachypnea	7
Murmur	148
Arrhythmia	12
Fetal echo concern	8
Suspected coarctation	10
Rule out PDA	182
Follow up congenital heart disease	9
Genetic syndrome	21
Persistent pulmonary hypertension	21
Clot, endocarditis, or catheter position	28
Suspected pericardial effusion	5
Suspected hypertrophic cardiomyopathy	13
Hemodynamic instability	9
Hypertension	2
Kawasaki disease	2

TABLE 2. Diagnoses

Diagnosis	Studies (Patients)
Stable congenital heart disease	107 (90)
Atrioventricular septal defect	5 (2)
Ventricular septal defect	70 (58)
Atrial septal defect	21 (21)
Pulmonary valve stenosis	4 (4)
Ebstein's anomaly/tricuspid regurgitation	3 (2)
Aortic insufficiency	2 (2)
Left ventricular diverticulum	2 (1)
Complex congenital heart disease	16 (12)
Ebstein's anomaly/pulmonary atresia	1 (1)
Critical coarctation	2 (2)
Critical aortic valve stenosis	4 (1)
Critical pulmonary valve stenosis	2 (2)
Tricuspid valve atresia	1 (1)
Hypoplastic left heart syndrome	2 (2)
Double outlet right ventricle	3 (2)
Total anomalous pulmonary venous return	1 (1)
PDA	86 (68)
Persistent pulmonary hypertension	12 (11)
Septal hypertrophy	18 (7)
Intracardiac clot/vegetation	11 (2)
Ventricular dysfunction	6 (4)
Normal	244 (170)

TABLE 3. Impact of Telemedicine on Patient Transport

Diagnosis	Patients
Transports avoided	14
Persistent pulmonary hypertension	8
Left ventricular dysfunction	2
Suspected hypoplastic left heart on ultrasound	1
Double outlet right ventricle	1
Right ventricular hypertrophy	1
Left ventricular diverticulum	1
Transported patients	19
Ebstein's anomaly/pulmonary atresia	1
Critical coarctation	1
Critical aortic valve stenosis	1
Critical pulmonary valve stenosis	2
Tricuspid valve atresia	1
Hypoplastic left heart syndrome	2
Double outlet right ventricle	1
Total anomalous pulmonary venous return	1
Large right atrial thrombus	1
Ventricular septal defect/heart failure	1
PDA	7

discretion of the pediatric cardiologist who interpreted the study.

We speculate that the immediate availability of an echocardiographic diagnosis likely prevented unnecessary transport in 14 cases (Table 3). In these cases, the referring physician believed that the child most likely had critical heart disease and would not have been comfortable waiting for interpretation of an echocardiogram sent by courier or an on-site consultation. The telemedicine encounter revealed diagnoses that could be managed at the community hospital.

Echocardiograms were interpreted in real time with continuous audio interaction between the sonographer and the attending pediatric cardiologist in 95% (473 of 500) of cases. Recommendations for additional views or adjustment of echocardiography machine settings were made in each of these cases. Real-time guidance was especially helpful in suprasternal notch and subcostal sagittal imaging. Depth, color Doppler sector size, and color Doppler scale were frequently adjusted from routine adult settings during the teleconference.

The referring physician participated in the teleconference in 91% (453 of 500) of studies with immediate feedback of diagnoses and management recommendations. In all other cases, the results and recommendations were communicated to a nurse practitioner or a resident. Each telemedicine encounter was immediately followed by a facsimile report sent to the referring hospital unit. The patients' parents were present for the teleconference in 16 cases.

The average time from request for echocardiogram (time when sonographer was available to perform the study) to completion of the videoconference was 28 ± 14 minutes. This was significantly shorter than the waiting time (12 ± 16 hours) for the videotape to be delivered by courier and interpreted. Studies performed late in the day were often not received until the next business day. Total videoconference time was 20 ± 8 minutes, and waiting time was 8 ± 11 minutes. Approximately three fourths of the time (15 ± 6 minutes) was devoted to the echocardiogram itself, and the rest was dedicated to discussing the findings with the referring physician.

On-site consultation was requested in addition to echocardiography in 46% (228 of 500) of the studies. Telemedicine eliminated the need for consultation in 194 cases and allowed the cardiologist to delay the visit until the end of the day in an additional 26 cases. This resulted in average time savings of 4.2 person-hours/wk based on travel and consultation time.

The total number of pediatric echocardiograms (telemedicine and conventional) per 1000 live births performed at the referring hospitals was not significantly different during the 12-month period immediately before and the 30 months after the initiation of telemedicine (Fig 1). The percentage of pediatric echocardiograms performed at each hospital that were referred to our practice for interpretation did increase significantly after the initiation of telemedicine: 63% to 81% ($P < .01$) in Silver Spring, Maryland, and 0% to 100% ($P < .001$) in Cheverly, Maryland.

DISCUSSION

This is the largest series to date on utilization of neonatal telecardiology, focusing on low-cost, real-time application of this technology in community nurseries. Telemedicine substantially altered patient care, improved sonographer proficiency, and prevented unnecessary transports in our study. No clinically significant diagnostic errors resulted from telemedicine interpretations when compared with videotape. Telemedicine benefited our practice by increasing patient referrals and improving time management without increasing utilization of echocardiography.

The earliest clinical publication on utilization of telemedicine in clinical cardiology was reported in 1989.[14] In 1993, Sobczyk et al[12] described store and forward telemedicine from a remote neonatal inten-

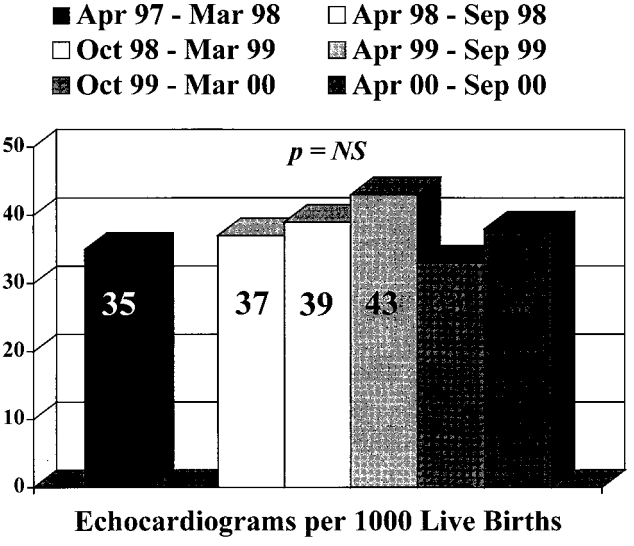

Fig 1. Utilization of echocardiography during the 12 months immediately before (black bar) and 30 months (divided into 6-month periods) after (white and gray bars) installation of telemedicine.

sive care unit to a tertiary care center in Kentucky over plain old telephone systems lines. Although 9 of 47 studies had missing data, only 1 of these led to a delay in management. Trippi et al[15–17] described accurate utilization of this technology in adults to provide emergency department consultation for assessment of ventricular function, ischemia, pericardial effusions, and valvular disease using routine echocardiography and dobutamine stress echocardiography.

Live transmission of neonatal echocardiograms over ISDN lines was first reported by Fisher et al[8] in 1996. He interpreted echocardiograms transmitted over a single ISDN line in 3 patients. Casey et al[5,6] reported 97% accuracy of remote transmission of echocardiograms in 61 neonates by pediatricians over 2 ISDN lines. The number of ISDN lines necessary for accurate interpretation of echocardiograms was evaluated by Houston et al.[18] They concluded that 1 and 2 lines were acceptable for M mode and spectral Doppler but that 3 lines were necessary to interpret accurately black-and-white and color Doppler 2-dimensional echocardiography. We used 3 ISDN lines in our study because 1- or 2-line transmissions result in unacceptably low frame rates. Three ISDN lines provide transmission speeds of 384 Kbps, which afford frame rates of 23 to 30 frames per second.

Real-time guided performance and transmission of echocardiograms by adult sonographers from underserved regions in Louisiana over 3 ISDN lines was 100% accurate when compared with videotape interpretation in 60 neonatal echocardiograms.[11] In this study, the telemedicine diagnosis led to an immediate change in management in 42% of patients, including transport of 5 patients and cancellation of transport in 5 others. Randolph et al[10] used higher bandwidth terrestrial 1 lines for transmission of 161 live neonatal echocardiograms in 133 patients from a primary care center in Grand Forks, North Dakota to the Mayo Clinic in Rochester, Minnesota. All studies were believed to be diagnostic, and 59% resulted in a change in management or future follow-up. The percentage of patients in our study with cardiac diagnoses and the number whose care was altered was similar to previous reports.[5–7,10–12]

Neonatal telecardiology can be cost-effective. In the Louisiana study, cost savings from avoided transports during the 7-month study period exceeded the total costs (computers and ISDN lines) of the telemedicine project.[11] Cost savings from avoided transports also exceeded telemedicine costs in a real-time model using broadband technology for pediatric echocardiography in 3 Canadian Maritime Provinces.[7] The impact of telecardiology on length of stay of low birth weight infants in a regional level III neonatal intensive care unit in North Carolina was evaluated by Rendina et al.[19,20] They found a statistically nonsignificant reduction in length of stay of 5.4 days in the first 6 months of their study compared with the 6 months before telemedicine. They projected that cost savings during a 1-year period would be $1.3 million. The cost of telemedicine in their model was $33 per echocardiogram. Additional monetary benefits of telemedicine that are more difficult to quantify include cost savings from prevention of delayed or incorrect management and avoidance of the financial burden of travel and lost wages on the patient's family.[21]

One potential argument against the implementation of neonatal telecardiology is the impact on utilization of echocardiography. In our study and all of the studies referenced above, primary care physicians or neonatologists are responsible for ordering the echocardiograms and may overuse this test. Scholz and Kiensle[22] compared the diagnostic yield of echocardiograms ordered by pediatric cardiologists and community physicians as part of a telemedicine program in Iowa. They found no significant difference in percentage of positive echocardiograms (85% vs 73%) in patients younger than 1 year when ordered by a pediatric cardiologist or a primary care provider. However, there was a large, statistically significant difference (75% vs 17%) in the diagnostic yield in patients older than 1 year. Our study also showed no increase in the utilization of echocardiography in the first year of implementation.

One must choose between real-time videoconferencing and store and forward technology when developing a telemedicine program. We chose real-time transmission because it offers several advantages[23]: live guidance of inexperienced sonographers with the option to obtain additional views, immediate interpretation and communication with the referring neonatologist, sonographer education, and facilitation of family conferencing. There is some image degradation, but the spatial and time resolution at 384 Kbps is of diagnostic quality. Live studies transmitted at slower speeds come across in a more staccato manner and may be less accurate.[18] Although we had provided several hours of hands-on training in echocardiography of congenital heart disease to the adult sonographers who performed our studies, we believed that a diagnostic-quality neonatal echocardiogram could not be obtained as a series of 1-second cine loops necessary for store and forward transmission.

Store and forward transmission does offer advantages over live telemedicine[23]: highest possible image quality, ability to acquire a study at one site and transmit it from another, hard copy of the echocardiogram at the receiving end, and no requirement for a cardiologist at the tertiary care center to be available at the time the study is being performed. The clinical setting, budget, sonographer experience, and cardiologist time constraints all must be taken into consideration when choosing between store and forward and real-time transmission.

Tele-echocardiography has the potential to change immediate treatment of neonates, including initiation of prostaglandin therapy in patients with ductal dependent heart disease, medical treatment of PDA, and adjustment of ventilator settings and inotropic support. Early medical and surgical care of neonates with life-threatening heart disease can significantly reduce morbidity and mortality. Telemedicine also enables patients who have heart defects that require

only outpatient follow-up to be scheduled for outreach clinics.

It is not always easy to distinguish between significant lung disease and congenital heart defects in a cyanotic newborn. Infants with lung disease or transitional circulation, in whom it was not possible to rule out cardiac defects, had been transported before telemedicine. Tele-echocardiography has the potential to prevent unnecessary transports, resulting in decreased morbidity and direct financial savings.[10,11]

The neonatal intensive care units in this study relied on anterior-posterior chest radiographs to confirm umbilical venous catheter position. Although catheter position is not an indication for echocardiography, unsuspected placement in the left atrium can be seen and corrected during a teleconference. Umbilical venous catheter position in the left atrium may result in significant morbidity,[24] and routine chest radiography and blood gas sampling often fail to identify accurately the anatomic location of the catheter.[25,26]

One of the most important benefits of real-time telemedicine is increased echocardiography quality and sonographer proficiency and efficiency.[4] Additional views were suggested in all live transmissions, and major and minor diagnoses not previously encountered were pointed out to the sonographers in many cases. Average study time was <20 minutes. These interactions add to expertise gained from previous instruction in congenital heart disease. Ultimately, this will improve the quality of studies performed when telemedicine is not available.

Telemedicine can play an important role in expanding the patient base of a pediatric cardiology practice.[11,27] Community hospital outreach is a significant part of many pediatric cardiology practices. Urban areas often are oversaturated with pediatric cardiologists and cardiac surgery programs. Referrals of neonates with heart disease are critical to build and sustain a high-quality pediatric cardiac surgery program that performs a substantial volume of cases annually.[28] This is especially important in a free-standing children's hospital with no delivery service. Telemedicine increased referral of neonates to our practice while saving a significant amount of time for our physicians.

The legal ramifications of using telemedicine for echocardiography diagnoses are still evolving, but there have been no telemedicine lawsuits to date.[21,29] Legal questions may also arise when a tertiary care center provides free equipment or support to a referring hospital or practice. The legality of such arrangements depends on the details of the arrangement; it is advisable to seek legal counsel when developing a telemedicine program. Licensure requirements for telemedicine vary by state and may pose limitations.[29] Physicians who interpret telemedicine studies in our practice hold licenses in the District of Columbia and Maryland.

Telecardiology can be profitable as a result of professional echocardiography interpretation fees and downstream revenue from patient referrals, especially those that require open-heart surgery. However, reimbursement for telemedicine consultation is limited and may discourage many physicians from participating. Only 17 states provide Medicaid reimbursement for telemedicine services for a limited number of procedures.[30] Medicare reimbursement for telemedicine has been limited to live interactive consultations in rural health professional shortage areas.[29] Telemedicine advocates are seeking legislation that would broaden the coverage to include any Current Procedural Terminology service and include store and forward technology.

Despite the numerous reports of diagnostic accuracy, positive impact on patient care, and cost-effectiveness of neonatal telecardiology, there are many obstacles to more routine implementation. There are many different software, hardware, and telephone line options available, but none are specifically designed for cardiology. Neonatologists and primary care providers may be concerned that telemedicine may decrease bedside presence of consulting cardiologists when telemedicine is used in local hospitals. Telemedicine does result in cancellation of consultations in patients without heart disease in our practice, but this does not have a negative impact on patient care or referring physician satisfaction. Telemedicine does not change our practice of examining infants with significant heart disease and counseling their families at the community hospital.

There were 3 minor diagnostic errors in our patients when compared with diagnoses on follow-up studies. It is possible that the initial echocardiogram missed important diagnoses in additional patients. The decision to perform follow-up visits and echocardiograms was not standardized in our study; some members of our department order echocardiograms on all patients who are younger than 6 months, whereas others base the decision on clinical criteria. The limitations in the diagnostic capabilities of neonatal tele-echocardiography are no greater than those of echocardiograms performed directly on this patient population by experienced cardiologists or sonographers. Elevated pulmonary vascular resistance in the first days of life can mask accurate diagnosis of lesions with left to right shunts and pulmonary outflow track obstruction.

Although our study had a large number of patients, it was based at 1 tertiary care center and may reflect the bias of our style of practice. The use of historical controls to evaluate patient referrals and utilization of echocardiography may not control for other confounding variables during the 2 time periods. An American Society of Echocardiography grant-supported multicenter study is currently in progress to evaluate the nationwide importance of this technology in pediatric cardiology.[27] This study compares medical and financial outcomes of neonates with access to tele-echocardiography to patients who are served by traditional means.

CONCLUSION

Real-time transmission of neonatal echocardiograms from community hospitals over 3 ISDN lines is accurate and has the potential to improve patient care, enhance echocardiogram quality, aid sonographer education, and have a positive impact on refer-

ral patterns and time management without increasing the utilization of echocardiography. Rapidly evolving technology likely will result in widespread implementation of telemedicine. Multicenter, double-blinded, randomized evaluation of this technology is appropriate to evaluate its role in pediatric cardiology more systematically.

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