The Impact of Telemedicine in Cardiac Critical Care

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Telemedicine was recognized in the 1970s as a legitimate entity for applying the use of modern information and communications technologies to the delivery of health services.1 The earliest mention of telemedicine in cardiology can be traced back to early twentieth century when electrocardiographic data were first transmitted over telephonic wires.2 Telecardiology is one of the fastest growing fields in telemedicine. The advancement of technologies and Web-based applications has allowed better transmission of health care delivery. Although improvements in cardiac care have led to a substantial decline in cardiac mortality over the last 50 years, cardiovascular diseases are still the leading cause of death in the United States. It is estimated that more than 2000 Americans die of cardiovascular disease every day.3 Increases in life expectancy have led to concomitant increases in the prevalence of coronary artery disease and chronic heart failure. It is hoped that the rapid developments in telecardiology will benefit this increasing population of patients and play an important role in further improvements cardiovascular

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outcomes into the twenty-first century. This article discusses current advancements, and the scope of telemedicine in cardiology and its application to the critically ill.

Current telemedicine applications include:

- Tele–coronary care unit (tele-CCU): telecardiologist and teleconsultation in the cardiac care unit
- Tele–electrocardiogram (tele–ECG): prehospital electrocardiogram (ECG) triage and thrombolysis in patients with ST segment elevation myocardial infarction (STEMI)
- Tele–echocardiogram: teleconsultation for congenital heart disease and valvular disease
- Tele–heart failure monitoring, including telephonic and physiologic monitoring

TELE–CORONARY CARE UNIT

Several clinical trials have studied the tele–intensive care unit (tele–ICU) model. Various studies have determined that, if implemented properly, tele–ICU can reduce mortality, length of stay, and complication rates, and improve best-practice adherence. Tele–ICU technology allows continuous secure transmission of patients’ vital signs from an intensive care unit (ICU) to a monitoring center in real time. In addition, monitoring center staff provide teleconsultation and support to bedside physicians and nurses by continuous surveillance and 24-hour alert system. Tele–ICU consultation in the CCU allows continuous monitoring of vital signs, ECG, blood pressure waveforms, oxygen saturation, pulmonary artery catheter waveforms, as well as respiration and body temperature. This process also allows real-time communication and teleconsultation with cardiologists. The feasibility of this concept was studied by Nikus and colleagues.7 In the Finnish study, remote surveillance of the CCU and cardiology ward was performed by a telecardiologist who had access to electronic medical records. The telecardiologist role was supportive, and this person was available for consultation and emergencies. The remote access of hospital intranet and server applications proved reliable and technically feasible. The study indicated a potential for reducing the delay for diagnostic and therapeutic interventions.

Early diagnosis of acute myocardial infarction and appropriate reperfusion by means of percutaneous coronary angioplasty (percutaneous coronary intervention [PCI]) or thrombolysis has been shown to reduce morbidity and mortality, especially in the setting of STEMI. The 2013 American Heart Association/American College of Cardiology STEMI guidelines reinforced the need for regional medical systems to provide reperfusion therapy as rapidly as possible.10 Much attention is being paid to the concept of prehospital thrombolysis en route to the CCU (Fig. 1).11,12

Teleconsultation and remote interaction of a paramedic with a cardiologist available in a CCU holds great promise to reduce delay and increase patient survival. Teleconsultation with the support of wireless and mobile technology additionally allows monitoring and surveillance during transport. Smartphone technology also allows highly accurate interpretation of angiographic lesions and may also serve as a supplementary tool for emergency situations in the critically ill.

Telecardiology currently encompasses a wide variety of applications, including the monitoring of cardiac rhythm and function remotely with software technology. Two of the most important tools within the cardiologist domain are the 12-lead ECG and the two-dimensional and three-dimensional echocardiogram. With wireless technology, cardiologists can remotely access information from patient records and offer timely diagnostic and treatment recommendations.
One of the most important applications of telecardiology is the ability to transmit a recorded ECG to a cardiologist for evaluation. In 3G (third-generation) wireless technology, ECG transmission can occur with the use of mobile phones/tablets at home. The data are delivered via Bluetooth to the hospital. ECG transmission can occur without Internet access as well. Technology has been developed to record ECG signals as audio inputs. This input is transmitted to a hospital with a landline or mobile phone. This technology has allowed patients without Internet access, such as those in rural areas, the ability to record and transmit data to specialized centers. One of the deficiencies of this method is the weak signal quality that may be generated.

With the advent of 3G technology and transmission control protocol/internet protocol (TCP/IP), ECG transmission has become reliable and the signal quality is enhanced.

Clinical trials related to tele-ECG monitoring have proved its applicability in a real-world setting. Because the time to reperfusion is crucial to improving prognosis in patients with acute myocardial infarction, there have been many studies of prehospital ECG interpretation and early triage of patients with myocardial infarction before reaching the hospital.

Brunetti and colleagues reported preliminary data with respect to prehospital ECG triage in patients with STEMI. In this single-center study, patients with STEMI transferred by regional emergency medical service (EMS) were enrolled in the study. Patient were randomized to receive prehospital ECG triage by telecardiology support and directly transferred to cardiac catheterization for primary PCI or transferred to the emergency department where the diagnosis would be made. Times to balloon and PCI treatment (85% vs 35%; P<.001; +141%) were significantly shorter in
patients triaged with telecardiology ECG in the EMS registry, in both short-distance and long-distance groups versus controls. In the MonAMI (MonashHEART Acute Myocardial Infarction) study, prehospital ECG triage and activation of the emergency room infarct team resulted in more patients achieving guideline recommendations. Rasmussen and colleagues showed that almost 90% of patients living within 95 km, with prehospital diagnosis and triage of STEMI, could be treated with primary PCI within 120 minutes.

MORTALITIES AND LEFT VENTRICLE FUNCTION

Mortalities have been studied with respect to prehospital triage. Sivagangabalan and colleagues found that ambulance field triage versus emergency room triage for patients with STEMI significantly reduced door-to-balloon times ($P<.001$) and 30-day mortality, and preserved left ventricular ejection fraction. Field triage decreased revascularization times, and improved early survival. Other investigators have shown that ambulance transmission of electrocardiographic data and triage benefits long-term (1 year) survival as well. Chan and colleagues found that prehospital triage was an independent predictor for survival at 1 year (hazard ratio [HR], 0.37; 95% confidence interval [CI], 0.18–0.75; $P = .006$).

Concerns have arisen in the cardiology community regarding the accuracy of clinical diagnosis of STEMI with minimal clinical information during telemedicine consultation. A great emphasis is placed on the rapid diagnosis and triage of patients with ECG interpretation when there is scanty history. McCabe and colleagues’ study of physician accuracy emphasizes this fact. In this cross-sectional study, there is significant physician disagreement in interpreting ECGs that are concerning for STEMI, and poor agreement for ECG interpretation among specialties. Even after adjusting for experience, there was no significant difference in the odds of accurate interpretation alone, thus indicating that ECGs should not be the only diagnostic test.

Cost-effective of ECG telemedicine is not well studied. Some of the first data on the issue are from an observational study by Brunetti and colleagues. The cost analysis is an observational study based in the Apulia region in Italy. Patients who called the local EMS during 2012 and underwent prehospital triage with telemedicine ECG in cases of suspected acute cardiac disease were included. The ECGs were read remotely by a cardiologist. The cost of usual care versus this method of triage was calculated. Although the cost was calculated and value added tax was not considered, there was a potential saving in presumed lives per year saved and cost per quality-adjusted life year gained.

ECHOTELEMEDICINE

Echocardiography is a vital tool for cardiologists to evaluate ventricular function and valvular disease in the critically ill. Progressive telemedicine technology has a great potential to improve access to specialists in the ICU.

The first mention of interpretation of echocardiography by telemedicine support was in the 1980s, by Finley and colleagues. In 1987 they established a real-time pediatric echocardiography service at a tertiary care center with service to regional hospitals. The system of transmission used was dial-up broadband video transmission. About 70% of the studies were urgent examinations. A comparison between transmitted images and bedside in-person images showed few differences in diagnoses and unnecessary transfers. In 1996, Trippi and colleagues described the use of tele-echocardiography in emergency consultation telemedicine. In their prospective study, urgent echocardiograms were performed off hours (nights, weekends, holidays)
assessing for ventricular function, ischemia, valvular disease and so forth. Interpretations of the echocardiograms were compared with interpretations made by reviewing videotapes in a blinded manner. Off-site echocardiographers reviewed the images in a cine-loop format transferred to home laptop computers. Abnormalities were identified in more than 80% of the studies, including wall motion abnormalities, pulmonary hypertension, aortic dissection, valvular dysfunction, and tamponade. Telemedicine and videotape interpretations correlated 99% of the time and the time to generate official echocardiogram reports were reduced significantly. In the same year, Trippi and colleagues also performed dobutamine stress echocardiography on 26 patients in emergency rooms admitted for chest pain who were considered low risk for myocardial infarction. The studies (echocardiography cine-loops and ECG tracings) were interpreted by an off-site cardiologist. The images were transmitted to the laptop computer of the cardiologist by traditional phone line linked to a computer modem. Myocardial infarction was ruled out in 25 of the 26 patients.

Recent advances in wireless and smartphone technology have led to echocardiographic interpretation with mobile-to-mobile consultation with predictable accuracy.

Pediatric cardiology has been the first field to embrace the concept of tele-echocardiography. Many neonates in small towns and rural areas do not have access to pediatric sonographers or cardiologists. This lack of access may cause a considerable delay in diagnosis. Perhaps the severe shortage of specialists in the field has preempted the early development of telemedicine services. Accurate remote diagnosis and the exclusion of congenital heart disease in patients has had an impact on treatment plans and may produce cost savings by reducing transport needs and unnecessary work-up.

One obvious limitation of tele-echocardiography is that a skilled operator is required for proper ultrasonography image acquisition, and the quality of the examination depends heavily on the operator’s skills. To overcome this issue, Courreges and colleagues developed and studied a robotic teleultrasonography system (OTELO). It consists of 2 stations, an expect station where the sonographer controls a virtual probe, and a patient station consisting of a real probe held by a lightweight robot. The real probe is positioned on the patient. A total of 52 patients had ultrasonography examinations at 2 different hospitals. The diagnosis obtained with the remote scanning system agreed in at least 80% of the cases with the diagnosis made by conventional scanning. Disagreements with the final diagnosis occurred with lesions caused by low resolutions, suboptimal scanning, and inadequate image acquisition.

Recent technology allows live streaming of echocardiographic imaging and simultaneous video conferencing over the Web. The EchoCart by StatVideo permits video communication between caregivers/families with physicians who can guide the imaging procedure, facilitating understanding about the patient. Because the streaming is over the Web, there is a cost saving as well.

In spite of limitations, real-time tele-echocardiography has been effective in assisting with challenging cases requiring complex medical management. An example of this is the case report by Otto and colleagues. The case discussed teleultrasonography consultation between cardiologists at the University of Texas at Galveston and staff in a research center in Antarctica about a patient with pericarditis. The use of this technology prevented unnecessary medical evacuation and transfer, allowing the patient to receive treatment at the center. Other promising applications of tele-echocardiography have been seen on the International Space Station and in heart transplant procurement.
ROBOTIC CARDIAC CATHETERIZATION

In the PRECISE (Percutaneous Robotically Enhanced Coronary Intervention) study, Weisz and colleagues\textsuperscript{41} showed that robotic percutaneous coronary intervention by means of the CorPath 200 robotic system (Corindus Vascular Robotics, Waltham, MA) was successful in 98.8\% of patients. The system consists of a remote interventional cockpit with a bedside disposable cassette that facilitates operator-guided manipulation of guidewires, catheters, stents, and balloons. In the current study, the operator remained in the same catheterization laboratory as the patient. Remote robotic cardiac catheterization trials are currently being formulated in which the operator will attempt revascularization from a distant site. In the future, this may enable patients from underserved regions to derive the benefit of percutaneous intervention.

CHRONIC HEART FAILURE MONITORING

There are currently more than 5 million Americans with a known diagnosis of heart failure and about 650,000 new diagnoses are made yearly.\textsuperscript{42} An additional 3 million patients are expected to develop heart failure in the United States by 2030.\textsuperscript{43} The worsening heart failure epidemic is a significant driver of health care expenditure. The cost of health care services, medications, and lost productivity caused by heart failure was estimated to exceed $30 billion in 2013, with the mean cost of a heart failure admission averaging about $23,000.\textsuperscript{42} The United States Centers for Medicare and Medicaid Services began public reporting of all-cause readmission rates after a heart failure admission in 2009.\textsuperscript{44} Subsequently, the Patient Protection and Affordable Care Act of 2010 established financial penalties for hospitals with the highest readmission rates within 30 days of discharge.\textsuperscript{45} Thus, there is an unmet need to develop new strategies to improve heart failure care overall, and a particular focus to reduce readmissions specifically.

Notable progress in heart failure management has been made with new drug therapies and remote monitoring of patients with heart failure. Because of the labor-intensive nature of heart failure management, remote monitoring has become appealing, and is potentially a cost-effective method of home management and prevention of readmission. Telemedicine support in particular has evolved to include telephone communication or electronic monitoring with peripheral devices and video consultation.\textsuperscript{46} Many studies have had conflicting data regarding the improved outcomes related to telemedicine in caring for patients with heart failure.

Rich and colleagues\textsuperscript{47} showed that nursing-directed, multidisciplinary inventions, including education, and follow-up (individualized home visits and telephone contact) reduced the rates of readmission substantially and increased quality-of-life scores. A clinical trial by Riegel and colleagues\textsuperscript{48} indicated that standardized nurse case management provided to sick patients with heart failure by telephone in the first 6 months after discharge can provided cost savings, less resource use, and improved patient satisfaction.

HEART FAILURE MONITORING

Various forms of supportive monitoring have evolved to care for the medically complex heart failure population.

\textit{Telephone-based Monitoring}

One form of support is via telephone. Nursing-directed live phone calls are made to patients and information regarding patients’ status is collected at intermittent periods.
If there seems to be a clinical change or progressive deterioration, patients are instructed to go to their physician or hospital for follow-up. The studies vary in design and in the level and complexity of intervention.

Riegel and colleagues placed a heavy emphasis on patient education. The patients’ clinical statuses were followed by registered nurses for the first 6 months after discharge. The nurses were also instructed to educate patients regarding their disease processes and to emphasize deterioration of illness with the help of decision support software. Reports of clinical statuses were sent to the patients’ physicians, who in turn chose appropriate interventions and therapies. This process was able to reduce hospitalization rates by close to 50% and reduce inpatient costs. In DeBusk and colleagues study in 2004, low-risk patients with heart failure were randomized to nursing intervention with regular care or regular care alone. The intervention group received symptoms monitoring, education, and medications for heart failure with the help of a study protocol. Patients were contacted via telephone intermittently. Additional calls and coordination of care with physicians was the responsibility of the nurse. The study showed no reduction in hospitalization rates between the two groups and thus no benefit. The DIAL trial compared frequent centralized telephone intervention by a nurse trained in the management of chronic heart failure with usual care. The objective was to educate and monitor the patients. The focus was adherence to diet, drug treatment, fluid status, and symptoms monitoring. The nurses used software to determine the frequency of calls, and algorithms were used to adjust the diuretic dose. With this intervention, there was a significant reduction in admissions for heart failure in the intervention group (relative risk reduction, 29%; \( P = .005 \)). A better quality of life was noted in this group (mean total score on Minnesota Living with Heart Failure questionnaire, 30.6 v 35; \( P = .001 \)) compared with the nonintervention group. A similar trial by Dunagan and colleagues randomized patients to usual care or scheduled telephone calls by nurses emphasizing self-care and guideline-based therapy as prescribed by primary physicians. The nurses screened for heart failure decompensation and could make changes in diuretic dose accordingly. The intervention patients experienced a delay to encounter (HR, 0.67; 95% CI, 0.47–0.96; \( P = .29 \)), hospital readmission, and heart failure–specific readmission. In the first 6 months, hospital costs, hospital days, and admissions were significantly lower but this difference was not seen at 1 year. There was little impact on quality of life, functional status, or mortality.

**Mortality and Heart Failure Telecardiology**

There are many trials with new technologies for remote monitoring related to chronic heart failure, including structured telephone calls, videophone, interactive voice-response devices, and telemonitoring (Fig. 2).

In the subanalysis and meta-analysis by Conway and colleagues, 2 of the 4 modalities, structured telephone calls and telemonitoring, were effective in reducing the risk of all-cause mortality (relative risk [RR], 0.87; 95% CI, 0.75–1.01; \( P = .06 \); and RR, 0.62; 95% CI, 0.50–0.77; \( P < .0001 \), respectively) and heart failure–related hospitalizations (RR, 0.77; 95% CI, 0.68–0.87; \( P < .001 \); and RR, 0.75; 95% CI, 0.3–0.91; \( P = .0003 \), respectively). More randomized studies need to be done to focus on effectiveness of remote monitoring in heart failure. A meta-analysis by Clark and colleagues assessed whether remote monitoring for patients with chronic heart failure (structured telephone support or telemonitoring) without regular clinic or home visits improves outcomes. Remote monitoring reduced the rates of admission to hospital for chronic heart failure by 21% (95% CI, 11%–31%).
and all-cause mortality by 20% with benefits to quality of life and some cost benefits.

A meta-analysis by Schmidt and colleagues\(^{54}\) of both telephone support and monitoring of vital signs/data concluded that scientific data on vital sign monitoring are limited, but that it may have positive effects related to mortality. Both modalities seem to be effective, but there is no evidence to suggest that one type is superior to the other.

AUTOMATED PHYSIOLOGIC MONITORING

Koehler and colleagues\(^{55}\) designed a study to determine whether physician-led remote telemedical management (RTM) would reduce mortality in patients with chronic heart failure (class II or III). The system was a wireless Bluetooth device connected to an ECG monitor, a blood pressure monitor, and a weighing scale in the patients’ homes. The patients performed a daily self-assessment with the devices and the data were transmitted to the telemedicine center. Physicians in the telemedicine center were available 24 hours a day, 7 days a week for consultation, instituting treatment, or in case a patient asked to speak with them. The median follow-up was 26 months. Compared with usual care, RTM had no significant effect on all-cause mortality (HR, 0.97; 95% CI, 0.67–0.41; \(P = .87\)) or on cardiovascular death or heart failure hospitalization. The Japanese HOMES-HF (Home Telemonitoring Study for Patients with Heart Failure) study is currently underway with the
aim of investigating whether an automated physiologic monitoring system (body weight, blood pressure, pulse rate) in a heart failure treatment program could reduce mortality and readmission rates after acute decompensated heart failure. All patients are New York Heart Association functional class II to III and have been discharged for the hospital within 30 days. The primary end point is a composite of all-cause death and rehospitalization because of worsening heart failure. According to the study protocol, participants were enrolled until August 2013 and followed until August 2014.

A large proportion of patients with heart failure with reduced ejection and severe left ventricular dysfunction receive device therapy in the form of implantable cardioverter defibrillators (ICDs) or cardiac resynchronization devices. It is possible to use data stored in these devices remotely to guide heart failure therapy. For example, it is possible to calculate intrathoracic impedance between pacing or ICD leads and the pulse generator. Thoracic impedance is thought to be inversely related to pulmonary fluid because water is a better conductor of electricity than air. In the FAST (Fluid Accumulation Status Trial) study intrathoracic impedance monitoring was more sensitive predictor of hospital admission for heart failure than weight measurement. The DOT-HF trial did not show a decrease in hospital admissions based on intrathoracic impedance monitoring and paradoxically showed an increased admission rate.

Invasive monitoring of left atrial pressure by means of an investigational implantable lead sensor is currently being studied. The lead is connected to a subcutaneous antenna coil that relays left atrial pressure remotely via secure computer-based management. The first observational trial using invasive left atrial pressure–guided therapy did show a decrease in heart failure admissions in patients managed with the left atrial sensor. A large multicenter randomized trial, the LAPTOP-HF (Left Atrial Pressure Monitoring to Optimize Heart Failure) trial, is currently underway to validate these findings.

Despite the development of comprehensive systems for the management of patients with heart failure, hospitalization rates remain exceptionally high. In spite of systematic study of home monitoring, there is limited evidence that it improves readmission rates or mortality. Telemonitoring management has failed to show effectiveness in patients with advanced heart failure, but may show promise in low-risk patients who still require intermittent care.

SUMMARY

The impact of telecardiology consultation in critically ill patients continues to evolve and includes many promising applications with potential positive implications for admission rates, morbidity, and mortality.

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