Telemedicine ECG-Telemetry with Bluetooth Technology

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Abstract

The newest Bluetooth communication technology was added to our previously developed Internet based information system, wich collects the short- and long-term digitized ECGs with the relevant clinical data for the management of the patients. A wireless communication protocol was developed using the Bluetooth system for a short distance (10-20m) radio-frequency data transmission. This unit could send compressed records to a WEB Server via GSM phone modem. During the study 3850 ECG based telemedicine consultations took place. 1663 ambulatory monitoring with on-line monitoring via the Internet were done. The thrombolysis time-delay in acute myocardial was studied of 36 patients, home telecaring was done in 39 patients with acute myocardial infarction immediately after the hospital discharge, and monitoring in a nursing hospital was used.

1. Introduction

Telemedicine presents unique opportunities for both patients and clinicians where it is implemented in direct response to clear clinical need [1]. Newly designed computer-based applications and development of wireless technology have allowed the transmission of 12-lead electrocardiograms (ECG) from remote locations to the computers of cardiologist's [2]. ECGs are among the most commonly performed tests in medicine and are "the procedure of first choice" in the evaluation of patients with chest pain, syncope, or dizziness. The ACC/AHA guidelines [3] addressed categories of pts defined by whether they had known, suspected, or no evidence of cardiovascular (CV) disease. For each patient category, the guidelines evaluated use of ECG as a baseline test, for evaluation of response to therapy, for follow-up, and before surgery. For each of these items the guideline definiate three classes (appropriate, equivocal and inapropriate. These 36 cells were determined as objectums for the indication process.

The proper interpretation of the ECG based on the knowledge of the clinical context. The accuracy and the value of interpretation are enhanced by having clinical information about the patient. Knowledge of prior ECG patterns can improve diagnostic accuracy and triage decisions for patients with current ECG. Handling technical errors and artifacts are also important: misplacement of one or more ECG electrodes is a common cause for errors in ECG interpretations. Electrical or mechanical artifacts such produced by poor electrode contacts or tremors can simulate life-threating arrhythmias. Excessive body motion can cause significant baseline wander that may simulate a ST-segment shift of myocardial ischemia or injury. Studies assessing the accuracy of routine interpretations have demonstrated significant numbers of errors that can lead to clinical mismanagement [4,5]. The current systems with automated interpretation are not sufficiently accurate, especially in the presence of rhythm disturbances or complex abnormalities, to be relied on in critical clinical environments without expert review [6,7].

The development of our system conceptually based on the important progress was made during the latest period in several relevant areas of ambulatory electrocardiography (aECG) [8], including solid-state digital technology that facilitates transtelephonic transmission of ECG data, technical advances in long-term event recorders, improved signal quality and interpretation, improved computer arrhythmia interpretation. The ACC/AHA guidelines offer similarly structurated indication matrix as of the standard ECG (Class_I,II,III) the main parts are: the arrhythmias, the syncope and other clinical signs (dyspnoe, chest pain, fatigue), the ST-segment monitoring, neurological symptoms, the assessment of antiarrhythmic therapy, detection of proarrhythmia.

The role of aECG in clinical settings:

1. Diagnosis

In the assessment of symptoms that may be related to arrhythmias, aECG is most clearly established for evaluation of syncope. When continuous aECG is not diagnostic (the ability of 24-hour aECG to capture rare events such as syncope is low), intermittent recorders may be useful.

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2. Assessment of risk
In certain pts at high risk for arrhythmias, the ACC/AHA guidelines considered aECG Class_IIb (i.e., controversial, without the weight of evidence or opinion in support of appropriateness). Such "marginal" indications include pts with LV dysfunction after myocardial infarction, congestive heart failure, or idiopathic HCM. The ACC/AHA guidelines are not generally encouraging the use of aECG for either arrhythmia detection or analysis of HRV if the goal is risk assessment among pts without symptoms of arrhythmia.
3. Efficacy of antiarrhythmic therapy
aECG is considered appropriate for assessment of the efficacy of antiarrhythmic therapy in some pts with frequent, reproducible arrhythmia. Event recorders can be useful for documenting the relationship between recurrent arrhythmia and the interval between episodes, which is a useful measure of drug efficacy.
4. Assessment of pacemaker and ICD function
aECG can provide useful information by correlating symptoms with device activity and by detecting abnormalities in sensing and capture during chronic follow-up.
5. Monitoring for myocardial ischemia
The 1999 ACC/AHA guidelines do not unequivocally support any indications for routine clinical use of aECG monitoring for myocardial ischemia. The only indication that was rated as high as Class_IIa was detection of ischemia in pts with suspected variant angina. Because of complex technical requirements and diagnostic criteria, the guidelines recommend that aECG to detect myocardial ischemia be performed only by laboratories and personnel with specific training in this area.

2. Method

Our ECG telemedicine information system uses all the advantages of Internet communication. The ECG data of the portable digital ECG recorder are transmitted via radiofrequency route using the Blootooth system to the mobile phone. This remote site communicates with the central unit, which is implemented on a Web server. This special own developed database system collect all the ECG and other clinical data of a given patient and organizes the information flow between the patient, the end/user GP or physician, and the cardiologist expert of the virtual cardiological center. The central view module loads the ECG recordings and after the automated signal analysis the supervised interpretation is taken place. The standard and the long-term ambulatory ECGs were analyzed for rhythm disturbances and morphological abnormalities. The on-line ECG monitoring visualized on the WEB site.

The database mirrors the multidimensional approach of cardiological decision making. During the ECG diagnosis process the expert fills special data sheets (DS):

DS-1: Indication table of standard ECG
DS-2: Indication table of ambulatory ECG
DS-3: Table for symptoms, signs of cardiovascular disease
DS-4: Diagnostic procedure (x-ray, echocardiogram, and lab tests) table
DS-5: Telemedicine "Question-answer" text sheet
DS-6: Summary data table of a given patient at a define time

These sheets (layers) consist a 3-dimensional virtual problem space, where the filled elementary objects (positive values) reconstruct a multidimensional "information torso". During the query process the relevant values would be collect using the object-oriented programming and generated new tables are contain the result of various prospective studies (e.g. cases of ST-segment changes during chest pain syndrome, rhythm disturbances causing near syncope, misinterpretations of the ECG, changes of managing strategy in acute cardiological situations, drug induced ECG abnormalities).

The experts of the central cardiological virtual site use the on-line ECG-related knowledge base. The relevant text objects were collected from the literature from 1996.

The biggest problem of the interpretation of ECG is the incomplete clinical data at a given time. Out system helps to solve it by two ways. Firstly, the clinical data process is defined as a bi-directional (patient-, end-user doctor-, cardiologist-driven) temporarily changeable route. Secondly, the ECG interpretation could be performed with incomplete clinical data, because the decision making is based on the re-calculated ROC (Receiver Operating Characteristic) curves of various ECG diagnosis (e.g., LV hypertrophy, ST-segment displacements in various clinical conditions, ECG signs in definitive and suspected acute myocardial infarction). The ROC curve calculations were based on the clinical and ECG data of our 1910 patient records. The determination of sensitivity and specificity values are expressed as probability values for the ECG interpretations.

3. Study

In the first phase the development of the database was taken place using the above mentioned data sheet structure.

The other layers (DS-3: for symptoms, signs of cardiovascular disease, DS-4: diagnostic procedure (x-ray, echocardiogram, lab tests), DS-5: telemedicine "Question-answer" text sheet, DS-6: Summary data table of a given patient at a define time are also integrated in the object oriented database. The communication protocol make the bidirectional information (text, SMS, digitized ECG) change between the four remote contributors and the central expert (patient, general practitioner, in- and outpatient cardiology department)

possible. The cardiologist uses the on-line knowledge base which is updated in every 3 months.

4. Results

From November 1999 to May 2001 17 general practitioners, two cardiologist of hospital departments used our portable electrocardiograph. During the study 3850 ECG based telemedicine consultations took place. Table 1. shows the data of these consultations showing the clinical settings, the most important consequences of the decision support.

Table 1. Telemedicine consultations during the study

ECG abnormality	Significant changes in patient management	Number of undefinied cases	Total number
Left atrial abnormalities	4	89	192
Rigt atrial abnormalities	14	55	164
LV hypertrophy	118	211	698
RV hypertrophy	42	98	241
LBBB	22	8	68
RBBB	19	2	46
WPW-syndrome	9	3	17
Myocardial ischemia and infarction	466	196	1214
Drug effects	154	112	176
Electrolyte and metabolic abnormalities	33	13	46
Atrial fibrillation	162	14	328
Atrial flutter	10	16	28
Premature ventricular beats	214	26	338
Supraventricular tachycardias	29	31	188
Ventricular tachycardias	18	4	18
Heart blocks	56	16	88

During ambulatory monitoring 1663 recordings were done, Table 2. represents the results of the registrations in various interval settings.

Table 2. Clinical signs during ambulatory (Holter) monitoring in various intervals.

Clinical settings	Clinical settings	72-96 hour	48-72 hour	24-48 hour	< 24 hour	All pts.
Unexplained syncope, near syncope, or episodic dizziness	Syncope	4	7	5	1	17
Unexplained recurrent palpitations	Palpitation	11	34	56	96	197
Episodic shortness of breath, chest pain, or fatigue	Dyspnoe	11	38	18	214	281
Neurological events when transient atrial fibrillation or flutter is suspected	Neurol.dist.	6	3	5	1	15
Post-MI pts with LV dysfunction (*)	PostüAMI LVD	7	5	11	79	102
Pts with CHF (*)	CHF	9	13	24	134	180
Idiopathic HCM (*)	HCM	2	5	3	11	21
To assess antiarrhythmic drug response in individuals in whom(**)	Drug response	36	18	24	246	324
To detect proarrhythmic response to antiarrhythmic therapy in high-risk pts	Proarrhythmia	4	3	21	65	93
To assess rate control during atrial fibrillation	AF-rate contr.	0	4	0	115	119
Recurrent (a)symptomatic nonsustained arrhythmias during outpatient therapy	Arrh.-outpatient	7	22	31	48	108
Pts with suspected variant angina	Variang angina	0	0	1	0	3
Evaluation of pts with chest pain who cannot exercise	Angina/no-exerc.	2	0	1	18	28
Pts with known CAD and atypical chest pain syndrome	CAD+atyp. ang	6	31	26	112	175

(*) detection of ventricular arrhythmia
(**) in whom baseline frequency of arrhythmia has been well characterized as reproducible and of sufficient frequency to permit analysis

In a smaller population the thrombolysis time-delay in acute myocardial was studied. Continuously recorded 12-lead ECGs of 36 patients were transmitted via the Internet to the coronary care unit where the registrations were interpreted by a cardiologist. Patients with an ECG diagnosis of acute myocardial infarction were carried to the emergency room immediately. In 32 patients the diagnosis of acute myocardial infarction could be verified with lab tests and they were thrombolyzed. The time of the arrival to the CCU and the beginning of the thrombolysis was 18 minutes (8-42) compared to the usual value of 36 minutes (13-54).

Home telecaring was done in 39 patients with acute myocardial infarction immediately after the hospital discharge. Table 3. represents the result of the continuous ECG registrations during the first four weeks. Re-hospitalization was necessary in 9 patients, 3 of them were symptom free during the prehospital phase.

Table 3. ECG abnormalities of postinfarction patients during home telemedicine care.

ECG abnormalities	No. of patients
Silent ischemia	8
Angina & ST-depression	7
Heart block (II. or III. Degree)	1
Non-sustained ventricular tachycardia	3
Sustained ventricular tachycardia	2
ECG signs of new myocardial infarction	2
Symptoms with no ECG abnormalities	12
Re-hospitalization	9

The CyberECG information system was used as a nursing hospital telecare system in 49 patients for 30-60 days with almost continuously ambulatory ECG registrations. Table 4. shows the various ECG abnormalities of the patients during the overall 1144 registration hours.

Table 4. ECG abnormalities in geriatric population in nursing home.

ECG abnormalities	No. of patients
Silent ischemia	24
Angina & ST-depression	13
Symptomatic bradycardia	4
Heart block (II. or III. degree)	3
Progression of QT-interval	2
Non-sustained ventricular tachycardia	9
Sustained ventricular tachycardia	3
ECG patterns for acute myocardial infarction	2
Symptoms with no ECG abnormalities	31

5. Discussion

Using the telemedicine ECG method the quick and adequate managing of patients with acute myocardial infarction in the prehospital phase could be done.

Home telecare system is a useful tool in managing postinfarction patients for re-hospitalization and during the rehabilitation process.

The ECG telemedicine in nursing houses would be solved the inconvenience of transportation of chronically ill patients when it is not necessary. The remote ECG surveillance of the geriatric population has the best cost/benefit ratio avoiding the unnecessary hospital admission, preventing the adverse effects of drugs and using telemedicine consultations with the patient and the medical staff.

Apart of the telemedicine-teleconsultations our information system uses the advantage of the well-structured database. Baseline examinations and periodic reexaminations in longitudinal population studies, together the ongoing surveillance for morbidity and mortality, provide unique opportunities for seeking ways to enhance the value of ECG recorded with digital technology and an inexpensive and noninvasive tool for prognosis and diagnosis. At the end of June 2001 all of the medical data and the digitized standard ECGs were collected of 12000 subjects in a well-defined region for epidemiological study.

Our system could capable of comprehensive ECG interpretation (for short term ECG morphological and rhythm analysis, evaluation long term Holter registrations or bedside ECG monitoring via the Internet) as well as access to online consultations for on-line knowledge-based system for remote diagnosis of cardiac arrhythmias and an on-line cardiologist for real-time interactive consultation using the available resources on the Internet.

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