A telecardiology framework for research and clinical decision support: Application to the study of HRV during haemodialysis

JD Trigo, Á Alesanco, P Serrano, J Mateo, A Recaj, I Pascual, RSH Istepanian, J García

***Abstract*— A telecardiology framework for research and clinical decision support is presented. The telemedicine framework provides with connection to three participant sites: the physician at the point-of-care, the remote information centre and the specialized cardiologist. At the point of care, a physician acquires the ECG and other relevant information during the clinical intervention and sends it to the information server. Every ECG file received is stored in the file server, linked to the patient database and processed by the MATLAB-based tools in the processing server, which automatically generates a results report and informs the cardiologist of this fact. The system has been applied in the study of HRV in patients undergoing haemodialysis. In this particular case, the report consists of trends of time-domain and frequency-domain HRV indexes along dialysis and other supplementary information. The framework has been evaluated by patients and hospital personnel, who valued very positively the system. The designed framework has been shown as an efficient and helpful tool for clinical diagnosis support.**

I. INTRODUCTION

THE electrocardiographic (ECG) signal is today the most widely used tool for non-invasive diagnosis of cardiovascular diseases. Many telecardiology applications already implemented and evaluated involve transmission (both in real-time and store-and-forward modes) of ECG signals over different types of communication networks (wired and wireless). Computer-based analysis of the ECG has been used during the last decades with significant success. Interpretation systems have been utilized e.g. to separate automatically normal from abnormal ECG tracings. By using the assistance of computer systems, marked reduction in cardiologists' time and cost has been achieved [1]. Recently, innovative signal processing and analysis techniques have been developed by means of joint efforts of engineers and physicians, resulting in more powerful indexes used for clinical decision support. These new signal processing techniques may be available to medical users (not necessarily involved in their development) through ECG processing servers which could support the diagnosis in the clinical routine [2]-[3].

Another important clinical area where telemedicine has been successfully applied in is dialysis. First projects already showed that technology enabled staff to perform a wide range of clinical procedures, from routine outpatient consultations and monitoring infections to making decisions about retrieval or confirming decisions to operate. Moreover, telemedicine networks enabled to provide improved services [4]. Most of the latest experiences carried out have been mainly focused on automated monitoring of dialysis sessions [5], including communication between the patient's cycler and a computer in the dialysis unit, allowing data transmission and storage, and live patient-physician interaction [6]. In a recent work, a telemedicine system that monitors blood pressure and heart rate by cellular telephone at home in patients on continuous ambulatory peritoneal dialysis was presented [7].

The heart rate variability (HRV) is an extended index to analyze the mechanisms controlling the cardiovascular system. Previous work pointed out the relationship between dialysis and HRV. HRV may have prognostic value in haemodialysis patients identifying an increased risk for sudden death. Decreases in some HRV measures, particularly those reflecting long-term variability, have been shown as independent predictors of cardiac death in chronic haemodialysis patients [8]. Other studies also suggest that haemodynamic instability is strongly associated with a decreased HRV and an impaired sympathovagal balance. Patients with ischemic heart disease reduced left ventricular systolic function and decreased HRV may be at the highest risk to be haemodynamically unstable during haemodialysis. The role of early detection and treatment of ischemic heart disease in preventing symptomatic hypotensive episodes in these patients remains to be determined [9]. The low frequency-high frequency ratio was found to be the most

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influential HRV determinant of death in other study and could help to identify patients at-risk [10].

Most of previous works on this area used a reduced set of HRV indices to study the relationship between HRV and dialysis, some concentrated on time indices [11] and others on frequency indices [8]-[10]. Latest advances on HRV analysis recently leaded to new methods proposed to identify cardiovascular diseases [12]-[13]. Therefore, it could be of high interest to give the possibility to specialists to use conventional and new developed indices for studying the effects of haemodialysis on HRV in order to identify patients at-risk of for sudden-death.

In this paper a framework for research and clinical decision support in the area of telecardiology is presented. The scenario for evaluation of the system is the study of HRV during haemodialysis

II. TELECARDIOLOGY FRAMEWORK

The telemedicine framework consists of three participant sites (see Fig. 1) including the physician at the point-of-care, the specialized cardiologist and the remote information server. At the point of care, a physician acquires the ECG

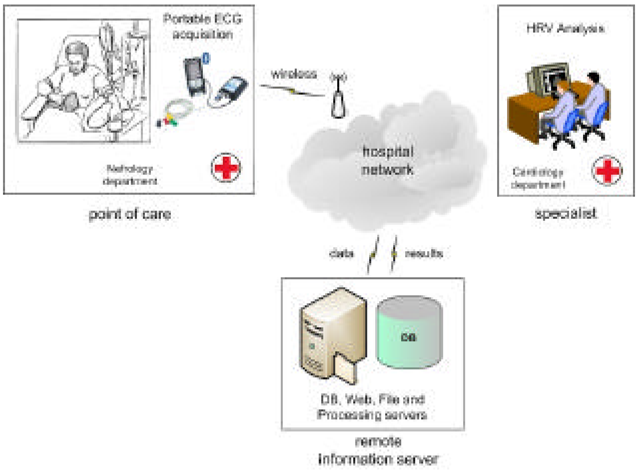

Fig. 1. Scenario for the telemedicine framework

and other relevant information during the clinical intervention using a mobile device and sends it to the information server. Then the information is processed and a results report is automatically produced and stored on the server. Finally, the specialist connects to the information server and gets the results to be analyzed and used in the patient diagnosis.

A. *Data acquisition and transfer*

ECG acquisition is supported by a small portable ECG signal recording unit (gMOBIlab by gTEC, Graz-Austria).

Fig. 2. ECG viewer for the PDA

The mobile biosignal amplifier provides a two channel ECG recorder. Each channel is sampled with 1024 Hz and 16 bits per sample. The biosignal amplifier is connected to a PDA (with 640x480 resolution screen), where different applications have been programmed and included. ECGs can be stored following the SCP_ECG standard directly on the PDA and viewed during acquisition or after recording using the viewer shown in Fig. 2. Additionally the PDA provides a mobile web

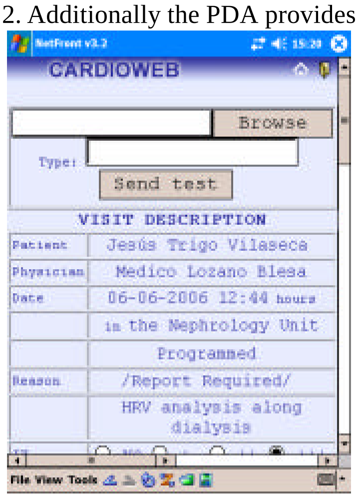

Fig. 3. Web client for the PDA

client in order to have access to and to introduce relevant patient data or events during recording via a mobile web browser (see Fig. 3). The data collected at the point of care is sent through a secure wireless connection to a gateway in the hospital network and finally to the information server. The mean transmission time was 15’08’’ ± 38’’.

B. *Data storage and results report generation*

The information server consists of several modules including the web server (Apache Tomcat), the patient database (MySQL), the MATLAB-based processing server

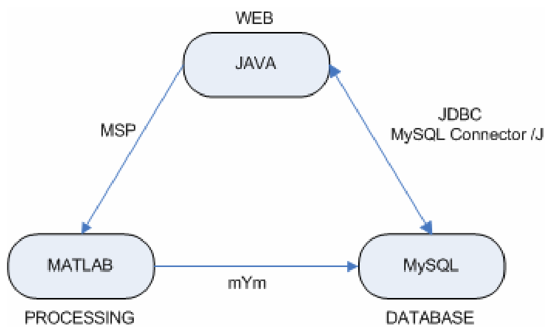

Fig. 4. Links provided in the information server

and the file server. ECG files are stored on the file server and linked to the patient database, which is a standardized database oriented to a cardiology department and designed jointly with the cardiologist. The web server (programmed using *struts* technology) permits secure access from web browsers both at the point of care (using a PDA) and in the cardiologist computer (using a PC).

Once the ECG has been sent to the server, the received information is taken from the file server and a results report is automatically generated after application of the advanced signal processing techniques in the MATLAB-based processing server.

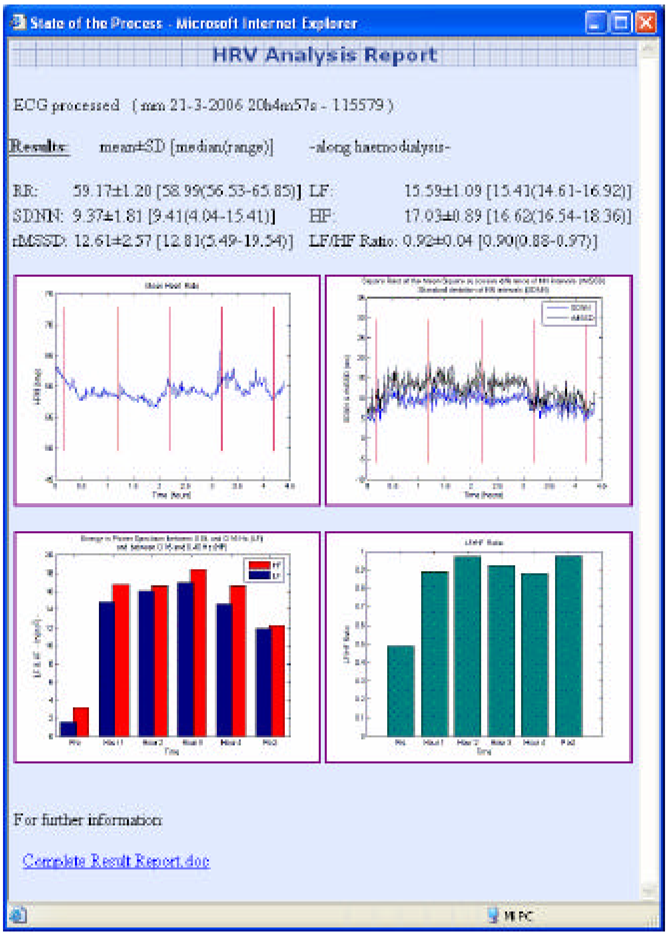

Fig. 5. Summary HRV results report

In the information server, some connections between the different modules have been set up (see Fig 4). The connection between Java and Matlab has been established by means of Matlab Server Pages (MSP) [15] which enables developing technical web pages using extended HTML tags. Java shares some data with Matlab extracted from the database (e.g. patient information,…), whilst the whole core intelligence for signal processing is programmed in Matlab. When the processing procedure ends up, the database is updated with the results generated by Matlab. To achieve this goal, mYm [16] has been used. mYm is a Matlab interface to MySQL server which makes possible the modification of database fields in a Matlab environment. Some general results are stored directly in the database for quick consultation with a web browser, but a complete results report with detailed information is generated, stored in the fileserver and linked to the patients' database.

Fig. 6. ECG recording in the haemodialysis unit (the ECG acquisition device and PDA are on the tray).

C. *Result analysis and diagnosis*

The cardiologist is automatically informed via email of the report generation and has access to the results in the information server (Fig. 5). The cardiologist may also see in his computer the complete ECG signals recorded using an ECG viewer and a detailed repot if needed. With the results provided by the processing server the specialist has additional information which can be helpful in the clinical decision and to stratify patients at risk.

III. APPLICATION TO THE STUDY OF HRV DURING HAEMODIALYSIS

The telecardiology framework has been applied and evaluated to provide support in the study of HRV in patients undergoing haemodialysis. The complete setting is shown in Fig. 6. The protocol consists in ECG signal recording during haemodialysis. Besides, 10 minutes prior and 10 minutes after dialysis were also recorded in order to compare indexes during and out of the dialysis process. This protocol has been followed in a preliminary study of 31 patients with renal disease. Two months were needed in order to accomplish the objectives. Due to the duration of the dialysis and to the proximity between sessions, a couple of long lasting batteries were necessary. ECG acquisition time was in mean of 4 hours 19 minutes ± 11 minutes and mean ECG file size was 60,7 Mbytes.

The next HRV indices were automatically measured following [7]:

- Time domain HRV indices:
  - NN, number of normal beats
  - NE, number of non-normal beats (ectopic beats)
  - mHR, mean Hear Rate
  - SDNN, standard deviation of the normal-to-normal (NN) QRS intervals
  - rMSSD, root mean squared of successive NN differences, calculated after linear detrending of the HR series
  - pNN50, percentage of intervals larger than 50 ms respect to the total
- Frequency domain HRV indices:

Power spectral density (PSD) of HRV, estimated from the linearly detrended and interpolated heart timing signal [14], resampled at 2 Hz, reducing the effect of ectopic beats.

TABLE I
EVALUATION BY PATIENTS

	Yes(N)	No(N)
Clarity of project information given	31	0
Did you feel comfortable during project?	29	2
Are you better attended?	28	3

An example of the summary results report for a dialysis patient is shown in Fig. 5. In this HRV report the trends of the main time and frequency HRV indices are included, showing their variation along the dialysis process. A complete file results is also produced and stored in case the cardiologist decides to use more information than the summarized in the report. Statistical tools are also included on the server to obtain averaged results from the study group.

IV. SYSTEM EVALUATION

The first step when evaluating projects or technologies consist on precise formulation of the objectives that this evaluation pursues. Normally, two grand objectives are defined: general and specific. General objective describes the main, generic or widest purpose of evaluation (such as assessing a telemedicine project implementation) and specific one, which describes the concrete aims that intend to be achieved with the evaluation (e.g. determine whether or not

TABLE II
EVALUATION BY PERSONNEL

General evaluation	Yes	No
Opportunity of the project to specific needs	v	
It is easy to use?	v	
It is intuitive?	v	
Would you use the system in future?	v	
Technical quality		
Technical characteristics present enough quality to permit diagnosis, treatment, etc?	v	
Technical problems in the system?	v	
Frequency of failures	once a month	
Impact over the personnel		
Need of organizational changes to introduce the telecardiology system in the dialysis routine?	v	
How many?	some	
Were these changes well accepted?	v	
Additional time due to the use of the telecardiology system during dialysis	20±5 m	
Impact over the patients		
Reaction of the patient to the use of the system	calmness	
Could be associated with the use of the system any differences regarding patient satisfaction, anxiety, care, acceptation, etc.?		v
Were patients worried about attention responsibility, data confidentiality, etc?		v

the designed tool is useful for clinical decision).

A. Evaluation by patients

Patients were informed of the project previously to be included in the study. A short questionnaire was fulfilled to obtain their general evaluation. As shown in Table 1, more than 90% of patients answered positively to the cardiology system.

B. Evaluation by the hospital personnel

The telecardiology framework was also evaluated by the hospital personnel involved in the project. Four main aspects of the system were analyzed: general evaluation, technical quality, impact over the personnel and impact over the patients. Two physicians were involved in the project and fulfilled the questionnaire in agreement. As shown in Table 2, the hospital personnel also valued positively the system, emphasizing its technical quality and usability. They accepted the necessary changes without complaints and observed and assessed the reactions of the patients when undergoing the HRV analysis.

V. DISCUSSION AND CONCLUSIONS

During first ECG recordings, technical problems where mainly due to physicians needed to become familiar with the device, PDA, etc. Long lasting batteries were needed to cope with the large amount of information registered on the PDA, since a dialysis ECG was 4-5 hours long. However, this was not a problem since the system operates in store-and-forward mode, and hence no large bandwidth communication networks are needed.

Preliminary results on this reduced patient set showed that they may show different patterns of changes of HRV during haemodialysis and that this study should be further completed with a large population.

The final evaluation showed a very good acceptance of the system by the patients. From the hospital personnel point of view, the system constitutes a helpful tool for clinical diagnosis support and mainly for research purposes. The main advantage is that they obtain in an automatic way new indices from the system which permit them to explore aspects of the cardiovascular system not considered before. Currently more patients are involved in the project to validate preliminary clinical results and to screen patients at risk.

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