REMOTE CARDIAC SURVEILLANCE UTILIZING ADVANCED SIGNAL PROCESSING AND TELECOMMUNICATION TECHNOLOGY

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ABSTRACT

**Aim:** Computer-assisted processing of intramyocardial electrograms employing internet-based transmission to specialized service centers.

**Materials and methods:** Implantable pacemakers provided with broad-bandwidth electrogram telemetry and using fractally coated electrodes render possible the acquisition of intramyocardial electrograms from the spontaneously beating as well as from the paced heart. These signals are transmitted via the Internet to the service center in Graz where processing is performed using tailored software. A patient report is generated and returned to the sending hospital.

**Results:** This methodological approach has been evaluated in different clinical studies including multi-center studies. In the first studies rejection surveillance by telemonitoring in patients after heart transplantation has been assessed. In more recent studies different kinds of cardiomyopathy have been considered. The feasibility of remote cardiac surveillance as well as the reliability of the technical equipment has been proven. The most essential result of those studies, however, is a growing body of evidence that intramyocardial electrograms represent information on risk assessment and the hemodynamic performance of the heart that cannot be obtained from surface electrograms. In total up to now more than 350 patients from about 22 hospitals around the globe have been included in this ongoing assessment study.

**Conclusions:** Remote cardiac surveillance can be realized with the already available technology for implantable pacemakers, telecommunication and signal processing. However, extended possibilities can be expected from the convergence of the different telecommunication technologies that are under development. Pacemaker technology will be advanced to semi-intelligent implants with special regard to risk monitoring in patients with potentially life-threatening conditions.

**Key words:** Intramyocardial electrograms, signal processing, internet transmission, cardiac telemonitoring

1. INTRODUCTION

Acquisition of high-resolution intramyocardial electrograms (IEGMs) both from the spontaneously beating and the paced heart has become possible only a few years ago. Electrodes with low residual polarization, preferable electrodes with fractally coated surface, are positioned either in the epicardial wall or after transvenous introduction in the right atrium or the right ventricle as usual. Shape and morphology of the acquired electrograms significantly depend on the exact position of the recording electrode. For electrograms from the spontaneously beating heart the transmission bandwidth should preferably range between 0.3 and 200 Hz in order to represent those low and high frequency components that are required for detailed analysis and processing of the signal morphology. If electrograms shall be transmitted only from the paced heart, transmission bandwidth may be restricted to 40 Hz as the upper frequency [9]. In most cases evaluation is based on the individual trend course of selected parameters that can be clearly identified with pathological impacts.

Although IEGMs in comparison with the traditional surface ECG recordings have some serious shortcomings, e.g. the restricted potential for standardization with regard to well-defined electrode positions and the still lacking clinical knowledge about those electrograms, IEGMs also offer some remarkable advantages. One of the most important advantages is that the recording electrode always remains in the same myocardial position heart independent from breath-related displacements of the heart within the body. Other important advantages are combined with Ventricular Evoked Responses (VERs) from the paced heart. In the case of VERs it is possible to use the same pacing rate for all examinations and thus to eliminate the effects of the more or less fluctuating spontaneous heart rate. Additionally the pacemaker pulse supports the triggering for signal averaging and consequently facilitates parameter extraction.

2. METHODS

Fig. 1 shows the methodological approach for IEGM acquisition from the spontaneously beating as well as from the paced heart by an extracorporeal data acquisition device. If a dual-channel pacemaker is implanted, electrograms can be recorded subsequently from two different sites. In such cases each electrode can be employed for pacing with the other electrode used for recording. Applying this mode it has been possible to determine the excitation propagation velocity in human hearts [7]. In most cases recording is limited to sequences of one minute duration that contains about 80 to 110 beats.
After supplement of clinically relevant data, compression and adequate encryption, the complete data string comprises about 40 kBytes. Of course, each hospital can develop its own study protocol and define its own data input mask. Until now all hospital-based firewall concepts have been carefully considered, no transmission problem or erroneous transmission has occurred during the past evaluation period of about 7 years with more than 30,000 transmissions via the Internet from different countries and continents to Graz. Usually the transmission via Internet to Graz requires only some seconds. Data processing in Graz is performed completely automatically if the employed algorithms and procedures have been sufficiently evaluated. The most usual procedural steps after de-codification and decompression are:

- heat beat detection;
- heart beat classification: this is a very important step and may require the detection of fusion beats in a sequence of VERs even when the region of capture is smaller than a few percent;
- rhythm analysis in case of spontaneous events;
- beat-to-beat and trend analysis in order to recognize and quantify fluctuating signals;
- averaging in order to compute the electrogram that is representative for the pre-determined class of IEGMs;
- parameter extraction;
- report generation;
- data compression and encryption.

Usually the report represents the whole history of this individual patient, e.g. for heart transplant patients from the day of heart transplantation. If this history is very long (in some cases heart transplant patients are already monitored by the data processing center for more than 5 years) the period that is represented in the report can be shortened.

In cases for which the algorithms and procedures have not been sufficiently evaluated, e.g. for special clinical studies that have been designed in accordance with the data processing center, analysis is performed appropriately by specialists who simultaneously are developing the computer-assisted procedure and tailored software for parameter extraction.

The generated report is transmitted back to the sending hospital via the Internet. The transmission time is again in the range of a few seconds. Hence, if completely automatic data processing is employed, the report can be back in the sending hospital within 2 – 3 minutes. The report can be visualized either on a monitor or after printing. Usually the necessary programs for visualization are supplied by the data processing center in Graz. The print-outs can be included into the medical history that is maintained in the hospital for the respective patient.

Many affiliated hospitals make additional use of the knowledge and facilities that are available in the data processing center by:

- asking the center to perform the data securing and data back-up for the hospitals. For this reason the data processing center has to provide sufficient capacities and to respond immediately to the hospitals requests;
- requesting statistical evaluations and comprehensive support for scientific reports from the data processing center.
3. RESULTS

At the beginning, the remote analysis of intramyocardial electrograms had mainly been aiming at surveillance of heart transplant patients in order to early detect rejection episodes. Another aim had been to assess the potential of advanced pacemaker and telecommunication technology. From this study it soon has become obvious that:

- present pacemaker and telecommunication technology provides reliable facilities for cardiac telemonitoring based on IEGMs [6];
- the evoked responses offer a higher potential for standardization in comparison with the electrograms from the spontaneously beating heart, thus increasing both the short-term and long-term reproducibility [1]. Especially the short-term reproducibility represents the beat-to-beat variability in signal morphology and may be a critical factor in certain cases. Frequently signal characteristics are hidden by the beat-to-beat variability in the signal morphology;
- IEGMs represent information on the cardiac performance that cannot be obtained from the body surface electrograms. The most challenging feature is to utilize IEGMs for the monitoring of hemodynamically relevant cardiac parameters;
- the developed concept can be utilized for multicenter studies, especially in double-blinded studies. The data processing center can guarantee identical procedures for signal analysis and data processing for all participating hospitals.

Data with clinical relevance must not be supplied to the data processing center. The data processing center additionally can supply the statistics for the monitored parameters [3].

Until now the following parameters have been considered:
- rejection monitoring in heart transplant patients;
- detection of risk development in heart transplant patients independent of rejection episodes.

The respective prognostic index is still under consideration, however, its validity is more and more enhanced [4];
- hemodynamic monitoring, e.g. assessment of end-diastolic volume, stroke volume and Left Ventricular Outflow Tract Gradient LVOTG, based on IEGM evaluation [2],[8];
- post-surgery surveillance in patients after severe heart surgery with special regard to the development of arrhythmias and occurrence of sudden cardiac death.

Tab. 1 presents the most recent statistics of the Graz service center for remote cardiac telemonitoring. The main groups are patients after heart transplantation, patients with different kinds of cardiomyopathy, and patients with coronary heart disease. But the diagnostic potential of remote IEGM analysis is more and more recognized also for other cardiac related diseases and for post-surgery monitoring.
Currently, more than 20 clinics in Europe, USA, and Brazil are supported by remote intramyocardial electrogram analysis.

Tab. 1: Most recent statistics of the data processing center in Graz on remote IEGM analysis in combination with Internet transmission.

<table>
<thead>
<tr>
<th>Patient group (01.12. 2000)</th>
<th>Patients</th>
<th>Examinations</th>
<th>Recordings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart transplantation</td>
<td>284</td>
<td>8 255</td>
<td>28 154</td>
</tr>
<tr>
<td>Hypertrophic cardiomyopathy</td>
<td>40</td>
<td>109</td>
<td>720</td>
</tr>
<tr>
<td>Dilative cardiomyopathy</td>
<td>10</td>
<td>29</td>
<td>312</td>
</tr>
<tr>
<td>Coronary heart disease</td>
<td>21</td>
<td>43</td>
<td>577</td>
</tr>
<tr>
<td>Post cardiac surgery monitoring</td>
<td>6</td>
<td>17</td>
<td>67</td>
</tr>
<tr>
<td>Others</td>
<td>14</td>
<td>35</td>
<td>394</td>
</tr>
<tr>
<td>Over all</td>
<td>375</td>
<td>8 488</td>
<td>30 224</td>
</tr>
</tbody>
</table>

4. DISCUSSION

Although the experience regarding the evaluation and clinical interpretation of IEGMs is very short in comparison with the large pool of experience with body surface electrograms, the technology-based acquisition and computer-assisted processing of IEGMs may open new and fascinating chances for the monitoring and diagnosing of cardiac failure. It has been shown that information of clinical relevance can be obtained from IEGMs that is not available from body surface electrograms. The hemodynamic monitoring and assessment of cardiac performance utilizing electrophysiological signals from the heart may stimulate more research activities in this field.

It has to be considered that the incidence of potentially life-threatening and disabling cardiac conditions is still increasing in most countries and yields growing expenses for the health care systems. For these reasons, remote and computer-assisted cardiac monitoring and therapy management are challenging chances. Until now, however, the real potential of this technological approach can only be estimated and needs further exploration.

5. CONCLUSIONS

Remote cardiac telemonitoring is possible by using the technology already available today, i.e. advanced pacemaker technology and data exchange in worldwide data transmission networks like the Internet. In future and after the establishment of even more advanced and integrated network technologies, i.e. by the convergence of GMS and UMTS technology with both Internet and satellite-based GPS and communication technology, remote cardiac telemonitoring will offer the potential for improved cardiac rhythm management. The cardiac situation of patients can be monitored independent of their present location. This development will additionally lead to another motivation for improved implantable devices, e.g. for risk monitoring with integrated semi-intelligent evaluation algorithms and watch-dog function.

REFERENCES

A partir de registros obtenidos de marcapasos implantados se obtienen electrocardiogramas y variables cardíacas que se transmiten vía Internet al centro de Servicio en Graz donde se emplea un programa especializado para el análisis de las señales y se reporta un informe sobre el paciente enviándose al hospital de origen. La viabilidad de la vigilancia cardíaca remota entre varios centros; así como la fiabilidad del equipo técnico ha sido probado en más de 350 pacientes de aproximadamente 22 hospitales alrededor del mundo, permitiéndose un estudio continuo de gran interés entre los especialistas.