A System for Comprehensive ECG Waveform and Trend Analysis Accompanying Polysomnographic Sleep Apnea Detection

C Zywietz[1], B Widiger[2], R Fischer[2], G Joseph[2]

[1]BIOSIGNA, Hannover, Germany; [2]Medical School, Hannover, Germany

Abstract

Performance of analysis algorithms for sleep apnea detection revealed that results were best when besides heart rate variability morphologic ECG parameters were considered.

We have therefore set up a system for simultaneous recording of 12 lead ECGs during polysomnographic data acquisition. The PC based system HES LKG has been used and its analysis and data presentation programs have been extended to handle the large data amount of 400-600 MBytes per night recording.

The system has been installed at the sleep laboratory of Marburg University. Up to now 50 night recordings from 40 patients have been acquired. The ECG data are processed in 10s data segments. Raw data and results can be stored in the standard SCP format.

1. Introduction

Sleep apnea detection has gained interest since epidemiological studies indicate a high prevalence in males and females in the general population [1,2]. Obstructive sleep apnea is the most common of the different types of sleep related breathing disorders. It is characterised by repetitive cessations of respiratory flow during sleep. Detection and verification of sleep apnea is done so far by means of polysomnographic examinations in specific sleep laboratories of hospitals. The polysomnographic recordings comprise acquisition of EEGs, EOGs, EMGs, of the respiratory nasal airflow, of the respiratory movement of the ribcage and of the abdomen and of oxygen saturation (SaO_2). Also snoring is recorded and quantified by the total volume of a microphone fixed at the larynx of the patient. It is obvious that the polysomnographic examination is a time consuming and expensive procedure.

In the 2000 CinC conference there was a specific challenge for the scientific contributions to detect sleep apnea from single channel ECG recordings. Altogether recordings of 70 patients with and without sleep apnea have been provided by the sleep laboratory Marburg (Germany) via the PHYSIONET of the MIT [3]. For all of the recordings annotations where made on apnea and apnea free sleeping periods.

For half of the recordings the annotations where publicly provided as well. Essentially the approach for detection of the sleep apnea phases within the ECG records where based on heart rate variability measurements [4]. The results for detection of sleep apnea within the records and for minutes allocation where surprisingly high reaching more than 95% of sensitivity and specificity.

A meta analysis of the performance results by Penzel et al [5] revealed, that the best performance was obtained in cases where morphologic ECG parameters have been used as well. This result has encouraged us to begin a new study and to perform besides the polysomnography recordings of the full 12 channel ECG all over the night.

2. The HES LKG system

The hardware of the analysis system for long term recording of ECGs (LKGs) consists essentially of a stand alone ECG amplifier with fibre optic bi-directional communication to a PC via the RS232 interface: Such a system has been described e.g. at CinC 2000 [6].

While the principle system layout of the workstation described could be kept the data acquisition and the result presentation has been significantly changed.

Figure 1: Main GUI of the LKG Analysis System.

2.1. ECG acquisition

The ECG recording is started at any time after the patient went to bed. Typically after going to bed the patient remains awake, he may read a book, listen to music or have some conversation which all might create artefacts not only in the ECG signal but also in the other signals acquired for the polysomnography. This first sleepless stage is, however, always being used as a reference for comparison with data acquired during sleep. The first phase may last a couple of minutes up to one hour or even more. The data acquisition program needs to work in one of the following modes:

   a) A monitoring mode for visual inspection of the ECG, electrode function etc.
   b) The regular recording mode with continuous storage of the ECG.
   c) An interrupt mode.

 If the patient e.g. leaves the bed for a while time stamps have to be introduced into the ECG recording for the respective interruption and additional recording times. At final termination of the recording the data sets of the recording periods are automatically assembled to make possible the continuous analysis of this record.

So far the ECG acquisition takes place in parallel to the polysomnographic recordings on a separate computer. The initial synchronisation of the records may be done by using the internal system clock. It is desirable that the internal system time of the different computers is set by a common time reference via intranet.

2.2. Analysis

ECG Analysis is performed continuously for data sections of 10 seconds . Every 10s a Representative Cycle is produced and approximately 800 measurements/10s data section are produced and stored. Besides, these measurements continuously for the record a beat table with pointers to each QRS complex including beat typing is performed.

The analysis is performed after the recording and takes on a 1 GHz Pentium IV processor in the order of 10 minutes for an eight-hour-ECG record. It should be noted that our processing scheme makes possible the generation of Standard SCP records with high compression (CR>10).

2.3. The user interface

The challenge for the result presentation, comes from the amount of data. At 500 samples/s/channel for an overnight ECG recording 230 MB of ECG raw data are obtained. 360 representative cycles for the 12 conventional leads are produced per hour, giving 34.560 representative cycles per 8 hour night-record with approx. 800 measurements for each of the 10s data sections. The problem is today not anymore the amount of necessary storage capacity but a user interface that allows

meaningful and understandable presentations of the data. Figure 2 shows the overall user interface for entering into more detailed result presentation.

Figure 2: GUI for Long Term ECG recordings.

On the left hand side a number of patient recordings is shown from which one can be selected in the usual way, e.g. by a mouse click.

On the right hand side on top the patient, the recording date and the name of an analysing physician, including the date is given. On the right hand side below is the view section with the various options to display data. There is also a function for preparing CD-ROMs. In view of the large amount of data per patient it is useful to have the complete data set for a patient including analysis results on one CD-ROM.

3. Results

In this section we will show a couple of result presentations from sleep recordings to illustrate the function of the various display options.

Figure 3: Raw Data Display + Options

Figure 3. depicts a 10s raw data section of a recording. In the center of the figure a menu is shown where the various display options for the data can be seen.

On top of this sub-window beginning and end of the recording is displayed. For graphical presentation either the absolute time T of recording or the time relative to the beginning (rel(t)) can be chosen.

The recording speed can be selected between 10 and 200 mm/s, the number of leads, either one, the limb leads only or the chest leads only or 8 or 12 channels can be displayed. A complete "walk through" the record is possible. Also specific filters (mainly line frequency filters) can be switched on or switched off.

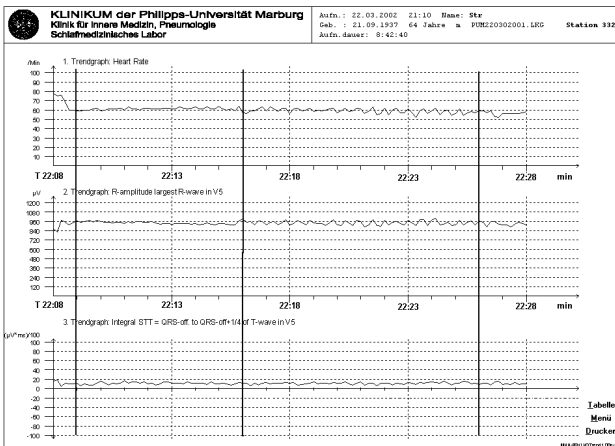Figure 4 shows a trendgraph for a time interval from T=22:08...22:28hr.

Figure 4: Example of a trendgraph plot

The most upper trace shows the heart rate, the trace in the middle shows the R amplitude of the (largest) R wave in lead V5. The trendgraph on the bottom shows the amplitude time integral of the interval between QRS offset and one quarter of the interval to T offset in lead V5. The three solid vertical lines show annotations for the onset of an apnea-free period to it's end, the onset of an apnea period and the third line marks the end of this apnea period. This graph indicates that the heart rate during the apnea period is "modulated" and a similar modulation can be seen in the R amplitude in V5. The ST-T integral during the apnea free and apnea period remains almost constant. The fluctuations seen are most likely due to measurement variability (please note amplitude quantization level in this program is 5 µV/LSB.

Figure 5 shows in the foreground the menu that can be reached if the menu button in the trendgraph as shown on figure 4 (right bottom corner) is used. Composition and resolution of data display is highly flexible. On top of the left hand side of the foreground menu onset and offset of recording is shown and again, the absolute time or the relative time interval for display on the trendgraphs may

be chosen.

Figure 5: Options for creation of trendgraphs

For each of the trendgraphs one out of more than 100 parameters can be chosen as well the lead and the range on the vertical axis for optimal visualization. On the bottom, left hand side it can be seen that also the time interval for the trendgraph may be chosen between 10 min and 24 hours. In this way an overview over a complete record up to 24 hours is easily possible as well as zooming to an interval length of 10 min for any desired time.

So far long time sleep recordings with a single channel ECG heart rate and heart rate variability were the key parameters to look at.
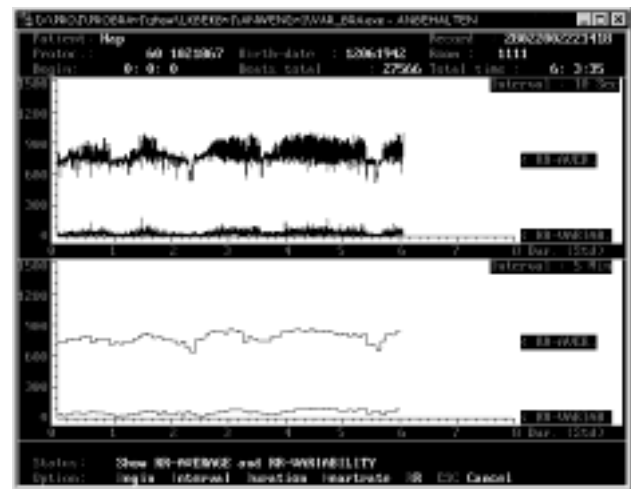

Figure 6: Example of average RR and RR Variability

For this purpose a program has been developed (see figure 6) that allows to show the RR intervals as tachograms and the RR variability. In the upper and the lower part starting point of the record and the duration

(that is the length of the time window) for the record as well as averaging intervals may be set and displayed. In this way "unfiltered" as well as strongly "low pass filtered" trendgraphs can be shown. The selectable interval ranges are 10s, 30s, 60s, 3 min, 5 min, 10 min to 60 min. In this way high resolution records as well as a smoothed trends can be observed.

Another useful display of RR interval information is the so called Poincaré plot. Typically the actual RR interval is drawn on the ordinate whereas the preceding RR interval is placed on the horizontal axes. In case of regular rhythm with some variance in heart rate, a single cluster with a certain dispersion on a 45 degree line may be observed as shown in figure 7.
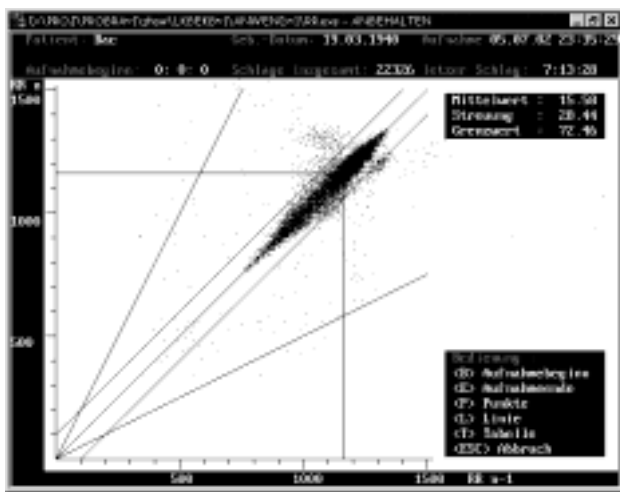

Figure 7: "Normal" Poincaré plot

In case of complex arrhythmia with systematically changing RR intervals because of extrasystoles, specific clusters can be seen as shown on figure 8.
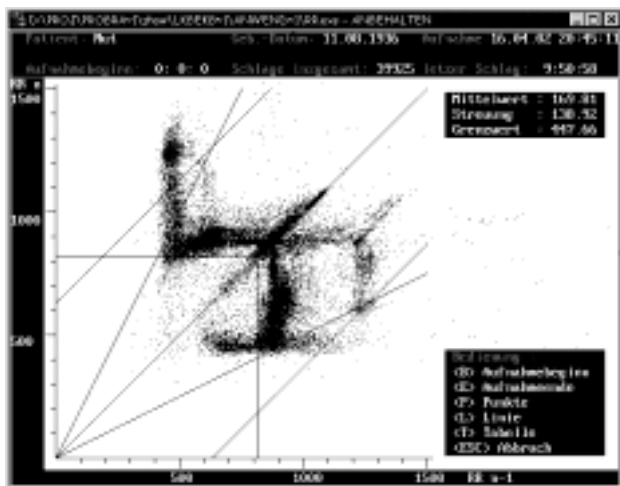

Figure 8: Poincaré plot of arrhythmia data

Also for this program the time window for the interval of data to be displayed can be selected. The lines parallel to the 45° center line show 95% intervals. This program allows also via a menu export of numerical data for a table, e.g., Excel and for further processing.

4.   Discussion and summary

The HES LKG system has been extended for analysis of long time 12 lead ECG sleep recordings. To facilitate easy ECG data analysis specific review features such as trend graph functions which allow data display for time intervals from 10 min to 24 hrs have been implemented. Also histogram functions for statistical display of data have been introduced.

So far ECG recording and polysomnographic data recording run on separate PCs. Even if a time synchronised recording start is maintained, continuous time stamping is desirable because sampling intervals exhibit tolerances which accumulate to synchronisation errors after several recording hours.

The ECG processing takes place for 10s data segments and allows to store raw data and processing results in the SCP Standard format.

Acknowledgements

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Address for correspondence.

Christoph Zywietz
Feodor-Lynen-Str.21
D 30625 Hannover/Germany
E-mail: zywietz.christoph@biosigna.de