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Cross-Correlation based comparison between the conventional 12-lead ECG and an EASI derived 12-lead ECG

Abstract: The 12-channel ECG is an important tool used for the diagnosis and treatment of various cardiac and other related diseases. The recording procedure requires the exact placement of 10 electrodes on the patients, because incorrect placement can lead to improper signals and, consequently, to false diagnoses. In addition, the placement of 10 electrodes is time consuming, often interferes with clinical processes, and is less patient-friendly. One possible solution could be the usage of a vector-based, 5-electrode, 12-lead monitoring ECG system (EASI).

The aim of this work is to establish a quantitative comparison between the conventional 12-lead ECG and an EASI ECG by cross-correlating signals of the same type.

For this purpose, we used a conventional 12-lead ECG device, Schwarzer Cardiotek GmbH; and an EASI device, Schwarzer Cardiotek GmbH. All instruments were made available by the company CRS medical GmbH. Both devices were simultaneously connected to an informed, healthy volunteer and signals were recorded under resting conditions. Cross-correlation functions were calculated and analysed by using Matlab R2015a between the same original and filtered signal types, e.g. conventional and EASI lead I. Time lags between the recordings were compensated adequately. All signals, up to two conventional signals, were of high quality. We found a high degree of correlations between 10 of 12 leads (r > 0.9).

However, the conventional recording system is more sensible to artifacts, muscle activities and noise, very likely due to its more complex electrode configuration and larger electrical sensing area. A visual inspection of the conventional and EASI time courses by an expert also indicated that EASI is useful in clinical practice.

We compared a conventional 12-lead ECG with an EASI ECG by signal correlations. The results indicate that EASI is well suited for cardiologic routine: simplified electrode placement and reasonable signal quality. However, additional investigations are required, especially to test EASI for diagnostic purposes and with more sophisticated statistical methods.

Keywords: EASI, Electrocardiogram, Cross-correlation, Derived 12-lead ECG

1 Introduction

In cardiac centers and many hospitals and medical practices the current standard for the analysis of electrocardiogram (ECG) signals is the conventional 12-lead ECG derived from 10 electrodes. The 12 leads consist of 6 limb leads according to Einthoven and Goldberger and 6 Wilson chest leads. Especially in diagnostic questionings all 12 leads are needed and the signal quality plays an important role. However, the conventional 12-lead ECG system is impractical because of its time-consuming electrode positioning and, of course, many cables and electrodes hinder clinical processes and patient’s comfort.

One possible solution could be the EASI-derived 12-lead ECG which is based on vectorcardiography and only uses 5 electrodes. Signals derived from 4 thorax leads plus 1 reference lead are converted into 12 leads inspired by the leads of the conventional system. Due to the fewer number of electrodes and the related easier handling and positioning, interferences with processes occur less and patient comfort increases.

1.1 Aim of the study

This study was carried out to verify the accuracy of a derived EASI system in comparison to the conventional 12-lead ECG. Therefore a quantitative measure between the conventional 12-lead ECG and an derived EASI ECG by cross-correlating signals of the same type was established.

2 Methods

2.1 Description of the devices

The conventional 12-lead ECG requires 10 electrodes. To measure the frontal plane projection of the heart vectors, electrodes
are placed on the right arm, left arm and left leg, doing so, Einthoven and Goldberger leads I, II, III and aVR, aVL, aVF can be recorded and analysed. In addition, six electrodes are placed on the thorax to record and analyse the horizontal plane and view the leads V1, V2, V3, V4, V5 and V6. However, the precision of the electrode placement is important for diagnosis. A ground reference is placed on the right leg [1, 2]. The electrodes used were those enclosed with the Schwarzer cardiotek GmbH devices.

The derived EASI 12-lead ECG uses 5 Electrodes which are placed on the upper sternum (S), the lower Sternum (E) at the level of the fifth inter-costal space and on the right and left midaxillary lines (I and A) at the same level as E. A fifth ground electrode is placed under I [3, 4]. EASI is using defined coefficients to compensate variabilities of different thoraxes and to reconstruct the signal paths from the conventional 12 leads.

The measurements were recorded by the means of the hemodynamic monitoring systems evosuperior and evoprim by Schwarzer Cardiotek GmbH. The 12-lead device and the EASI Lead System (single use electrodes from LecStrip, Schwarzer Cardiotek GmbH), as well as the laboratory, were made available by the company CRS medical GmbH.

2.2 Study population

The study population was represented by 4 informed, healthy male volunteers. Both devices were simultaneously connected, so that in altogether 15 electrodes were placed on the subject and signals were recorded under resting conditions. Conventional lead V6 had to be moved 2 cm toward the anterior axillary line just beside the EASI electrode A, because of a placement conflict between the A electrode and electrode V6 [5]. A total of 24 12-lead ECG measurements were recorded from both systems. Therefor the ECG leads acquired with conventional ECG were compared with the corresponding EASI leads.

2.3 Data analysis

The 12 leads of the conventional 12-lead ECG were compared to the 12 leads of the EASI ECG by signal correlations. A high-pass filter with a cut-off frequency of 5 Hz was used to compensate breathing artifacts which may deform the raw signals. Scaled cross-correlation functions were calculated and analysed by using Matlab R2015a between the same original and as well filtered signal types, e.g. conventional and EASI lead I. Time lags between the recordings were compensated adequately. The resulting cross-correlation coefficients are a measure for the linear similarity of a conventional and a related EASI signal type, e.g. lead I. This method was chosen to evaluate the accuracy of the signals received from EASI leads in comparison to the signals from the conventional leads. A cross-correlation coefficient close to 1 indicates a high match between the two leads.

3 Results

The following results arise from cross-correlations between filtered ECG signals from conventional leads and their corresponding filtered EASI ECG leads. The mean scaled cross-correlation coefficients from in total 144 leads are shown in figure 1. For each signal type 12 conventional and 12 related EASI signals were analysed. Coefficients from $r=0.7$ to $r=0.9$ can be assessed as a high degree of correlation, coefficients from 0.9 as very high correlations. On average lead V6 revealed the highest degree of correlation. The leads III and aVL revealed the lowest degree of correlation due to a great difference in the signal waveforms between conventional and EASI caused by strong noise influences in both conventional leads.

![Cross-correlation coefficients with its standard deviations as error bars](image)

Figure 2 shows the filtered conventional (red) and EASI (green) ECG lead V6 in detail. The signals were superimposed after compensation of their time difference obtained by cross-correlation, leading to the fact, that R-points of the signals appear simultaneously. Recognizable is a higher degree of noise in the conventional signal seen by its signal fluctuations. The conventional signal has also higher amplitudes than the EASI signal.
4 Discussion

This study found a high degree of correlations from the conventional and EASI system between 10 out of 12 leads (r > 0.9). This means the EASI system is able to reconstruct the waveforms of the 12 leads adequately. It was noticeable that the conventional system is more sensible to artifacts, muscle activities and noise, probable due to its more complex electrode configuration, larger sensing area and different signal filters. The tested EASI system uses filters like high-pass and low-pass filters to suppress noise. And because no limb leads are needed and the therewith involved lower number of electrodes, motion artifacts and limb muscle activities can be reduced. The received good EASI signal reconstruction of the 12 leads is probably caused, inter alia, by the homogeneous and average chest anatomies of the probands.

Despite high-pass filtering the recorded signals, in order to remove breathing artifacts, lower correlations for leads III and aVL are due to a poor signal quality of the conventional signals, i.e. noise and artifact induced signal deformations. These interferences could be eliminated with additional filters, e.g. low-pass and non-linear filters, better electrode-tissue contact and thus, higher correlations should be obtained.

A visual inspection of the conventional and EASI time courses by an expert indicated that EASI can be considered to be useful in clinical practice. The expert couldn’t recognize medically relevant differences between both systems by comparing the related signals. However, the EASI leads were often easier to read because of the lower noise.

5 Conclusion

Which recording system, 12-lead conventional or EASI system, is best suited for ECG diagnosis depends on the specific application. Therefore decision criteria could include reproducibility of results, time needs for placement of electrodes, potential signal disturbances or interferences, patient comfort and interplays with clinical processes. Based on the basic researches and results, EASI is superior in the points of reproducibility (by easier electrode placement), time exposure, interferences and patient comfort [2, 4, 6]. Differences in signal waveforms in comparison to the conventional system hardly exist which can be confirmed by the correlation coefficients in 10 out of 12 leads.

In order to test the accuracy of the defined EASI coefficients which compensate different chest anatomies and reconstruct the signal waveforms, it is necessary to evaluate many probands with different thoraxes like men and women, tall and small people and probands with obesity. In order to test the EASI system to diagnostic questionings like regional pathologies it is needed to evaluate many probands with such acute symptoms. If these data can be collected, then the above-mentioned method can be used to clarify the diagnostic suitability of the EASI system.

On the basis of the available results it’s reasonable to assume that the 12-lead EASI derived ECG could be useful for general practitioners, who aren’t in regular need to apply a 12-lead ECG and don’t have the need to clarify diagnostic questionings in detail.
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