Telemetric ECG Evaluation Using Einthoven-Leads

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Abstract

A test data set consisting of 1264 ECGs is compared and evaluated by means of cross correlation with 24584 validated ECGs. The calculations are first carried out for all 12 medical leads and subsequently only for the 3 leads according to Einthoven. The aim of the investigation is to estimate the changes in the sensitivity and specificity between the 12-channel- and the 3-channel evaluation. Basis of the evaluations are the computed probability distributions for the classes of main diagnoses "ventricular hypertrophy", "myocardial infarction", "conduction disturbance" and "ischaemia". The results are checked in an blind test using the CSE test data set.

1. Introduction

A 12-lead standard-ECG requires specially qualified medical personnel. The wrong arrangement of electrodes can lead to considerable falsifications and misinterpretations of the ECG [2]. The evaluation of the ECG traces usually requires cardiological experience going far beyond the knowledge of a general practitioner. A qualitative evaluation of the measurement by a medical layman, similar to measuring the blood pressure, is out of the question for the ECG.

Due to the technical progress in telecommunications, the use of telemedical solutions becomes increasingly easy. Under the aspect of spatial distance, this does not only apply to the communication between two medical institutions (doctor/doctor), but also to medical care for patients at home (doctor/patient). Concerning the measurement of an ECG at a patient's home is of vital importance that the electrodes can be arranged quite easily and correctly being accepted by both doctor and patient. The 12-channel standard-ECG with the chest leads according to Wilson [1] must be ruled out as measurement method for this purpose, as it is not suited for home care. In the present work we will not investigate the various approaches aimed at enabling a patient to carry out ECG measurements himself (e.g. by means of belt systems or the like), but we will study the possibility of an ECG measurement at the extremities, as was suggested by Einthoven already in 1903.

2. Goal

The changes in sensitivity and specificity of a wave form recognition ECG evaluation method [3] are determined when instead of the 12-channel standard ECG only the leads at the extremities (according to Einthoven) are utilized. The investigation is done by means of applying the method to a test set of 1264 ECGs.

3. Test Data Set

From PTB's ECG-database CARDIODAT [3], a sample of 1264 cases was taken from a total of approx. 27,000 ECGs and compiled to give a test data set. Thereby, the following marginal conditions were applied:

- All cases in which electrode faults occurred, e.g. mixing up of the right and left arm, or extreme signal disturbances, e.g. by contact loss of individual. electrodes during the measurement, were excluded.
- All children's ECGs were excluded (age limit: 16 years).
- All ECGs where age and sex were not stored in the database were excluded.
- ECGs for which no sufficient number of comparably similar signal patterns was stored in the database were excluded.

These 1264 cases of the test data set were assigned to 1472 diagnoses according to the AHA classification [7]. The diagnoses were distributed among the cardiological classes of main diagnoses as follows:

- normal diagnoses 640
- ventricular hypertrophy 157
- myocardial infarction 276
- conduction disturbance 225
- ischaemic diseases 174

4. Method

The investigations are carried out by applying the PTB-developed ECG signal pattern method [3] along with the ECG follow-up [4] which builds up on that method. This means that each ECG of the test data set is compared lead by lead with the ECGs of a reference database. Since the test data set was part of the whole reference data set, the leave-one-out cross validation [6]

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was applied. The pattern comparison is done by cross correlation after normalisation of a characteristic ECG beat. After classification of the correlation results, those cases are separated from the entirety of database reference-ECGs in a ranking process whose signal patterns best matched with the test-ECG. By means of the

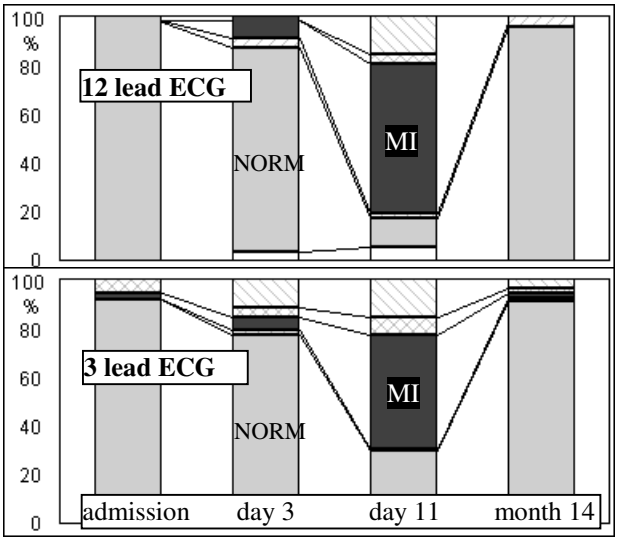

Fig. 1: Follow-up of a patient with myocardial infarction (MI), taking into account 4 ECG measurements over a period of 14 months. The upper distribution is calculated from the 12-channel standard ECG, the lower from the 3 leads according to Einthoven. Classification according to groups of main diagnoses.

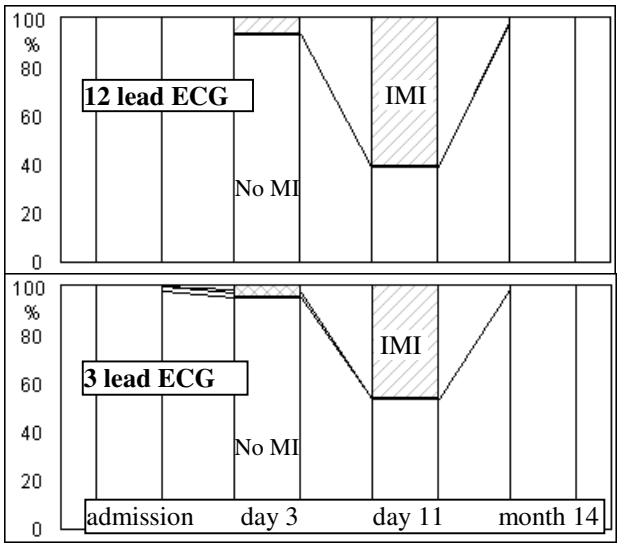

Fig. 2: Follow-up of a patient with myocardial infarction corresponding to Fig. 1. Classification according to the location of the infarction (IMI : inferior myocardial infarction.

No. of leads: 12 (12-channel standard)
No. of test-ECGs: 1264

	Database	Program
Main diagnoses	1472	1756
Norm	640	574
VH	157	327
MI	276	381
Block	225	244
ISC	174	230

	Sensitivity	Specificity	Correct diagnosis
NORM	78.1%	88.1%	500 / 640
VH	58.6%	78.8%	92 / 157
MI	77.5%	83.1%	214 / 276
Block	72.4%	92.2%	163 / 225
ISC	61.5%	88.7%	107 / 174

Total Accuracy = 73.1%

Table 1: Evaluation of the ECG test data set using leads I, II, III (Einthoven), aVR, aVL, aVF (Goldberger) and (V1, V2, V3, V4, V5, V6 (Wilson). Calculation of sensitivity and specificity for the groups of main diagnoses Norm (healthy persons), VH (ventricular hypertrophy), MI (myocardial infarction), block (conduction disturbance), ISC (ischaemia).

No. of leads: 3 (Einthoven)
No. of test-ECGs: 1264

	Database	Program
Main diagnoses	1472	1877
Norm	640	480
VH	157	356
MI	276	485
Block	225	296
ISC	174	260

	Sensitivity	Specificity	Correct diagnosis
NORM	63.4%	88.1%	406 / 640
VH	56.7%	75.9%	89 / 157
MI	72.8%	71.3%	201 / 276
Block	73.0%	87.4%	165 / 225
ISC	64.9%	86.5%	113 / 174

Total Accuracy = 66.2%

Table 2: Evaluation of the ECG test data set using leads I, II, III according to Einthoven. Calculation of sensitivity and specificity for single groups of main diagnoses.

known diagnoses of the reference cases, a distribution of probable diagnoses is derived for the test-ECG. If for one patient several ECG-measurements were carried out, the different distributions of the probable diagnoses can be summarized to one diagram, cf. figure 1. By means of this distribution, a follow-up-check of a patient is possible on the basis of several ECG-measurements without the individual ECG signals having to be assessed visually by a cardiologist. The cardiological experience needed is stored in the ECG-database.

In the present work, each ECG from the ECG test data set is compared with 24584 reference-ECGs by signal pattern correlation. By means of the known diagnoses of the reference cases, the evaluation of a test ECG is carried out in a two stage decision process. From the results on the whole test set the sensitivity, specificity and total accuracy are calculated.

The ECG test data set is investigated in two separate calculations:

1. All 12 leads are used (according to Einthoven, Goldberger and Wilson)
2. Only leads I, II, III are used (according to Einthoven).

For both variants (12 lead evaluation and 3 lead evaluation) the same two stage decision process was applied.

5. Results

Tables 1 and 2 show the results of the test calculations (1264 ECGs, 1472 single diagnoses). The conditions for the investigations were for both cases - with 12 leads (Table 1) and with 3 leads (Table 2) - identical.

In Table 3, the results (12 ECG leads versus 3 ECG leads) are summarized for comparison.

	12 leads			3 leads		
	Sens	Spec	Tot. Acc	Sens	Spec	Tot. Acc
Norm	78.1	88.1	500 / 640	63.4	88.1	406 / 640
VH	58.6	78.8	92 / 157	56.7	75.9	89 / 157
MI	77.5	83.1	214 / 276	72.8	71.3	201 / 276
Block	72.4	92.2	163 / 225	73.3	87.4	165 / 225
ISC	61.5	88.7	107 / 174	64.9	86.5	113 / 174

Table 3: Comparison of the obtained sensitivities (Sen), specificities (Spec) and values for total accuracy (Tot. ACC) based on the ECG test data set and use of 12-lead ECGs and 3-lead ECGs.

Table 4 shows the comparison for sensitivity, specificity and total accuracy as differences between the evaluation with 12 leads minus the evaluation with 3 leads. As the values show, the results deteriorate in almost all classes of diagnoses except for the sensitivities in the case of blocks and ischaemias.

	Diff. Sens	Diff. Spec	Diff. Tot. Acc
Norm	14.7%	0%	94
VH	1.9%	2.9%	3
MI	4.7%	11.8%	13
Block	-0.9%	4.8%	-2
ISC	-3.4%	2.2%	-6

Table 4: Differences in sensitivity (Diff. Sens), specificity (Diff. Spec) and total accuracy (Diff. Tot. Acc) on the basis of the ECG test data set and use of 12-lead ECGs versus 3-lead ECGs.

6. Validation according to CSE

Table 5 shows the results of the validation of the above demonstrated method by means of the CSE-test data set [5]. In the blind test against 1220 ECGs with validated diagnoses, the method described under section 4 is applied by using both, all 12 medical leads (according to Einthoven, Goldberger, Wilson) and 3 leads only (according to Einthoven). The aim of the investigation is to show which deteriorations occur in the different groups of diagnoses with regard to sensitivity and specificity if - instead of the 12 ECG leads - only the 3 leads according to Einthoven are used. Therefore, in Table 5 the columns Diff. Sens and Diff. Spec are of special interest.

7. Discussion

From the results gained with PTB's test data set and the blind test with CSE, the following conclusions can be drawn:

- The obtained specificity values usually lie clearly above the values for sensitivity. This applies to both the 12-channel evaluation and the 3-extremity leads.
- As expected, the values for sensitivity and specificity when using 3 leads are in most of the cases worse than those when using 12 leads. This applies especially to anterior myocardial infarctions. The groups of diagnoses conduction disturbance (block) and ischaemia (ISC), however, show an improvement in the sensitivity values (see Table 4).
- If one class of diagnoses performs less well than other classes when using 12 leads, e.g. right ventricular hypertrophies, the result with 3 leads, too, is only moderate. Good results with 12 leads also give good results with only 3 leads. An exception to this are anterior myocardial infarctions. In the case of 3 leads, a distinct deterioration in the sensitivity occurs here, as expected.
- The sensitivities and specificities obtained with the CSE test data set were better than results of the

CARDIODAT test data set. Reasons for this might be a better validation and better selection of cardiological cases of the CSE data set and differences with respect to the composition of the test data sets.

	Sens	Diff. Sens	Spec	Diff. Spec
Norm	77.5%	3.7%	90.2%	0.9%
LVH	51.6%	6.6%	92.9%	-1.2%
RVH	36.4%	0%	98.4%	1.4%
BVH	37.7%	-0.9%	98.5%	-0.8%
AMI	51.2%	12.3%	91.4%	3.9%
IMI	66.5%	8%	92.1%	1.6%
MIX	61.0%	6.1%	95.6%	1.3%
MI	74.9%	1.4%	80.8%	3.4%

Table 5: Validation of the method by means of the CSE test data set. Groups of diagnoses: Healthy persons (NORM), left ventricular hypertrophy (LVH), right ventricular hypertrophy (RVH), biventricular hypertrophy (BVH), anterior myocardial infarction (AMI), inferior myocardial infarction (IMI), myocardial infarction anterior and inferior (MIX), ventricular hypertrophy and myocardial infarction (MI). Stated are the sensitivity (Sens) and specificity (Spec) as well as the differences in comparison with the CSE-test with 12 leads (Diff. Sens, Diff. Spec).

8. Summary and Outlook

By means of the probability distributions, on which the PTB pattern recognition method is based, a feasible evaluation of the ECG can be achieved for some classes of main diagnoses even if only 3 leads (Einthoven) are used. For some cardiological clinical pictures, the monitoring of a patient at home could thus become feasible. This must be discussed especially under the aspect that an ECG which has just been measured can be assessed in its temporal development with the help of the ECG follow-up [4].

Further information can be obtained from:
http://ekg.berlin.ptb.de

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