Computer Interpretation of the 12-Lead Electrocardiogram, the Frank-Lead Vectorcardiogram and the Reconstructed Vectorcardiogram

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Abstract

The purpose of this study was to assess the diagnostic accuracy of the computer interpretations of the electrocardiogram (ECG), the vectorcardiogram (VCG) and their combination (COMB) on a large data base of 2810 patients with adequate clinical documentation. On a series of 2414 patients without ventricular conduction defect, the evaluation also included the VCG reconstructed from the 12-lead ECG (VCGr), and its combination with the ECG (COMBr). We found that COMB and COMBr reached the highest level of overall accuracy, the highest specificity, and the highest sensitivity in diagnosing left ventricular hypertrophy, mixed myocardial infarction (MI) and MI associated with hypertrophy. The VCGr was equivalent to the original Frank VCG except in inferior MI. On another series of 396 patients with ventricular conduction defect, the sensitivity of COMB was superior for ventricular hypertrophy and MI, at the expense of a lower specificity. It is concluded that the combination of the diagnostic results obtained by two computer programs is worthwhile, and that the reconstructed VCG might be considered for clinical use.

1. Introduction

The equivalent value of the 12-lead electrocardiogram (ECG) and the Frank-lead vectorcardiogram (VCG) in terms of basic information content is generally acknowledged [1,2]. The two techniques are, however, probably complementary in terms of diagnostic content. Previous studies led in the Frame of the European CSE project suggested that the combination of results provided by different computer programs, including ECG and VCG programs, yielded a higher diagnostic accuracy than that obtained by individual programs [3-5]. Because of the limited availability of VCG recording, some have advocated the use of a reconstructed VCG (VCGr), that is a VCG synthesized from the 12-lead ECG [4-5]. The purpose of this study was to compare on a large documented data base the diagnostic results obtained by the computer interpretations of the ECG, the Frank VCG and the reconstructed VCGr and by their combination, i.e., the combination of ECG and VCG (COMB) and the combination of ECG and VCGr (COMBr).

2. Material and methods

2.1. Study population

Over a 5 year period we gathered a large data base of 15-lead records (simultaneously recorded 12-lead ECG + Frank XYZ leads) from our general hospital population. This local data base consisted of a total population of 2810 patients subdivided into a group of 2414 patients with only "type A" diagnosis, i.e., with QRS duration $\leq$ 120 ms and conditions verifiable from independent clinical sources, and another group of 396 patients with major ventricular conduction defects, i.e., with QRS duration $>$ 120 ms and also documented clinical diagnosis.

In the "type A diagnosis" group, there were 1471 men and 943 women, mean age 53.4 years (18 to 91 years). It included 1042 normal subjects without organic heart disease (NORM), 174 patients with left ventricular hypertrophy (LVH), 32 with right ventricular hypertrophy (RVH), 279 with anterior myocardial infarction (AMI), 589 with inferior infarction (IMI), 203 with both localizations of infarct (MIX) and 95 with both ventricular hypertrophy and infarction (VH+MI).

In the "conduction defect" group, there were 320 males and 76 females, mean age 53.4 years (21 to 88 years). Among these 396 cases with major ventricular conduction defects, there were 134 cases with complete left bundle branch block (LBBB), 167 cases with complete right bundle branch block (RBBB) and 95 with non-specific intraventricular block, all defined according to standard electrocardiographic criteria. The conduction defect was isolated, i.e., without underlying cardiac

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disease, in 95 instances. It was associated with a structural heart abnormality in 301 patients: 80 LVH, 4 RVH, 56 AMI, 89 IMI, 35 MIX and 37 VH+MI.

2.2. Computerized interpretation

In each case with a "type A" diagnosis, the 12-lead ECG was analyzed by the recently developed Cardionics ECG program [6] and the Frank-lead VCG by the Louvain VCG program [7]. The "Combined interpretation" (COMB) was obtained by a weighed averaging of the individual results provided by the two programs, as previously explained [8]. The reconstructed VCG (VCGr) was obtained through a multivariate regression technique applied to a linear weighed combination of the 8 independent ECG leads [9]. This VCGr was also analyzed by the Louvain program and, by merging the results provided by the ECG and VCGr interpretation, another combination (COMBr) was obtained. On the "conduction defect" data base, only the computer interpretations of the ECG, VCG and COMB were assessed.

2.3. Diagnostic evaluation

The rules for data collection and validation, for obtaining a combined interpretation from the individual ECG and VCG analyses, for scoring and evaluating the results were same as in the CSE study [3,8]. Briefly, every case was clinically validated on the basis of ECG independent data taken from history, physical examination and various non-invasive and invasive diagnostic tests. This clinical diagnosis represented the gold standard used for the diagnostic assessment of the computer interpretation. Only the diagnostic statements with the highest probability level were taken into account, except in some conditions with multiple abnormalities, e.g., MIX and VH+MI, where additional testing was undertaken. The occurrence of several diagnostic statements on a same probability level led to a decreased score in cases with single disease states, as the point allotted had to be split among several cells of the misclassification matrix. Standard formulas were used to compute various indices of diagnostic performance, e.g., diagnostic accuracy, sensitivity and specificity, positive and negative predictive values. Differences in the diagnostic indices between the various classifiers (ECG, VCG, VCGr, COMB and COMBr) were assessed by means of the Wilcoxon's signed rank test or the McNemar's test according to the continuous or discrete quality of the measurements.

3. Results

3.1. "Type A" diagnosis group

The total diagnostic accuracy, which is the proportion of completely correct classifications across all diagnostic categories was higher with the combined interpretation (COMB: 85%, COMBr: 83.5%) than with the ECG alone (82%, NS), the VCG alone (78%, $p<0.001$) and the VCGr (74.3%, $p<0.001$).

Table-1 Sensitivity(%)/Specificity(%) (Type A diagnosis)

	N	ECG	VCG	VCGr	COMB	COMBr
NORM	1042	91/93	91/90	92/86	95/90	96/88
LVH	174	72/97	68/97	72/96	76/98	77/97
RVH	32	77/99	73/98	67/99	75/99	70/99
AMI	279	80/96	68/96	70/95	79/97	80/96
IMI	589	82/95	74/96	66/96	80/97	75/97
MIX	203	56/99	59/99	49/99	69/99	64/99
VH+MI	95	68/100	57/100	60/100	74/100	76/100

Table 1 shows the results expressed as sensitivity and specificity values for the various diagnostic categories. The correct classification rate for normals (NORM) was significantly higher with the two combined interpretations than with either ECG, the VCG or the VCGr ($p<0.0001$) at the expense of a higher rate of pathological cases mislabelled as "normal". In the pathological categories, all 5 classifiers reached a specificity level equal to or greater than 95%. The combined interpretation (COMB and COMBr) yielded a significantly higher sensitivity than that of the ECG, VCG or VCGr in the categories of LVH, MIX and VH+MI. The ECG program had the highest sensitivity in AMI (80.2%), IMI (82.2%) and RVH (77%). The VCGr was equivalent to the original Frank VCG except in two categories where it was less accurate: IMI (66% vs 74%, $p<0.001$) and MIX (49% vs 59%, $p<0.001$).

Figure 1 shows the ROC diagram for the differentiation between the presence and absence of LVH: the combined interpretations reached the highest sensitivity for a low level of false positives (<3.5%). Figure 2 shows the results for the differentiation between the presence and absence of myocardial infarction: the best compromise between sensitivity and specificity was represented by COMB while the ECG had a higher rate of false positives (5.4%).

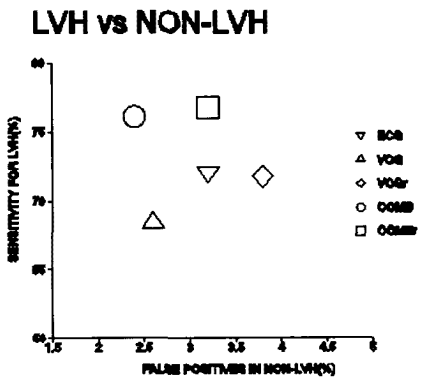

figure-1

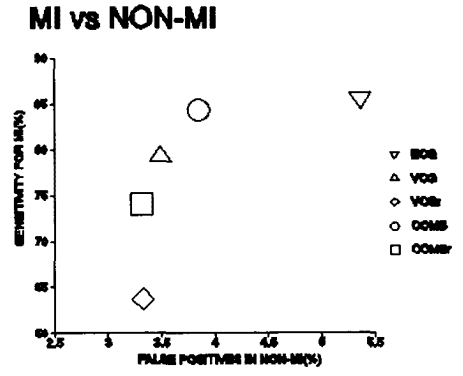

figure-2

3.2. Ventricular conduction defect group

Table 2 shows the results of the ability of the three classifiers, ECG, VCG and COMB to diagnose the presence or absence of "type A" categories among the 396 patients with major intraventricular conduction defect (QRS > 120 ms). The specificity, i.e., the ability to diagnose an isolated ventricular conduction defect (category "other") was lower with the combined interpretation than with either the ECG or the VCG ($p<0.0001$). On the other hand, COMB was superior to the ECG in the diagnosis of LVH ($p<0.001$), IMI ($p<0.05$) and VH+MI ($p<0.01$). It was also superior to the VCG interpretation in the diagnosis of LVH ($p<0.01$), AMI ($p<0.01$), IMI ($p<0.05$) and VH+MI ($p<0.05$). The only significant difference between ECG and VCG was found in the category of AMI where the accuracy of the ECG interpretation was higher than that of the VCG.

Table-2 Percentages of correct classification of type A diagnosis in cases with Ventricular conduction defect

Group	N	ECG		VCG		COMB
OTHER	95	62.1		57.9	****	40.0
				****		
LVH	80	28.7		33.1	**	43.7
				***		
RVH	4	00.0		37.5		25.0
AMI	56	54.2	**	36.6	**	53.6
IMI	89	47.6		48.1	*	55.2
				*		
MIX	35	28.6		28.6		41.4
VH+MI	37	48.6		54.0	*	63.0
				**		

4. Discussion

In patients with only type A diagnosis, the combined interpretation using either the ECG and the VCG (COMB), or the ECG and the VCGr (COMBr) led to the highest level of total accuracy, to the best global specificity and to the highest sensitivity in the categories of LVH, MIX and VH+MI. COMBr was equivalent to the ECG interpretation in AMI while it was less performant in that IMI. In patients with major ventricular conduction defects, COMB led to a higher sensitivity for the detection of LVH, IMI, MIX and VH+MI, at the expense of a higher false positive rate when the conduction defect was isolated.

These results are closely related to the composition of the data base and the current status of the two computer programs, for ECG and VCG analysis. The scoring technique applied after the weighed averaging of the individual ECG and VCG diagnostic outputs might have favorably influenced the results obtained with the combined interpretation. This outcome is also explained by the fact that two computer programs, each acting with its own logic and striving at a correct diagnosis by the best of its criteria, will have a higher probability of leading to a correct diagnosis when they are combined at

the level of their diagnostic output. This is similar to a consensus opinion reached by different observers when they have to arrive at a common decision after having made up their mind independently [10].

It is also remarkable that the combination of the ECG interpretation with that of the VCG reconstructed from the simultaneous 12 conventional leads improved over the individual interpretation of either the ECG or the Frank VCG in several type A diagnostic categories. Our findings support two hypotheses, i.e., (1) that the diagnostic information present in the original Frank VCG is also contained in the simultaneously recorded ECG and can be retrieved from the phase-relationship analysis provided by the reconstruction algorithm and (2) that the fact of displaying the same information twice, in two different forms, scalar and vectorial, can enhance the diagnostic capability of the computerized interpretation [4,11]. It remains to be seen whether the integration into a single computer program of the best set of ECG and VCG criteria, whether they originate from the original Frank VCG or the reconstructed VCG, might further improve the diagnostic accuracy over that obtained by simply integrating the diagnostic outputs of the two different programs.

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