Digital Phono- and Electro-Cardiography: Predicting Echocardiographic Parameters for Telemedicine Screening

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Abstract

Our study was performed to assess the clinical value of digital phono- and electrocardiography (dPCG and dECG) in telemedicine application for screening. Relevant echocardiographic parameters (left ventricular (LV), both atrial dimensions; ejection fraction (EF), aortic Vmax, the grade of mitral and tricuspid regurgitation (MR and TR: semiquantitative grade I-III, the left ventricular mass index (LVMI)) were estimated from the dPCG and dECG data. The study population consists of 790 patients selected from our database; 395-395 patients were in the training and the test groups. The signal analysis of the dPCG consists of: discrete FFT analysis; automated heart sound detection; filtering and averaging; multivariate discriminant analysis. The dPCG estimated Vmax, EF, MR and TR, the prediction based on dECG for LVIDd, LVMI, LA and RA dimensions showed highly significant results.

1. Introduction

Based on the comprehensive work of Tavel [1], our team decided to develop a large phono-echocardiographic and ECG database for the non-invasive estimation (modeling) of various heart disease and disease states [2-4]. The most important studies on clinical phonocardiography [5-7] did not use large database for the analysis, and it would be a serious limitation of their clinical usefulness. The advanced signal analysis, the potential telemedicine application may be give a new power of this old-new method.

2. Methods

The study population consists of 790 patients selected from our large database containing all of the relevant clinical parameters: the digital, 12-lead ECG, the 30-second dPCG registration and the complete echocardiographic video. 395-395 patients were in the training and the test groups.

The automated measurement of the dECG and dPCG registrations ((TriTest device, sampling rate 1 kHz, in the range of 20-12000 kHz) were supervised by two cardiologists. The morphological parameters (amplitudes, time-intervals) of the ECG, and 170 phono-spectrogram measurements in one cardiac cycle were served for the further analysis.

3. Results

Both of the dPCG and dECG analysis began with the factor analysis to reduce the large amount of input parameters. Table 1. shows the factor analysis of various ECG parameters in the case of sinus rhythm. Using the principal component analysis, 18 components were extracted. The F1 factor represents 13.58% of the variance, the cumulative percent of the first four's variance is 37.4%. The most important parameters were used in the MDA.

Table 1. Factor analysis of ECG parameters (in sinus rhythm) (coefficients below 0.5 are zero-valued).

ECG	F1	F2	F3	F4
	1	2	3	4
LA_trans	0	-0.548	0	0
LA_Area	0	-0.611	0	0
RA_long	0	-0.626	0	0
RA_trans	0	-0.576	0	0
RA_Area	0	-0.66	0	0
R_I	0	0	-.551	0
R_II	0	0.558	0	0
R_III	0	0.535	0	0
R_aVFI	0	0.588	0	0
R_V2	0	0	0	0.510
R_V4	0	0	0	0.574
R_V5	0	0	0	0.593
R_V6	0	0	0	0.532
S_II	0	0	0	0.611
S_aVF	0	0	0	0.547
S_V2	0	0	0.593	0
S_V3	0	0	0.664	0
S_V4	0	0	0.626	0

ECG	F1	F2	F3	F4
S_V5	0	0	0.518	0
II_T-to-P1minmax	0.788	0	0	0
II_P-duration	0.769	0	0	0
III_T-to-P1minmax	0.756	0	0	0
III_P-duration	0.766	0	0	0
V1_T-to-P1minmax	0.639	0	0	0
V1_P-duration	0.769	0	0	0
PII_1st_T	0.788	0	0	0
PIII_1st_T	0.756	0	0	0
PV1_1st_T	0.639	0	0	0

Table 2. Factor analysis of ECG parameters in atrial fibrillation (coefficients below 0.2 are zero-valued).

	1	2	3	4	5	6
QRS	0	0	0.786	0	0	0
fII	0	0	0	0.874	0	0
fIII	0	0	0	0.957	0	0
faVF	0	0	0	0.870	0	0
fV1	0	0	0	0	0.383	0
fV2	0	0	0	0	0.438	0
RII	0	0.883	0	0	0	0
RIII	0	0.805	0	0	0.276	0
RaVF	0	0.846	0	0	0.395	0
SV1	0.273	0	0.664	0	0.343	0
SV2	0	0.354	0.765	0	0.366	0
RV5	0	0	0	0	0.741	0
RV6	0	0	0.358	0	0.839	0
LA_Area	0.220	0	0.591	0	0	0.482
RA_Area	0	0	0.893	0	0	0
LVDd	0.593	0	0.468	0.418	0	0
IVSd	0.769	0	0	0	0	0
LVMass	0.906	0	0.228	0	0	0
LVMI	0.93	0	0.20	0	0	0
MR	0	0.23	0	0	0	0.89
TR	0	0	0	0	0	0
MR_VTI	0	0	0	0	0.67	0.61
TR_VTI	0	0	0	0	0.52	0.30

The factor analysis of the dPCG measurements is far more important, because of the large number of amplitude values of the time-frequency map. The used 170 box values were determined by the parameter reduction of more than 1000 values by the factor analysis.

At the next step the echocardiographic left ventricular end diastolic dimension (LVIDd), the ejection fraction (EF), the left ventricular mass index (LVMI), the aortic Vmax (detecting systolic failure or the grade of aortic stenosis), the rate of mitral and tricuspid regurgitation (MR, TR) were estimated using SPSS (V15.0) multivariate discriminant analysis (MDA) module.

These output variables converted into three discrete values, the input values were the 170 dPCG, and separately, the best dECG parameters determined by the factor analysis. The Wilks' statistic of the MDA model selects the best parameters and the unstandardized canonical discriminant function coefficients were determined (Table 3, 4, and 5 for the dECG input parameters).

Table 3. Canonical discriminant function (CDF) of the unstandardized coefficients for LVIDd estimation.

Parameter	Function 1	Function 2
QRS_T	0.074438	-0.02941
R_aVF	-1.21458	0.576215
R_V6	0.509615	-0.59927
S_V4	0.642333	2.071545
S_V6	-2.12986	-1.25901
V1_P-duration	0.008335	0.023761
PIII_2nd_T_corr	0.012306	-0.00378
PIII_2nd_Area	-0.13478	-0.25712
Constant:	-7.8649	-0.65885

Table 4. CDF of the unstandardized coefficients for LVMI estimation.

Parameter	Function 1	Function 2
QRS_T	0.061159	0.022874
R_III	-1.60416	1.738611
R_aVR	-1.93258	-1.15135
R_V6	0.605695	-0.92704
PII_2nd_T_corr	-0.01405	-0.02759
PIII_2nd_T_corr	0.020277	0.01712
Constant:	-5.71712	-1.48757

Table 5. CDF of the unstandardized coefficients for left atrial area (LA_Area) estimation.

Parameter	Function 1	Function 2
QRS_T	0.059714	-0.02554
R_aVR	-2.36806	-4.0458
S_I	-3.18466	1.88948
S_V2	-1.01791	1.842552
S_V3	1.994183	-0.72072
Constant:	-5.81357	1.317417

Table 6. CDF of the unstandardized coefficients for right atrial area (RA_Area) estimation.

Parameter	Function 1	Function 2
QRS_T	-0.03297	0.045872
R_III	1.172145	-0.40161
III_P2minmax	-3.32678	5.274863
V1_T-to-P1minmax	0.062558	-0.00203
V1_P-duration	0.020982	0.020181
PV1_2nd_Tcorr	0.026194	-0.0062
Constant:	-2.68679	-6.65305

For the LVIDd estimation the model selected 8 variables, the values of the Wilks' lambda decreased from 0.882 to 0.709 ($p < 0.0001$ in each step). For the 3 outputs, the test of function 1 through 2 and 2: Wilks' lambda 0.709 and 0.899; chi-square 132.93 and 41.09 (sign. $p < 0.001$).

Table 7. Classification results of LVIDd prediction based on dECG data

		Pred.			Total
Original		1	2	3	
Count	1	172	58	36	266
	2	29	42	21	92
	3	2	8	27	37
%	1	64.66	21.80	13.53	100
	2	31.52	45. 65	22. 82	100
	3	5. 405	21. 62	72. 97	100

The model selected 6 variables for the LVMI estimation, the values of the Wilks' lambda between 0.904 and 0.714 ($p < 0.0001$ in each steps). The test of function 1 through 2 and 2: Wilks' lambda 0.714 and 0.946; chi-square 130.47 and 21.41 (sign. $p < 0.0006$).

Table 8. Classification results of LVMI prediction based on dECG data

		Pred.			Total
Original		1	2	3	
Count	1	55	31	5	91
	2	64	126	52	242
	3	4	17	41	62
%	1	60.43	34.06	5.49	100
	2	26.44	52.06	21.48	100
	3	6.451	27.41	66.12	100

Five variables were selected for the estimation of LA, and 6 for RA dimensions. The Wilks' lambda for 1 through 2 is 0.798 (chi-square: 87.49, $p<0.001$), for 2 is 0.995 (chi-square: 1.752, $p<0.5$) for LA, and for RA: 0.731 (121.37, $p<0.001$), 0.932 (27.25 $p<0.001$), respectively.

Table 8. Classification results of left atrial (LA) dimensions with dECG data.

		Pred.			Total
Original		1	2	3	
Count	1	194	40	40	274
	2	27	40	36	103
	3	2	8	8	18
%	1	70.80	14.59	14.59	100
	2	26.21	38.83	34.95	100
	3	11.11	44.4	44.4	100

Table 9. Classification results of right atrial (RA) dimensions based on dECG data.

		Pred.			Total
Original		1	2	3	
Count	1	219	94	11	324
	2	18	43	8	69
	3	2	2	8	12
%	1	67.59	29.01	3.39	100
	2	26.08	62.31	11.59	100
	3	16.66	16.66	66.66	100

Based on the dPCG data (170 values for each cardiac cycle at the apex) the following echocardiographic parameters were estimated: aortic Vmax, ejection fraction (EF), mitral and tricuspid regurgitation (MR, TR). Variables (VAR_) 1-30 represent the S1 (from the highest frequencies to the lowest in 10 steps, in 3 time-segments), 31 to 90 the systole (in 6 time-segments), 91 to 110 the S2 (in 2 time-segments), and 111 to 170 the diastole (in 6 time-segments).

The Vmax parameter is estimated by 17 parameters (test of function 1 through 2: Wilks' lambda 0.111, chi-square 274.65; function 2: 0.489, and 89.352, both $p<0.001$). The same parameters for EF are: 7 variables (test of function: 0.391, 121.986, 0.811, 27.23, $p<0.001$); for MR: 7 parameters, (test of function: 0.416, 113.03, 0.78, 32.123, $p<0.001$); for TR: 7 parameters (test of function: 0.534, 81.274, 0.903, 13.166, $p<0.001$ and $p<0.02$).

Table 10. Classification results of Vmax prediction based on dPCG data

		Pred.			Total
Original		1	2	3	
Count	1	299	10	2	311
	2	16	35	2	53
	3	0	1	30	31
%	1	96.14	3.21	0.64	100
	2	30.19	66.04	3.77	100
	3	0	3.22	96.77	100

Table 11. LVMI prediction based on dPCG data

		Pred.			Total
Original		1	2	3	
Count	1	114	29	18	161
	2	21	84	26	131
	3	22	27	54	103
%	1	70.81	18.01	11.18	100
	2	16.03	64.12	19.85	100
	3	21.36	26.21	52.43	100

Table 12. MDA prediction of mitral regurgitation (MR) with dPCG data

		Pred.			Total
Original		1	2	3	
Count	1	191	29	6	226
	2	42	69	5	116
	3	8	13	32	53
%	1	84.51	12.83	2.65	100
	2	36.21	59.48	4.31	100
	3	15.09	24.53	60.38	100

Table 13. Prediction of tricuspid regurgitation (TR) based on dPCG data

		Pred.			Total
Original		1	2	3	
Count	1	172	50	7	229
	2	35	64	6	105
	3	4	5	52	61
%	1	75.11	21.83	3.05	100
	2	33.33	60.95	5.71	100
	3	6.55	8.19	85.25	100

4. Discussion and conclusions

Our study showed, that the method of multiple discriminant analysis could adequately predict the most important echocardiographic parameters by the time-frequency measurements of dPCG and dECG.

Table 14. Canonical discriminant function (CDF) of the unstandardized coefficients for TR estimation with dPCG data.

Parameter	Function 1	Function 2
	1	2
VAR00015	-1.987	1.41
VAR00021	0.952	0.115
VAR00082	-0.619	0.789
VAR00092	-0.139	-0.898
VAR00134	3.492	0.077
VAR00166	1.502	-0.302
(Constant)	-0.68	0.426

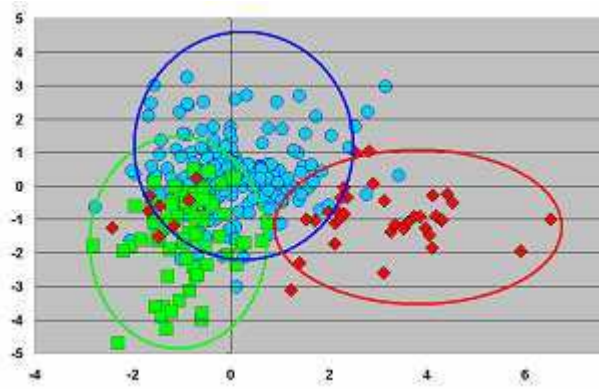

Figure 1. Two-function map for the representation of the discriminant power of the variables and the method of the individual stratification.

Table 14. and Figure 1. show how to use the results of complex statistical method. The two canonical discriminant functions (CDF) are calculated with the new patient's measurements and the unstandardized coefficients. This value will be compared with the use of the circles of the figure. Beside of the prediction (disease severity), the statistical meaning (strength) is also represented by the prediction matrix (in this example see Table 13).

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