Corresponding confusion matrix of the results (example within one fold of testing) is shown in Table 2. It is evident, that the classification of ISE and VPB segments is the most difficult. ISE segments were misclassified as ISM and VPB (5 and 6 segments from 22, respectively). On the other hand, 10 VPB segments (from 17) were misclassified as ISE.

In case of classification with RBF SVM method using PCA-reduced features, the mean classification ACCs for four types of QRS-T segments are: 0.93, 0.84, 0.96, and 0.94, respectively. Example of corresponding confusion matrix is shown in Table 2. Only 3 VPB segments were inaccurately recognized as ISE. Performed classification is more accurate comparing with the previous approach.

Table 2. Example of confusion matrix for linear discriminant function classification using lead II features and RBF SVM classification using PCA-reduced features.

| | | | Classifier output | | | |
			NOR	ISM	ISE	VPB
Linear DFA lead II	Real output	NOR	20	2	0	0
		ISM	1	18	3	0
		ISE	0	5	11	6
		VPB	0	0	10	7
RBF SVM PCA-reduced	Real output	NOR	20	2	0	0
		ISM	1	18	3	0
		ISE	0	0	22	0
		VPB	0	0	3	14

4.   Discussion and conclusions

According to the results, use of low number of morphological parameters calculated from one- or two-lead electrogram in combination with simple classification methods (such as k-NN or DFA) allows achieving of accurate results for four types of QRS-T segments. One of the best achieved classification result (ACC=1.00, 0.93, 0.97, and 0.96 for NOR, ISM, ISE, and VPB segments, respectively, in case of 10-NN classification using PCA-reduced features) is similar or even better comparing with that obtained with other methods. For example, overall ACC of binary classification (NOR/VPB) obtained with SVM and Gaussian RBF classifier using morphological, wavelet and higher order statistical features are approx. 0.90 and 0.92, respectively [1]. ACC for VPB is about 0.96 and NOR about 0.93 in case of classification with multilayer perceptron (MLP) using morphological and rhythm-based features [3] and overall ACC of binary classification (ischemic/normal) with MLP using higher order statistical and spectral features is 0.96 [5].

As expected, reduced ACC was mainly related to misclassifications between ISE and VPB groups with similar character of electrogram morphology. Selection of more informative features using statistical test or PCA and use of features derived from one-lead data only reduce time and PC memory requirements that can be quite high in case of multiclass classification.

References

[1] Alajlan N, Bazi Y, Melgani F, Malek S, Bencherif MA. Detection of premature ventricular contraction atthythmias in electrocardiogram signals with kernel methods. SIViP 2014;8:931-942.
[2] Park SM, Lee JH, Choi SW. Detection of premature ventricular contractions on a ventricular electrocardiogram for patients with left ventricular assist devices. Artif Organs 2014;38:1040-1046.
[3] Das MK, Ari S. ECG beats classification using mixture of features. ISRN 2014; 2014:1-12.
[4] Llamedo M, Martínez JP. Heartbeat classification using feature selection driven by database generalization criteria. IEEE Trans Biomed Eng 2011;58:616-625.
[5] Ronzhina M, Potočňák T, Janoušek O, Kolářová J, Nováková M, Provazník I. Spectral and higher-order statistics analysis of ECG: application to study of ischemia in rabbit isolated hearts. Computing in Cardiology 2012; 645-648.
[6] Sarma P, Nirmala SR, Sarma KK. ECG classification using wavelet subband energy based features. SPIN 2014; 785-790.
[7] Correa R, Arini PD, Correa L, Valentinuzzi ME, Laciar E. Acute myocardial ischemia monitoring before and during angioplasty by a novel vectorcardiographic parameter set. J Electrocardiol 2013;46:635-643.
[8] Kolářová J, Nováková M, Ronzhina M, Janoušek O, Veselý P, Olejníčková V, Provazník I. Isolated rabbit hearts – databases of EGs and MAP signals. Computing in Cardiology 2013; 551-554.

Address for correspondence.

Marina Ronzhina
Department of Biomedical Engineering
Technická 12
616 00 Brno
Czech Republic
ronzhina@feec.vutbr.cz