ARCHIVES OF ACOUSTICS
9, 1-2, 257-266 (1984)

ECHOCARDIOGRAPHY IN PULMONARY HYPERTENSION

P. FRÍDL, P. NIEDERLE, J. WIDIMSKÝ,
M. RIEDEL, R. JANDOVÁ

The Department of Internal Medicine of the Institute for Clinical and Experimental Medicine, Prague, Czechoslovakia

Echocardiographic and haemodynamic examinations were performed on 31 patients with mitral stenosis and on 49 patients with recurrent pulmonary embolism. The echocardiographic examination of the pulmonary valve was successful in 71 per cent and the measurement of right ventricular wall thickness in 95 per cent of patients. In patients with established pulmonary hypertension (mean pulmonary artery pressure 20 or more mm Hg) we observed a tendency to increased right ventricular wall thickness ($r = 0.47$, $p < 0.001$), the flattening of the $e-f$ slope ($r = 0.47$, $p < 0.001$) and a diminished a dip ($r = 0.36$, $p < 0.001$) on pulmonary valve echocardiograms. The higher correlation with mean pulmonary artery pressure ($\overline{PAP}$) was found for the RPEP/RVET ratio ($r = 0.55$, $p < 0.001$) and for the right ventricular internal dimension ($r = 0.65$, $p < 0.001$). The most reliable indicator of pulmonary hypertension is the ratio of the right to the left ventricular dimension ($r = 0.68$, $p < 0.001$). Echocardiographic parameters were compared with ECG parameters of the right ventricle hypertrophy.

1. Introduction

The degree of pulmonary hypertension (PH) is one of the most important prognostic factors in chronic pulmonary diseases. Moderate PH (mean pulmonary artery pressure 20-30 mm Hg) cannot be reliably detected by clinical methods — it can be only confirmed by direct pulmonary artery pressure measurements. Echocardiography is a modern non-invasive method, which makes possible the detection of the pulmonary valve (PV) and the measurement of the right ventricle (RV). The aim of our study is the critical reassessment of the diagnostic value of echocardiography in the detection of PH.

2. Methods

We studied two groups of patients: one group with reccurent pulmonary embolism (PE), who underwent heart catheterization and pulmonary angiography and another group with mitral stenosis (MS), also confirmed by haemodynamic examination. Echocardiographic examination was carried out by the one-dimensional *M*-mode technique with the Echo-cardio-Visor 03 (Organon Teknika, Holland). A 2.25 MHz transducer placed in the standard left parasternal position was used. We paid special attention to the echocardiogram of PV and RV. The interval between the invasive and non-invasive examinations ranged from 2 to 4 days.

The PV was examined in 49 patients with PE and in 31 patients with MS (average age 45.5 years). In the echocardiogram of the PV we evaluated diastolic $e-f$ slope, systolic opening $b-c$ slope and the maximum amplitude of the a dip. Using simultaneously recorded ECG we determined the right ventricular preejection period (RPEP) — as the interval between Q-wave and the onset of the valve opening, and the right ventricular ejection time (RVET) — as the interval between the valve opening and its closure. We used the RPEP/RVET ratio in our study.

RV examination was performed in 36 patients with PE and in 31 subjects with MS (average age 44.2 years). The right ventricular internal dimension (RVID) and right ventricular wall thickness (RVWT) were estimated at the peak of the R-wave of ECG. In cases when the endocardium could not be reliably identified, we suggest the RVD estimation 5 mm behind the anterior chest wall, as recommended by MATSUKUBO *et al.* [13]. The examined echoparameters of the PV and the RV were compared with the mean pulmonary artery pressure ($\overline{PAP}$).

We decided to prove the possibility of the combination of echocardiographic and electrocardiographic examinations in the detection of PH. We considered the echocardiographic examination to be positive when the right ventricular diameter was above 30 mm and/or the ratio of the right to the left ventricular diameter was higher than 0.5. In the case when the right ventricular wall was above 5 mm we considered the echofinding as positive only when at least one abnormal pulmonary valve parameter was present (i.e. the $e-f$ slope above 15 mm/s, the a dip 2 mm or less, and the RPEP/RVET ratio 0.5 or more). The electrocardiographic criteria of PH established by WIDIMSKÝ [25] were evaluated in our study. For positive diagnosis of PH in combination of both methods, either the positive echocardiography or the positive ECG was considered sufficient.

3. Results and discussion

The PV echogram of good quality was obtained for 57 patients, i.e. in 71 per cent. Echocardiographic detection of the PV is very difficult due to the anatomic position of the PV with respect to the anterior chest wall and its ten-

dency to be overlapped by pulmonary tissue during at least a part of the respiratory cycle [23]. Successful imaging of the PV is reported to range between 19.6 and 80 per cent [1, 2, 9, 11, 14, 15, 19] and this percentage seems to be higher in PH, when the PV echo becomes stronger and more easily detectable [6, 19]. The success rate is rather low in patients with chronic obstructive lung disease.

We observed only loose correlation between $\overline{PAP}$ and the pulmonary valve $e-f$ slope flattening (Fig. 1) with correlation coefficient 0.47 ,and no correlation was found between the mean pulmonary artery pressure and the pulmonary $b-c$ slope.

We found an inverse but also loose linear correlation between $\overline{PAP}$ and the depth of the a dip (correlation coefficient was 0.36 — Fig. 2). All of these parameters may vary with respiration and, therefore, regular breathing should be maintained during echocardiographic examination [6, 23]. The depth of the a dip is caused by the contraction of the right atrium and it depends significantly on the pressure gradient between the pulmonary artery and the right ventricle in the end diastole [14]. In patients with severe PH ($\overline{PAP}$ over 40 mm Hg) it is completely absent, but in the presence of RV failure the a dip occurs again, or its depth increases [1, 2, 7, 10, 12, 14, 24]. It may also be influenced by the contraction of the enlarged left atrium in patients with MS [16]. We think therefore that the $e-f$ slope and the a dip yield only complementary information in patients with existing PH.

The highest correlation coefficient in PV examination was found between the RPEP/RVET ratio and $\overline{PAP}$: $r = 0.55$ (Fig. 3). This ratio is the most frequently used parameter for detection of the present PH, because it does not vary with respiration and age [8]. As the difficulties with the accurate determination of the end of the RVET are well known (we were successful in 46 subjects), it was recommended to record the echocardiogram and the phonocardiogram together [17, 20].

The evaluation of the RVID and especially the determination of the RVWT are also associated with a number of technical problems (the precise identification of the endocardium and the epicardium of RV). The successful rate of good quality of the RVWT echogram depends on the site of visualisation, the position of the patients, the position, angulation and type of transducer [22]. In our study the successful estimation of this parameter was possible in 95 per cent of patients.

The RVWT exhibited a loose correlation with $\overline{PAP}$: $r = 0.47$ (Fig. 4), the specificity of this seems to be limited as well, probably due to technical problems with precise measurement.

A various degree of RV dilatation was demonstrated in patients with PH [5, 11, 15, 18, 21]. DEVEREUX *et al.* [4] demonstrated a significant relation between the RVID and the RV mass at autopsy. We found a significant correlation between this parameter and $\overline{PAP}$: $r = 0.65$ (Fig. 5). The increase of this

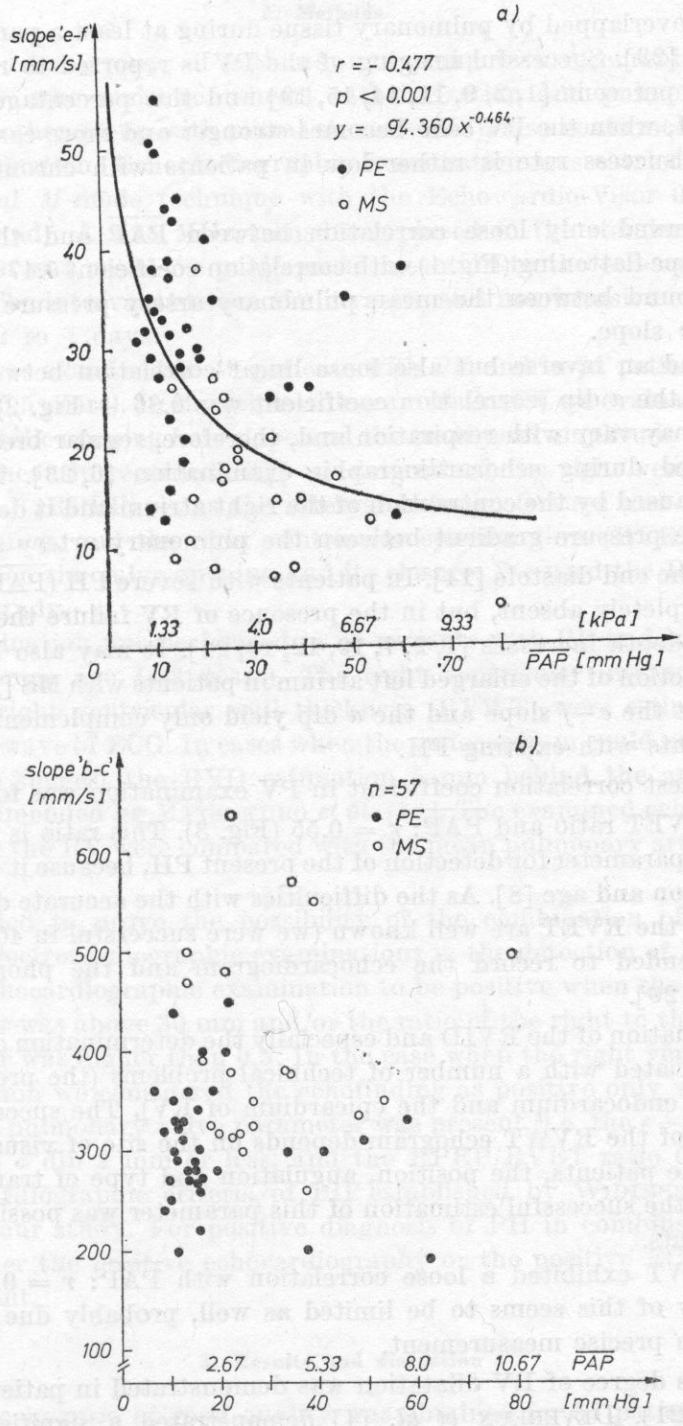

Fig. 1. The correlation between $e-f$ slope, $b-c$ slope and $\overline{\text{PAP}}$

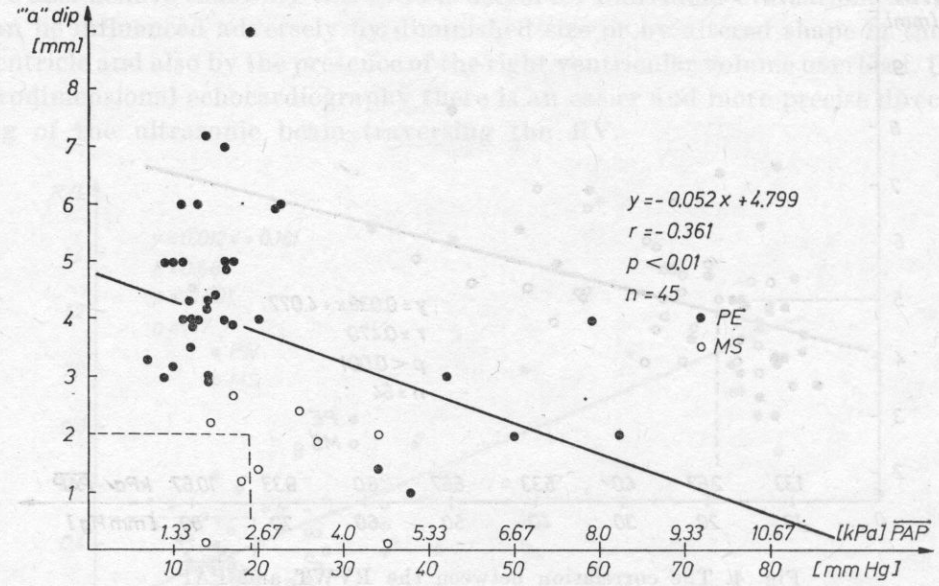

Fig. 2. The correlation between the *a* dip of the pulmonary valve and $\overline{PAP}$

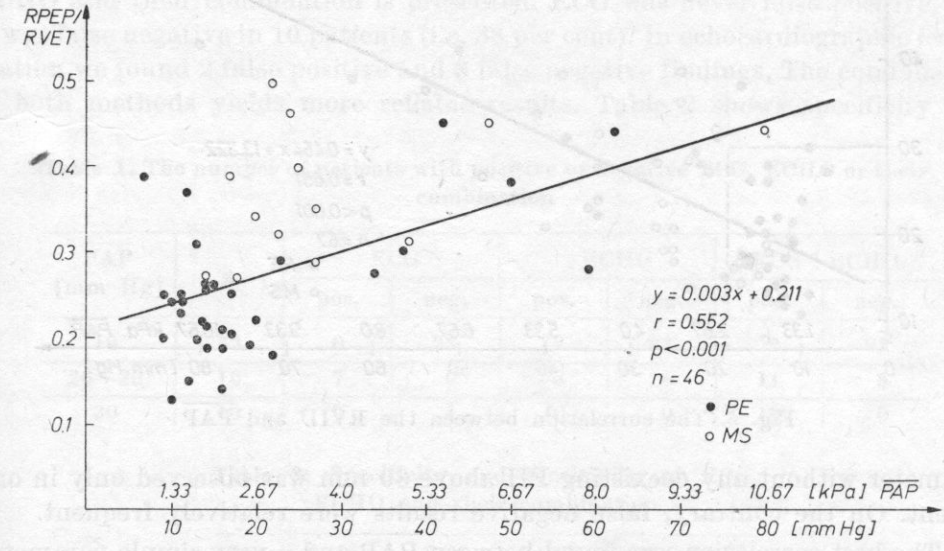

Fig. 3. The correlation between the RPEP/RVET ratio and $\overline{PAP}$

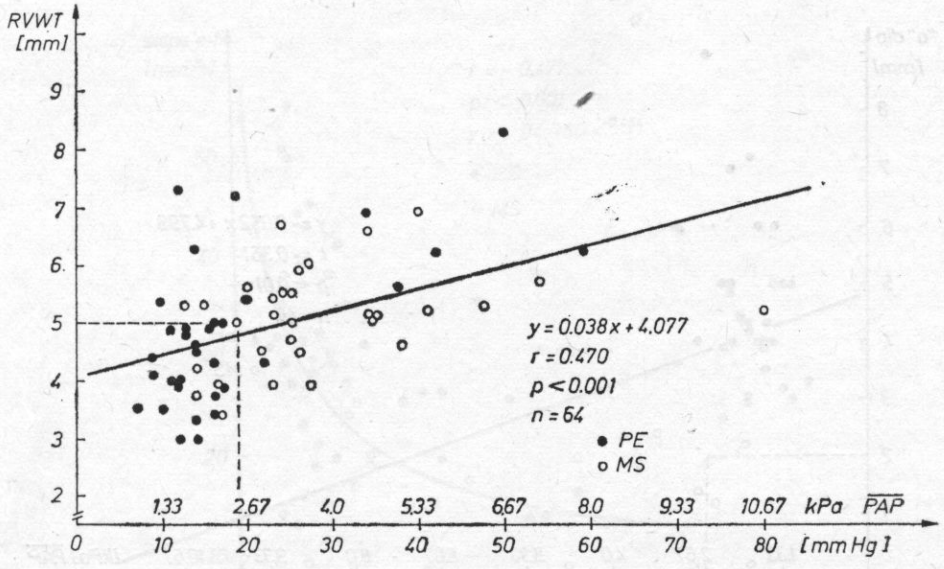

Fig. 4. The correlation between the RVWT and $\overline{PAP}$

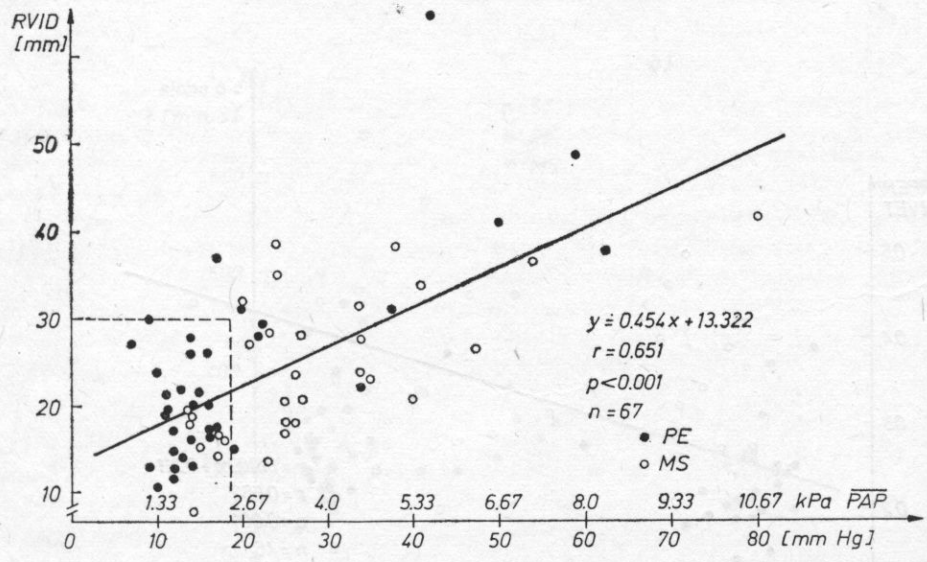

Fig. 5. The correlation between the RVID and $\overline{PAP}$

parameter without any coexisting PH above 30 mm was observed only in one patient. On the contrary, false negative results were relatively frequent.

The best correlation was found between $\overline{PAP}$ and a very simple parameter that was the ratio of the right to the left ventricular diameter (R/L), Fig. 6. We consider the increase of this ratio above 0.5 a reliable indicator of severe PH.

We also believe that only this ratio is useful for individual evaluation. Its value can be influenced adversely by diminished size or by altered shape of the left ventricle and also by the presence of the right ventricular volume overload. Using twodimensional echocardiography there is an easier and more precise directioning of the ultrasonic beam traversing the RV.

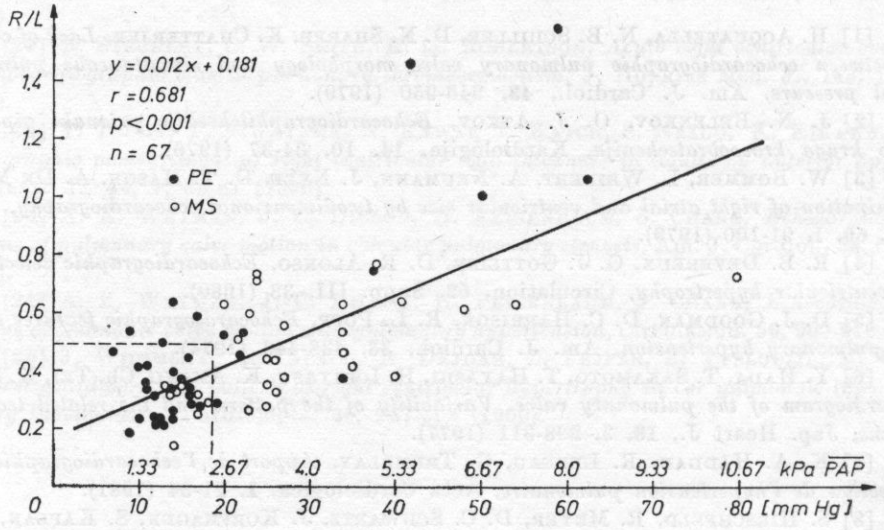

Fig. 6. The correlation between the R/L ratio and $\overline{PAP}$

In Table 1 the number of patients with positivity or negativity of ECG, ECHO and their combination is presented. ECG was never false positive, but it was false negative in 10 patients (i.e. 38 per cent). In echocardiographic examination we found 2 false positive and 8 false negative findings. The combination of both methods yields more reliable results. Table 2 shows specificity and

Table 1. The number of patients with positive or negative ECG, ECHO or their combination

$\overline{PAP}$ [mm Hg]	n	ECG		ECHO		ECG+ECHO	
		pos.	neg.	pos.	neg.	pos.	neg.
19	33	0	33	2	31	2	31
20–29	16	7	9	8	8	11	5
30	10	9	1	10	0	10	0

Table 2. Specificity and sensitivity of ECG, ECHO and their combination

Specification	ECG	ECHO	ECG+ECHO
sens. [%]	61.5	69.2	80.8
spec. [%]	100.0	93.9	93.9

sensitivity of both methods. As the ECG was never false positive, the specificity in combination remained high and the sensitivity raised. The results indicate that both methods should be used together.

References

[1] H. Acquatella, N. B. Schiller, D. N. Sharpe, K. Chatterjee, *Lack of correlation between echocardiographic pulmonary valve morphology and simultaneous pulmonary arterial pressure,* Am. J. Cardiol., **43**, 946-950 (1979).

[2] J. N. Belenkov, O. J. Atkov, *Echocardiographitcheskije priznaki gipertonii malovo kruga krovoobratschenija,* Kardiologija, **14**, 10, 34-37 (1976).

[3] W. Bommer, L. Weinert, A. Neumann, J. Neef, D. T. Mason, A. De Maria, *Determination of right atrial and ventricular size by twodimensional echocardiography,* Circulation, **60**, 1, 91-100 (1979).

[4] R. B. Devereux, G. J. Gottlieb, D. R. Alonso, *Echocardiographic detection of right ventricular hypertrophy,* Circulation, **62**, Supp. III, 33 (1980).

[5] D. J. Goodman, D. C. Harrison, R. L. Popp, *Echocardiographic features of primary pulmonary hypertension,* Am. J. Cardiol., **33**, 438-443 (1974).

[6] Y. Hada, T. Sakamoto, T. Hayashi, H. Ichiyasu, K. Amano, Ch. Tei, K. Kato, *Echocardiogram of the pulmonary valve. Variability of the pattern and the related technical problems,* Jap. Heart J., **18**, 3, 298-311 (1977).

[7] K. A. Haddad, R. Lebeau, G. Tremblay, *Apport de l'echocardiographie dans la detection de l'hypertension pulmonaire,* Acta Cardiologica, **1**, 21-34 (1981).

[8] S. Hirschfeld, R. Meyer, D. C. Schwartz, J. Korfhagen, S. Kaplan, *Measurement of right and left ventricular systolic time intervals by echocardiography,* Circulation, **51**, 304-309 (1975).

[9] S. Hirschfeld, R. Meyer, D. C. Schwartz, J. Korfhagen, S. Kaplan, *The echocardiographic assessment of pulmonary artery pressure and pulmonary vascular resistance,* Circulation, **52**, 642-650 (1975).

[10] R. Kaku, A. Neumann, W. Bommer, L. Weinert, D. T. Mason, A. N. De Maria, *Sensitivity and specificity of the pulmonic valve echogram in the detection of pulmonary hypertension,* Am. J. Cardiol., **41**, 2, 436 (1978).

[11] W. Kasper, T. Meinertz, F. Kersting, H. Löllgen, P. Limbourgh, H. Just, *Echocardiography in assessing acute pulmonary hypertension due to pulmonary embolism,* Am. J. Cardiol., **45**, 567-572 (1980).

[12] W. Lew, J. S. Karliner, *Assessment of pulmonary valve echogram in normal subjects and in patients with pulmonary arterial hypertension,* Br. Heart J., **42**, 147-161 (1979).

[13] H. Matsukubo, T. Matsuura, N. Endo, J. Asayma, T. Watanabe, K. Furukawa, H. Kunishige, H. Katsume, H. Ijichi, *Echocardiographic measurement of right ventricular wall thickness,* Circulation, **56**, 2, 278-284 (1977).

[14] N. C. Nanda, R. Gramiak, T. I. Robinson, P. M. Shah, *Echocardiographic evaluation of pulmonary hypertension,* Circulation, **50**, 575-581 (1974).

[15] P. Niederle, P. Frídl, J. Widimský, M. Riedel, *Echocardiographic diagnosis of pulmonary hypertension,* XVIth International Congress of Internal Medicine, Prague 1982, 388.

[16] D. J. Pocoski, P. M. Shah, *Physiologic correlates of echocardiographic pulmonary valve motion in diastole,* Circulation, **58**, 6 1064-1071 (1978).

[17] T. Riggs, S. Hirschfeld, G. Borkat, J. Knoke, J. Liebman, *Assessment of the pulmonary vascular bed by echocardiographic right ventricular systolic time intervals,* Circulation, **57**, 5 939-947 (1978).

[18] G. Rizzato, A. Rezzano, G. Sala, R. Merlini, L. Ladelli, G. Tansini, G. Montanari, L. Bertoli, *Detection of right heart impairment in sarcoidosis. Haemodynamic and echocardiographic study* (in press).

[19] T. Sakamoto, M. Matsuhisa, T. Hayaschi, H. Ichiyasu, *Echocardiogram of the pulmonary valve,* Jap. Heart J., **15**, 4, 360-373 (1974).

[20] T. Sakamoto, M. Matsuhisa, T. Hayashi, H. Ichiyasu, *Echocardiogram and phonocardiogram related to the movement of the pulmonary valve,* Jap. Heart J., **16**, 2, 107-117 (1975).

[21] R. Steckley, C. W. Smith, R. M. Robertson, *Acute right ventricular overload: an echocardiographic clue to pulmonary thromboembolism,* J. Hopkins Med. J., 143, 122-125 (1978).

[22] T. Tsuda, T. Sawayama, N. Kawai, T. Katch, S. Nezuo, K. Kikawa, *Echocardiographic measurement of right ventricular wall thickness in adults by anterior approach,* Br. Heart J., **44**, 1, 55-61 (1980).

[23] A. E. Weyman, J. C. Dillon, H. Feigenbaum, S. Chang, *Echocardiographic patterns of pulmonary valve motion in valvular pulmonary stenosis,* Am. J. Cardiol., **34**, 644-651 (1974).

[24] A. E. Weyman, J. C. Dillon, H. Feigenbaum, S. Chang, *Echocardiographic patterns of pulmonic valve motion with pulmonary hypertension,* Circulation, **50**, 905-910 (1974).

[25] J. Widimský, A. Valach, R. Dejdar, Z. Fejfar, Z. Vysloužil, M. Lukeš, *The electrocardiographic pattern of right ventricular hypertrophy in cor pulmonale (due to pulmonary tuberculosis,)* Cardiologia, **36**, 287-308 (1960).