

Novel Echocardiographic Techniques in the Diagnosis of Heart Failure

PhD Thesis

By Réka Faludi MD

Supervisor: Prof. Tamás Simor MD, PhD

Head of the Doctoral Program: Prof. Erzsébet Róth MD, DSc

Head of the Doctoral School: Prof. Sámuel Komoly MD, DSc

Heart Institute

University of Pécs, Pécs, Hungary

2010

1. Introduction

Heart failure is a complex clinical syndrome that can result from any structural or functional cardiac disorder that impairs the ability of the ventricle to fill with or eject blood. The syndrome of heart failure is a common manifestation of the later stages of various cardiovascular diseases, including coronary artery disease, systemic or pulmonary hypertension, valvular disease and primary myocardial disease. Echocardiography, what is the most frequently performed cardiovascular examination after electrocardiography, has revolutionized the diagnosis of heart failure. By the help of the common echocardiographic techniques – M-mode, 2-dimensional echocardiography and conventional Doppler – essential information regarding cardiac morphology, function and hemodynamics can be obtained non-invasively. Several challenging problems, however, required the further development of the echocardiographic technique, such as tissue Doppler imaging (TDI) and echocardiographic Particle Image Velocimetry. The aim of our work was to prove the usefulness of these novel echocardiographic techniques in the solution of some special problems in heart failure patients.

2. Objectives

- The aim of the study was to investigate the correlation between levels of B-type natriuretic peptide and the TDI and conventional Doppler echocardiographic parameters characterizing the global left ventricular diastolic function in patients with hypertrophic cardiomyopathy.
- Based on non-invasive studies, it has been reported that isolated resting longitudinal diastolic dysfunction of the right ventricle may be the sign of exercise induced pulmonary hypertension in patients with connective tissue diseases (CTD). The aim of our work was to confirm this observation by the help of our results obtained from TDI measurements and right heart catheterisation.
- We were planning to describe and distinguish left ventricular flow patterns in healthy hearts and in patients with different types of prosthetic mitral valves by the help of the new method of echocardiographic Particle Image Velocimetry. Flow-mediated energy dissipation in the left ventricle was also investigated.

3. Relationship between conventional and tissue Doppler echocardiographic parameters and B-type natriuretic peptide (NT-proBNP) levels in patients with hypertrophic cardiomyopathy

3.1. Introduction

Hypertrophic cardiomyopathy (HCM) is a hereditary cardiac disease characterized by primary myocardial hypertrophy. TDI has been reported to be a preload independent technique. Mitral annular early diastolic myocardial velocity (E') is a reliable index for evaluating left ventricular diastolic function, longitudinal systolic velocity (S) is characteristic of global left ventricular systolic function. Late diastolic velocity (A') is a parameter for assessing left atrial systolic function. The ratio of the early diastolic velocity of the mitral inflow to early diastolic velocity of the mitral annulus (E/E') provides a good estimate of left ventricular filling pressure. The plasma concentration of NT-proBNP is typically elevated in patients with isolated left ventricular diastolic dysfunction. The aim of our study was to determine the relation of diastolic mitral annular velocities combined with conventional Doppler indices to the NT-proBNP levels in patients with HCM.

3.2. Patients and methods

32 consecutive patients with HCM (21 male, 11 female, mean age 47 ± 14 years) were studied. Inclusion criteria were: normal sinus rhythm; ejection fraction $\geq 50\%$; absence of moderate to severe mitral regurgitation or prosthetic mitral valve.

In addition to the conventional transmitral flow patterns (E, A, E/A, DT, IVRT) myocardial early (E') and late diastolic (A') velocities were measured at the lateral and septal border of the mitral annulus by ATL HDI 5000 ultrasound system. E/E' ratio was calculated. Measurements were obtained from ≥ 3 consecutive beats. Lateral E/E' >10 or septal E/E' >15 were considered as elevated. NT-proBNP levels were measured by Roche-Elecsys test (immunoassay). NT-proBNP values were transformed into a natural logarithm (lnNT-proBNP).

3.3. Results

Lateral and septal E/E' indicated elevated left ventricular filling pressure in 10 (31%) and 8 (25%) patients, respectively. Mean NT-proBNP level turned out to be 543 ± 845 pg/ml. Elevated BNP level was found in 21 patients (66%). NT-proBNP levels negatively correlated with the lateral ($r = -0.59$, $p < 0.001$) and septal ($r = -0.391$, $p = 0.03$) A' values and showed a strong correlation with E/A as well ($r = 0.476$, $p = 0.007$). Weak, but significant correlation was found between the NT-proBNP levels and E/sepE' ($r = 0.392$, $p = 0.029$). No significant relationship was observed between NT-proBNP levels and other echocardiographic parameters. By stepwise multiple linear regression analysis the only significant predictor of lnNT-proBNP was lateral A' value, too ($r = -0.467$, $p < 0.05$) (Figure 1).

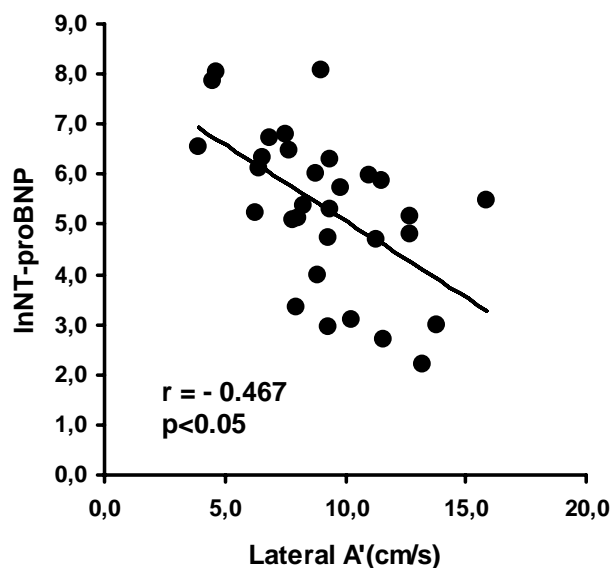


Figure 1 Linear regression between lateral A' and lnNT-proBNP

3.4. Conclusion

According to our results the main determinant of the NT-proBNP level is the A' parameter, characterizing left atrial systolic function. NT-proBNP showed a strong correlation with E/A as well. The latter result, however, must be interpreted carefully, because the E/A ratio does not show a linear correlation with the worsening of the diastolic dysfunction. A' velocity reliably quantifies left atrial contractile function in late diastole. In our study, A' tended to be

impaired parallel with the elevation of left ventricular filling pressure, showing a strong inverse correlation with NT-proBNP level. These data suggests that the missing link between left atrial function and NT-proBNP level may be the left ventricular diastolic function. At the same time, no, or very weak correlations were found between NT-proBNP and conventional or tissue Doppler parameters characterizing the global left ventricular diastolic function (DT, IVRT, E') or left ventricular filling pressure (E/E'). Our data suggest that left atrial wall stress may be an additional, direct determinant of the BNP synthesis.

4. Echocardiographic monitoring of right ventricular function in patients with resting or stress induced pulmonary arterial hypertension secondary to connective tissue diseases

4.1. Introduction

Several studies suggest that an abnormal rise in pulmonary artery pressure (PAP) during exercise in CTD patients with or without exertional dyspnoea, but with normal resting PAP, is a marker for the development of future resting PAH. Recent studies based on non-invasive measurements also suggested that isolated resting longitudinal diastolic dysfunction of the right ventricle may be the sign of exercise induced pulmonary hypertension. The aim of our work was to confirm this observation by the help of our data obtained by TDI measurements and right heart catheterisation.

4.2. Patients and methods

60 patients (mean age 54±8 years, 50 female) were examined: 15 healthy subjects and 45 patients suspicious for PAH secondary to CTDs. Myocardial systolic (S), early (E') and late (A') diastolic velocities were measured from apical 4-chamber view at the lateral border of the tricuspid annulus. Patients with CTD underwent right heart catheterization. If the resting mean PAP was lower than 30 mmHg, physical stress test was performed. Differences between groups were tested for significance using ANOVA.

4.3. Results

In 15 healthy subjects normal PAP (systolic PAP: 24.6±2.4 mmHg) was measured using echocardiography. 24 patients with CTD normal mean PAP (at rest: 18.0±3.2; at peak exertion 22.4±4.6 mmHg) was diagnosed by right heart catheterization. In 8 patients normal PAP-values were measured at rest (mean PAP: 22.8±1.7 mmHg) while elevated values were measured at peak exertion (39.8±6.3 mmHg). 13 patients belonging to the CTD-group had resting PAH (mean PAP: 37.9±10.9 mmHg). Table 1 outlines the main clinical and echocardiographic characteristics of our patient-groups. In the group of patients with stress induced PAH isolated diastolic, while in patients with resting PAH combined systolic and diastolic deterioration of right ventricular longitudinal function was found.

4.4. Conclusion

The right ventricular long axis function is guided by subendocardial fibres, which are most vulnerable to transitional or permanent pressure overload in patients with stress induced or resting PAH. Therefore determination of the tricuspid annular velocities provides an excellent tool for assessing the global systolic and diastolic function of the right ventricle. Our results - based on invasive and TDI measurements - confirmed the observations, suggesting that the isolated diastolic dysfunction of the right ventricle is the sign of stress induced pulmonary hypertension in CTD patients. In patients with resting elevation of pulmonary artery pressure combined systolic and diastolic dysfunction was found.

Table 1 Main clinical and echocardiographic characteristics of the study population

	Normal subjects (n=15)	Patients with CTD (n=45)			P
		Without PAH (n=24)	Stress induced PAH (n=8)	Resting PAH (n=13)	
Age (years)	50±6	54±7	58±8	55±8	NS
BSA (m ²)	1.74±0.15	1.76±0.16	1.76±0.14	1.71±0.26	NS
Male/Female	3/12	3/21	0/8	4/9	NS
NYHA class					
I	15				
II		24	8	7	<0.001
III				6	
Left ventricular EF (%)	63.5±2.3*	61.2±3.3	63.1±2.5#	59.0±3.7	<0.01
Mitral E/A	1.3±0.4	1.0±0.3	0.9±0.3	1.1±0.3	NS
Mitral E' (cm/s)	12.1±2.5	9.9±2.5§	9.2±1.3§	9.4±1.4§	<0.01
Mitral E/E'	5.9±1.3	7.1±2.4	8.0±1.2	7.9±2.6	NS
RV diameter (mm)	27.9±2.5†	31.8±4.1*	28.6±3.7†	38.4±8.2	<0.001
RVFAC (%)	56.9±4.6†	53.7±4.1†	54.8±3.7†	41.4±5.5	<0.001
Tricuspid E/A	1.37±0.21	1.20±0.28	0.91±0.17‡	0.97±0.09‡	<0.001
sPAP estimated (mmHg)	24.6±2.4†	30.0±7.0†	32.8±4.5†	52.7±18.7	<0.001
Tricuspid S (cm/s)	13.9±2.6*	13.1±2.7#	12.7±2.1	10.6±2.4	<0.01
Tricuspid E' (cm/s)	11.0±1.7	9.7±2.3	8.2±2.2§	8.4±1.1§	<0.01
Tricuspid A' (cm/s)	13.4±3.0	13.7±2.8	12.8±2.4	12.0±3.6	NS
Tricuspid E'/A'	0.86±0.25	0.72±0.19	0.67±0.24	0.76±0.22	NS

(BSA: body surface area; EF: ejection fraction; RV: right ventricle; RVFAC: right ventricular fractional area change; sPAP estimated: systolic pulmonary artery pressure estimated by echocardiography; #p<0.05 versus resting PAH; *p<0.01 versus resting PAH; †p<0.001 versus resting PAH; §p<0.01 versus normal; ‡p<0.001 versus normal)

5. Echocardiographic Particle Image Velocimetry: a new method to determine left ventricular flow pattern

5.1. Introduction

Echocardiographic Particle Image Velocimetry (Echo-PIV) is a new, feature tracking based approach to visualize and quantify left ventricular flow patterns in vivo. We investigated the vortex formations in healthy left ventricles and the impact of different types of prosthetic valves on intraventricular flow patterns and flow mediated energy dissipation.

5.2. Patients and methods

We examined 19 patients (mean age 57 ± 19 yrs, 10 female). Nine were healthy subjects and 10 had prosthetic mitral valves (5 bi-leaflet valves, 4 bioprostheses, 1 tilting disc). During contrast echocardiography a low dose of left heart contrast (0.1- 0.2 ml SonoVue) was administered intravenously. Apical four and three chamber views were obtained using Acuson Sequoia C512 ultrasound system. Digital off-line image analysis using a prototype software (Omega Flow Version 2.3.1.) allowed to explore intracavitary flow and to calculate measures of energy dissipation (relative pulsatile vorticity strength, RS, and vortex pulsation correlation, VPC) by means of PIV.

5.3. Results

In healthy hearts, a vortex filling the entire ventricle stores the kinetic energy of the blood and smoothly redirects the blood to the outflow tract (Figure 2). In patients with prosthetic valves, completely different flow patterns were identified depending on type, orientation and position of the valves as well as left ventricular geometry. Patients with prosthetic valves showed significantly higher LV energy dissipation than healthy subjects (Table 2).

5.4. Conclusion

Echo-PIV is feasible. It clearly distinguishes flow patterns in normal hearts from those in hearts with different types of prosthetic valves. Prosthetic valves change the normal diastolic flow pattern considerably. Thus, diastolic storage function for kinetic energy may be impaired in prosthetic mitral valve patients. Echo-PIV offers new insights into cardiac function and may be of future importance to optimize valve replacement therapy.

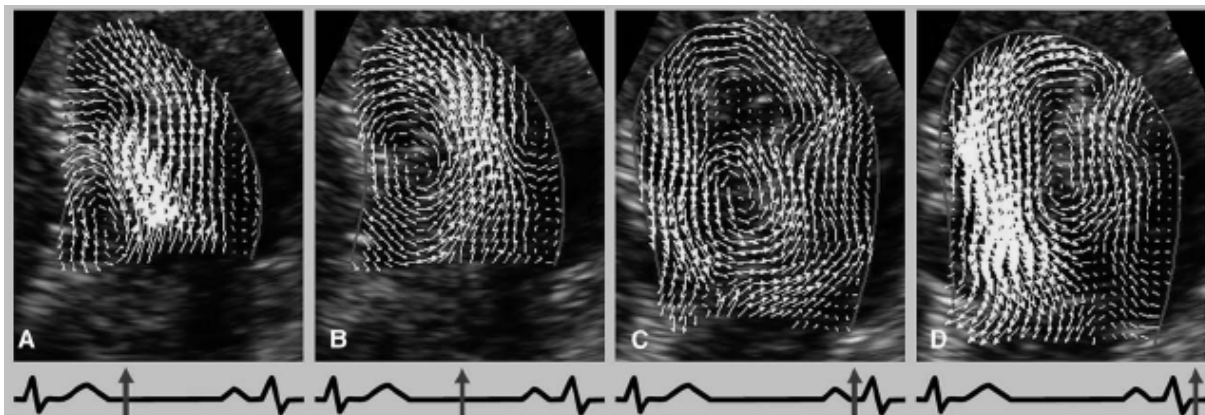


Figure 2 Flow pattern in a healthy left ventricle. Arrows indicating the instantaneous local direction and velocity of blood flow are superimposed on a contrast-enhanced greyscale image of a 4-chamber view.

Table 2 Characteristics of the left ventricular vortical flow in normal hearts and patients with prosthetic mitral valves

	Healthy hearts	All prosthetic valves	p [*]	Bi-leaflet valves	p ^{**}	Bioprosthetic valves	p ^{**}	Tilting disc valve	p ^{**}
VA (%)	50.3±5.9	53.5±13.6	0.352	50.6±16.7	1.000	56.9±8.5	1.000	56.2±15.2	1.000
RS	1.62±0.43	2.36±0.71	0.000	2.33±0.92	0.037	2.43±0.48	0.034	2.28±0.16	0.941
VRS	0.43±0.10	0.52±0.16	0.052	0.50±0.16	1.000	0.53±0.18	0.828	0.64±0.09	0.315
VPC	0.72±0.24	1.20±0.51	0.000	1.20±0.60	0.041	1.22±0.49	0.076	1.22±0.29	0.743

VA – vortex area in % of the left ventricular area. RS, VRS and VPC are parameters of flow pattern dependent energy dissipation in the left ventricle: RS - relative pulsatile vorticity strength; VRS - vortex relative pulsatile vorticity strength; VPC - vortex pulsation correlation. P-values vs. healthy hearts *) t-test, **) ANOVA post hoc test (Bonferroni)

6. Novel findings

6.1. Based on TDI measurement we proved a significant correlation between B-type natriuretic peptide level and the left atrial function in patients with hypertrophic cardiomyopathy.

6.2. By the help of TDI measurements and right heart catheterisation we confirmed the observation, that isolated resting longitudinal diastolic dysfunction of the right ventricle is the sign of exercise induced pulmonary hypertension in patients with connective tissue diseases.

6.3. Our results demonstrated, that the new method of echocardiographic Particle Image Velocimetry is able to describe and distinguish left ventricular flow patterns in healthy hearts and in patients with different types of prosthetic mitral valves.

6.4. By the help of echocardiographic Particle Image Velocimetry we proved, that flow-mediated energy dissipation in the left ventricle is significantly higher in patients with prosthetic mitral valves than in healthy subjects.

7. Publications of the author

7.1. Original papers and letters

7.1.1. In connection with the topic of the thesis

Faludi R., Tóth L., Pótó L., Cziráki A., Simor T., Papp L.: A B típusú natriuretikus peptid (NT-proBNP) szint és a diastolés funkciót jellemző hagyományos és szöveti Doppler-echokardiográfias paraméterek kapcsolata hypertrophiás cardiomyopathiában szenvedő betegekben. *Orvosi Hetilap* 2005;146:23-26.

Faludi R., Komócsi A., Bozó J., Kumánovics G., Czirják L., Papp L., Simor T.: Isolated diastolic dysfunction of right ventricle: stress induced pulmonary hypertension. (Letter to editor) *European Respiratory Journal* 2008;31:475-6. **IF: 5.545**

R. Faludi, M. Szulik, J. D'hooge, P. Herijgers, F. Rademakers, G. Pedrizzetti, J. U. Voigt: Left ventricular flow patterns in healthy subjects and patients with prosthetic mitral valves. An in-vivo-study using Echocardiographic Particle Image Velocimetry. *Journal of Thoracic and Cardiovascular Surgery* 2010;139:1501-10 **IF≈3.037**

7.1.2. Not in connection with the topic of the thesis

Faludi R., Molnár L., A. Tavakoli, Wéber Gy., László T., Mezőfi Beáta: A distalis ileum arteriovenosus malformatioja által okozott vashiányos anaemia. *Orvosi Hetilap* 1998;139:125-127.

Faludi R., Horváth I., Végh M., Trompos K., Lovász M., Cziráki A.: A 24 órás vérnyomás monitorozással szinkron EKG-elemzés jelentősége esszenciális hipertóniás betegekben. *Granum* 2005;8:33-35.

R. Faludi, L. Tóth: Letter to the Editor. *American Heart Journal* 2006;152:e13. **IF: 3.552**

Faludi R., Tóth L., Komócsi A., Varga-Szemes A., Papp L., Simor T.: Chronic postinfarction pseudo-pseudoaneurysm diagnosed by cardiac MRI. *Journal of Magnetic Resonance Imaging* 2007;26:1656-1658. **IF: 2.209**

Faludi R., Komócsi A.: Pulmonalis hypertonia: gyanú, diagnózis, kezelés. *Tüdőgyógyászat* 2008;2:27-34.

B. Bódis, O. Karádi, O. M. E. Abdel-Salam, **R. Faludi**, L. Nagy, Gy. Mózsik: Organoprotection and cytoprotection of histamine differ in rats. *Inflammopharmacology* 1997; 5: 29-41.

Czirák A., Horváth I., **Faludi R.**: Cilazapril-terápia hatása a vérnyomásra és a hemodinamikai paraméterekre essentialis hypertóniás betegekben. *Magyar Belorvosi Archivum* 1999; 52: 81-86.

Komócsi A., **Faludi R.**: Pulmonális artériás hypertensio. *Focus Medicinæ* 2007;9:15-18.

Mánfai B., **Faludi R.**, Rausch P., Bozó J., Tahin T., Földi E., Papp L., Simor T.: Bal pitvari reverz-remodelling pitvarfibrilláció rádiófrekvenciás ablációja után. *Cardiologia Hungarica* 2009;39:113-117.

Komócsi A., Pintér T., **Faludi R.**, Magyar B., Bozó J., Kumánovics G., Minier T., Radics J., Czirják L.: Overlap of coronary disease and pulmonary arterial hypertension in systemic sclerosis. *Annals of the Rheumatic Diseases* 2010;69:202-5. **IF≈7.188**

7.2. Citable abstracts

7.2.1. In connection with the topic of the thesis

R. Faludi, L. Tóth, A. Cziráki, I. Repa, L. Papp, T. Simor: Comparative study of left ventricular diastolic function using pulsed tissue Doppler and cardiac MR in patients with hypertrophic cardiomyopathy. *European Journal of Echocardiography (Suppl.)* 2003;4:61.

R. Faludi, L. Tóth, L. Pótó, A. Cziráki, T. Simor, L. Papp: Relationship between B-type natriuretic peptide levels, conventional Doppler and tissue Doppler echocardiographic parameters in patients with hypertrophic cardiomyopathy. *European Journal of Echocardiography (Suppl.)* 2004;5:S8.

R. Faludi, L. Tóth, T. Simor, L. Papp: NT-proBNP levels and left atrial volumes in patients with isolated left ventricular diastolic dysfunction. *European Journal of Heart Failure (Suppl.)*, 2005;4:52.

R. Faludi, L. Tóth, E. Földi, Gy. Költő, B. Gyömörei, T. Simor, L. Papp: Correlation between left ventricular mass and the parameters characterizing the left ventricular diastolic function in patients with hypertrophic cardiomyopathy. *European Journal of Echocardiography (Suppl.)* 2005;6:S107.

R. Faludi, L. Tóth, Gy. Költő, B. Gyömörei, T. Simor, L. Papp: Assessment of diastolic function using tissue Doppler echocardiography: what is the normal value of the mitral annular early diastolic velocity (Ea)? *European Journal of Echocardiography (Suppl.)* 2005;6:S179.

R. Faludi, L. Tóth, E. Földi, Gy. Költő, B. Gyömörei, T. Simor, L. Papp: Correlation between longitudinal systolic function of the left ventricle and the “non-velocity-type” parameters characterizing left ventricular diastolic function. *European Journal of Heart Failure (Suppl.)* 2006;5:61.

R. Faludi, J. Bozó, A. Komócsi, T. Pintér, G. Kumánovics, L. Czirják, T. Simor, L. Papp: Estimation of pulmonary artery pressure by pulsed wave tissue Doppler imaging of the tricuspid and mitral annulus. *European Journal of Echocardiography (Suppl.)* 2006;7:S202.

R. Faludi, L. Tóth, E. Földi, T. Simor and L. Papp: Main determinants of left atrial volume in patients suffering from hypertrophic and dilated cardiomyopathy. *European Journal of Heart Failure (Suppl.)* 2007;6:S155.

R. Faludi, B. Mánfai, E. Földi, J. Bozó, L. Tóth, P. Cziráki, L. Papp, T. Simor: 2D echocardiographic assessment of left atrial volume: validation by contrast enhanced MRI and CT angiography. *European Journal of Echocardiography (Suppl.)* 2007; 8:S40.

R. Faludi, M. Szulik, J. D'hooge, F. Rademakers, F. Van De Werf, G. Pedrizzetti, J.U. Voigt: Particle image velocimetry distinguishes pathologic and physiologic LV flow patterns in patients with infarcts and healthy subjects. *European Heart Journal (Abstract Supplement)* 2008;29:875.

IF: 8.917

R. Faludi, A. Komócsi, J. Bozó, G. Kumánovics, L. Czirják, L. Papp, T. Simor: Right ventricular dysfunction in patients with resting or stress induced pulmonary arterial hypertension secondary to connective tissue diseases. *European Journal of Echocardiography (Suppl.)* 2008;9:S53.

R. Faludi, M. Szulik, J. D'hooge, F. Rademakers, F. Van De Werf, P. Herijgers, G. Pedrizzetti, J.U. Voigt: Particle Image Velocimetry to assess left ventricular flow patterns in healthy subjects and patients with prosthetic mitral valve. *European Journal of Echocardiography (Suppl.)* 2008;9:S16.

R. Faludi, M. Szulik, J. D'hooge, F. Rademakers, F. Van De Werf, G. Pedrizzetti, J.U. Voigt: Particle image velocimetry distinguishes pathologic and physiologic LV flow patterns in patients with infarcts and healthy subjects. *European Journal of Echocardiography (Suppl.)* 2008;9:S24.

R. Faludi, M. Szulik, J. D'hooge, F. Rademakers, F. Van De Werf, G. Pedrizzetti, J.U. Voigt: Echo particle image velocimetry: A new tool to assess intracavitary flow patterns. *European Journal of Echocardiography (Suppl.)* 2008;9:S16.

R. Faludi, A. Walker, G. Pedrizzetti, J. Engvall, J.U. Voigt: Can feature tracking correctly detect motion patterns as they occur in blood inside heart chambers? Validation of Echocardiographic Particle Image Velocimetry using moving phantoms. *European Heart Journal (Abstract Supplement)* 2009;30:350. **IF≈8,917**

R. Faludi, L. Tóth, Á. Varga-Szemes, E. Földi, T. Simor.: Correlations between systolic and diastolic function in a group of subjects with variable degrees of left ventricular diastolic and systolic dysfunction. *European Journal of Heart Failure (Suppl.)* 2009;8:1456.

E. Gürel, K. Hristova, M. Szulik, **R. Faludi**, L. Van Casteren, R. Willems, J. D'Hooge, F. Rademakers, J.U. Voigt: The impact of function-flow interaction on left ventricular efficiency - a particle image velocimetry study. *European Heart Journal (Abstract Supplement)* 2009;30:50. **IF≈8,917**

E. Gürel, K. Hristova, M. Szulik, **R. Faludi**, J. D'Hooge, F. Rademakers, J.U. Voigt: Echocardiographic particle image velocimetry for the detailed analysis of left ventricular flow patterns. *European Heart Journal (Abstract Supplement)* 2009;30:51. **IF≈8,917**

Faludi R., Tóth L., Cziráki A.: A diastoles dysfunctio vizsgálatának új lehetőségei hypertrophiás cardiomyopathiás betegekben. *Magyar Belorvosi Archivum (Suppl.)* 2003;56:48.

Faludi R., Tóth L., Pótó L., Cziráki A., Simor T., Papp L.: A B-típusú nátriuretikus peptid szint és a szöveti Doppler echocardiográfiás paraméterek kapcsolata hypertrophiás cardiomyopathiás betegekben. *Cardiologia Hungarica (Suppl.)* 2004;34:C41.

Faludi R., Tóth L., Simor T., Papp L.: NT-proBNP szint és bal pitvari volumenek izolált bal kamrai diastolés funkciózavar esetében. *Cardiologia Hungarica (Suppl.)* 2005;35:A84.

Faludi R., Tóth L., Földi E., Gyömörei B., Költő Gy., Simor T., Papp L.: Mely tényezők határozzák meg a bal pitvari volumet hipertrófiás és dilatatív cardiomyopathiás betegekben? *Cardiologia Hungarica (Suppl.)* 2006;36:A82.

Faludi R., Szokodi I., Tóth L., H. Ruskoaho, O. Vuolteenaho, Papp L., Simor T.: Mely tényezők határozzák meg a nátriuretikus peptidok szintjét hipertrófiás és dilatatív cardiomyopathiás betegekben? *Cardiologia Hungarica (Suppl.)* 2007;37:A9.

Faludi R., M. Szulik, J. D'hooge, F. Rademakers, P. Herijgers, G. Pedrizzetti, J.U. Voigt: Bal kamrai áramlási mintázatok egészségesekben és mitrális műbillentyű-beültetést követően. *Cardiologia Hungarica (Suppl.)* 2009;39:A16.

7.2.2. Not in connection with the topic of the thesis

R. Faludi, L. Molnár, A. Tavakoli, Gy. Wéber, T. László, B. Mezőfi: Arteriovenous malformation of the gastrointestinal tract: an analysis of a case and a review of the literature. *Zeitschrift für Gastroenterologie* 1998; 36: 421. **IF: 0.896**

Cziráki A., Horváth I., **Faludi R.**: Prevention of nitrate tolerance with angiotensin converting enzyme inhibitors. *Perfusion* 2000;13:356. **IF: 0.167**

L. Tóth, T. Simor, **R. Faludi**, R. Sepp, I. Repa, L. Papp: Characterization of hypertrophic obstructive and non-obstructive cardiomyopathy using contrast agent enhanced cardiac MRI. *Journal of Cardiovascular Magnetic Resonance* 2004;6:298-299. **IF: 1.898**

T. Simor, L. Tóth, **R. Faludi**, L. Papp, I. Repa: Characterization of regional function in HCM using contrast agent enhanced cardiac MRI. *Journal of Cardiovascular Magnetic Resonance* 2004;6:301-302. **IF: 1.898**

L. Tóth, **R. Faludi**, T. Simor, L. Papp: Non compaction cardiomyopathy, family report. *European Journal of Echocardiography (Suppl.)* 2004;5:S15.

J. Bozó, **R. Faludi**, G. Kumánovics, L. Cziráki, A. Cziráki, T. Simor, L. Papp: Arterial stiffness and diastolic dysfunction in patients with systemic sclerosis. *European Journal of Echocardiography (Suppl.)* 2006;7:S33.

L. Tóth, **R. Faludi**, E. Földi, M. Knausz, Á. Varga-Szemes, L. Papp, T. Simor: Evidence based, MRI strengthened risk stratification strategy for hypertrophic cardiomyopathy patients - A follow up study. *European Journal of Echocardiography (Suppl.)* 2006;7:S205.

L. Tóth, **R. Faludi**, A. Tóth, Á. Varga-Szemes, I. Repa, L. Papp and T. Simor: Correlation of the extent of left ventricular noncompaction and left ventricular function. A MRI study. *European Journal of Heart Failure (Suppl.)* 2007;6:S161.

L. Tóth, Á. Varga-Szemes, **R. Faludi**, R. Sepp, V. Nagy, I. Repa, A. Varga, T. Forster, L. Papp, T. Simor: Which are determinant factors altering left ventricular function and clinical outcome of patients with isolated non compact cardiomyopathy? *European Journal of Echocardiography (Suppl.)* 2007;8:S165.

Á. Varga-Szemes, L. Tóth, **R. Faludi**, L. Papp, T. Simor: Assessment of regional left ventricular function in isolated left ventricular noncompaction. *European Journal of Heart Failure (Suppl.)* 2008;7:33.

L. Tóth, Á. Varga-Szemes, **R. Faludi**, A. Tóth, L. Papp, T. Simor: MRI study in isolated left ventricular noncompaction. *Journal of Cardiovascular Magnetic Resonance* 2007;9:406. **IF: 1.867**

Á. Varga-Szemes, L. Tóth, **R. Faludi**, L. Papp, T. Simor: Assessment of ECG abnormalities in patients with left ventricular noncompaction. *European Journal of Echocardiography (Suppl.)* 2008;9:S96.

Faludi R., Molnár L., Afshin T., Wéber Gy., László T., Mezőfi B.: A distalis ileum arteriovenosus malformatioja által okozott vashiányos anaemia. *Magyar Belorvosi Archivum (Suppl.)* 1996;49:57.

Faludi R., Cziráki A., Horváth I., Végh M., Trompos K., Lovász M.: A 24 órás vérnyomás monitorozással szinkron EKG-elemzés jelentősége esszenciális hipertóniás betegekben. *Cardiologia Hungarica (Suppl.)* 1998;28:41.

Faludi R., Sárszegi Zs., Keller J., Ajtay Z., Goják I., Cziráki A., Papp L.: Ergometria során magas rizikójúnak ítélt betegeknek alkalmazott új terápiás stratégia. *Magyar Belorvosi Archivum (Suppl.)* 2002;55:59.

Faludi R., Tóth L., Cziráki A., Simor T., Papp L.: Non-compact cardiomyopathy: Esetismertetés és irodalmi áttekintés. *Magyar Belorvosi Archivum (Suppl.)* 2004;57:47.

Cziráki A., Horváth I., **Faludi R.**, J.D. Catraves: A pulmonalis kapillárisendothelhez kötött angiotenzinkonvertáló enzim aktivitásának meghatározása betegekben. *Magyar Belorvosi Archivum (Suppl.)* 1998;51:218.

Cziráki A., Horváth I., **Faludi R.**: A pulmonalis és koronáriaendothel-funkció monitorozási lehetőségei betegekben. *Magyar Belorvosi Archivum (Suppl.)* 1999;52:18.

Cziráki A., Horváth I., **Faludi R.**: Angiotenzin konvertáló enzim inhibitorok hatása a nitrát toleranciára iszkémiás szívbetegekben. *Cardiologia Hungarica (Suppl.)* 2000;30:59.

Cziráki A., Csonka D., **Faludi R.**, Nyárfás G., Sárszegi Zs., Papp L.: A kilélegzett nitrogén monoxid vizsgálata ischaemias szívbetegekben. *Cardiologia Hungarica (Suppl.)* 2001;31:64.

Cziráki A., Csonka D., **Faludi R.**, Nyárfás G., Sárszegi Zs., Papp L.: A kilélegzett nitrogén monoxid vizsgálata ischaemias szívbetegekben. *Magyar Belorvosi Archivum (Suppl.)* 2002;55:39.

Király Á., **Faludi R.**, Hunyady B., Illés A., Késmárky G., Radnai B., Undi S., Nagy L.: A nyelvcsömömlés változása non-cardiac chest pain (NCCP) betegekben. *Magyar Belorvosi Archivum (Suppl.)* 2004;57:75.

Tóth L., **Faludi R.**, Knausz M., Simor T., Papp L.: Nonkompakt kardiomiopátia, családleírás, irodalmi áttekintés. *Cardiologia Hungarica (Suppl.)* 2005;35:A86.

Tóth L., **Faludi R.**, Földi E., Knausz M., Repa I., Papp L., Simor T.: A szív-MR vizsgálat jelentősége a hirtelen halál rizikójának felmérésében hipertrófiás kardiomiopátiás betegekben. *Cardiologia Hungarica (Suppl.)* 2006;36:A88.

Bozó J., **Faludi R.**, Tóth L., Simor T., Cziráki A., Kumánovics G., Czirják L., Papp L.: Myocarditis kialakulása scleroderma-myositis overlap szindrómában. *Cardiologia Hungarica (Suppl.)* 2006;36:A61.

Miklán D., Tóth L., **Faludi R.**, Bozó J., Czirják L., Cziráki A., Papp L., Simor T., Pintér Ö.: Iszkémiás szívbetegség előfordulása Takayasu-arteritises betegekben. *Cardiologia Hungarica (Suppl.)* 2006;36:A73.

Földi E., **Faludi R.**, Rausch P., Tahin T., Tóth A., Tóth L., Simor T., Papp L.: Összehasonlító bal pitvari volumen mérések 3D MR és CT-angiográfia valamint 2D-echokardiográfia alapján. *Cardiologia Hungarica (Suppl.)* 2006;36:D5.

Varga-Szemes Á., Tóth L., **Faludi R.**, Tóth A., Repa I., Papp L., Simor T.: Szív MR-vizsgálat izolált bal kamrai nonkompakt cardiomyopathiás betegekben. *Cardiologia Hungarica (Suppl.)* 2007;37:A72.

Varga-Szemes Á., Tóth L., **Faludi R.**, Papp L., Simor T.: EKG-eltérések vizsgálata nonkompakt cardiomyopathiás betegekben. *Cardiologia Hungarica (Suppl.)* 2007;37:C3.

M. Szulik, **R. Faludi**, J. D'hooge, F. Van De Werf, F. Rademakers, R. Willems, T. Kukulski, J.U. Voigt: Apical Transversal Motion - a new integrative approach to predict CRT response. *European Heart Journal (Abstract Supplement)* 2008;29:5. **IF: 8.917**

M. Szulik, J. Stabryla-Deska, **R. Faludi**, R. Willems, T. Kukulski, J.U. Voigt: Rocking heart or rocking apex? Where to analyze dyssynchrony? *European Journal of Echocardiography (Suppl.)* 2008;9:S101.

M. Szulik, **R. Faludi**, R. Willems, T. Kukulski, J.U. Voigt: Apical transversal motion: a new approach to assess left ventricular dyssynchrony in cardiac resynchronization therapy candidates. *European Journal of Echocardiography (Suppl.)* 2008;9:S151.

Mánfai B., **Faludi R.**, Rausch P., Tahin T., Földi E., Tóth L., Varga-Szemes Á., Papp L., Simor T.: A bal pitvar reverz-remodellációja pitvarfibrilláció radiofrekvenciás ablációja után. *Cardiologia Hungarica (Suppl.)* 2008;38:B43.

Mánfai B., **Faludi R.**, Rausch P., Tahin T., Földi E., Papp L., Simor T.: A bal pitvari geometria és funkció vizsgálata pitvarfibrilláció radiofrekvenciás ablációja után. *Cardiologia Hungarica (Suppl.)* 2008;38:G4.

B. Mánfai, **R. Faludi**, E. Földi, P. Rausch, T. Simor: Assessment of left atrial geometry and function prior to and after catheter ablation of atrial fibrillation. *Europace Journal* 2009;11: S6. (Abstract 386)

Varga-Szemes Á., Tóth L., **Faludi R.**, Papp L., Simor T.: A regionális bal kamra funkció vizsgálata izolált bal kamrai nonkompaktációban. *Cardiologia Hungarica (Suppl.)* 2008;38:B7.

Mánfai B., **Faludi R.**, Földi E., Rausch P., Bozó J., Tóth L., Cziráki P., Simor T.: Alkalmas-e a 2D echokardiográfias Simpson-módszer a bal pitvar térfogatának mérésére? A módszer validálása MR- és CT-angiográfia segítségével. *Cardiologia Hungarica (Suppl.)* 2009;39:A24.

Impact factor of original papers: 17.979

Impact factor of citable abstracts: 51.311

7.3. Lectures at international scientific congresses

- R. Faludi:** A "mobile" source of systemic embolism. EUROECHO Congress, Prague, 2006.
- R. Faludi:** Tracking cardiac blood flow: Phantom validation and clinical data. Myocardial velocity and deformation imaging symposium, Leuven, 2009.
- R. Faludi, M. Szulik, J. D'hooge, G. Pedrizzetti, F. van de Werf, J.-U. Voigt:** Echo Particle Image Velocimetry: A new tool to assess intracavitary flow patterns. Annual Meeting of the German Cardiac Society, Mannheim, 2009.
- R. Faludi, A. Walker, G. Pedrizzetti, J. Engvall, J.-U. Voigt:** Can feature tracking correctly detect motion patterns as they occur in blood inside heart chambers? Validation of echocardiographic particle image velocimetry using moving phantoms. Annual Meeting of the German Cardiac Society, Mannheim, 2009. (Poster)
- R. Faludi, M. Szulik, G. Pedrizzetti, P. Herijgers, J.-U. Voigt:** How do prosthetic mitral valves influence left ventricular flow patterns and energetics? An echocardiographic particle image velocimetry study in healthy subjects and patients with mitral prosthesis. Annual Meeting of the German Cardiac Society, Mannheim, 2009.
- R. Faludi:** Flow tracking - Patterns inside the heart. EUROECHO Congress, Madrid, 2009.

8. Acknowledgments

I would like to express my gratitude to all those who gave me the possibility to complete this thesis.

I am deeply grateful to my supervisors Prof. Dr. Tamás Simor and Prof. Dr. Erzsébet Róth, whose stimulating suggestions and encouragement helped me in all the time of research for and writing of this thesis.

I am indebted to my professors who supervised my work abroad, namely Prof. Dr. Jens-Uwe Voigt and Prof. Jan D'hooge from the Catholic University Leuven, for teaching me “professional science”.

I thank my former professors, Prof. Dr. Gyula Mózsik and Prof. Dr. Lajos Papp as well as my recent chief Dr. Sándor Szabados for the continuing support.

My former and recent colleagues from the I. Department of Internal Medicine and Heart Institute supported me in my research work. I want to thank them for all their help, support, interest and valuable hints. Especially I am obliged to Dr. András Komócsi and Dr. Levente Tóth.

Especially, I would like to give my special thanks to my Parents whose patient love enabled me to complete this work.