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Original Article

Protracted impairment of left atrial compliance after cryoballoon ablation in recurrence-free patients with paroxysmal atrial fibrillation

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Abstract: The relationship between alterations in left ventricular (LV) diastolic function and the incidence of recurrence, as well as the associated factors after cryoballoon (CB) and radiofrequency (RF) catheter ablation in patients with paroxysmal atrial fibrillation (Paf), require clarification. We enrolled 138 patients with Paf (RF/CB 69/69) who underwent the first catheter ablation and follow-up for 12 months. Transthoracic echocardiography was performed before and after ablation. An afterload-integrated index of LV diastolic function was calculated as diastolic elastance (Ed)/arterial elastance (Ea), Ed/Ea. No significant increases were observed in Ed/Ea 3 days after RF ablation in patients with (n=12) and without (n=57) recurrence. However, a significant increase was observed in recurrence-free patients with CB ablation (n=59; $P<0.05$), although this level was restored after 6 months. Ed/Ea 3 days after CB ablation was correlated with left atrial pressure immediately after ($r=0.630$, $P<0.001$), but not before ($r=0.290$, $P=0.159$), ablation. The increment of creatine kinase- myocardial band release was positively associated with that of Ed/Ea ($r=0.388$, $P<0.05$) after CB ablation. Thus, the transient manifestation of LV diastolic dysfunction after CB ablation, evaluated by a new echocardiographic index, was observed only in recurrence-free patients with Paf. Protracted impairment of left atrial compliance due to ablation-induced myocardial injury may be related to the lack of recurrence in patients after CB ablation.

Keywords: Cryoballoon ablation, diastolic dysfunction, paroxysmal atrial fibrillation, radiofrequency ablation, transthoracic echocardiography

Introduction

In the recommendations for left ventricular (LV) diastolic evaluation using echocardiography, the severity of diastolic dysfunction is assessed using a combination of several indexes [1, 2]. The established indexes of cardiac performance, including operant diastolic elastance [Ed, (E/e')/stroke volume (SV)] and effective arterial elastance [Ea, (0.9 × systolic blood pressure)/SV], are higher in women than those in men among elderly community-based populations [3, 4]. As LV diastolic function is affected by the extent of arterial elastance, we recently proposed the ratio of Ed to Ea [Ed/Ea=(E/e')/(0.9 × systolic blood pressure)] as an afterload-integrated index of LV diastolic elastance [5-7]. Ed/Ea is an independent prognostic factor in patients with heart failure with preserved ejection fraction (HFpEF) [8].

Ablation procedures confer a potential risk of decreased left atrial (LA) compliance in patients with paroxysmal atrial fibrillation (Paf), which can result in impaired LV diastolic function [9]. LA injury during the ablation procedure may be more severe in cryoballoon (CB) ablation than in radiofrequency (RF) ablation [10]. We recently observed transient manifestation of LV diastolic dysfunction shortly after ablation in patients with Paf, especially after CB ablation [11]. However, the relationship between alterations of LV diastolic function and recurrence of atrial fibrillation (AF) in both ablation procedures remains to be clarified. Therefore, we aimed to clarify this relationship in patients with Paf.

Table 1. Patient clinical and laboratory characteristics before ablation

	CB n=69	RF n=69	*P value*
Age, years	68 ± 12	67 ± 10	*0.706*
Men, %	64	55	*0.193*
Hypertension, %	71	65	*0.483*
Diabetes mellitus, %	15	16	*0.939*
Dyslipidemia, %	38	22	*0.062*
Systolic blood pressure, mmHg	129 ± 17	128 ± 16	*0.680*
Diastolic blood pressure, mmHg	70 ± 12	73 ± 10	*0.059*
Heart rate, bpm	63 ± 12	67 ± 13	*0.055*
Laboratory data			
FBS, mg/dL	107 ± 29	104 ± 16	*0.491*
eGFR, mL/min/1.73 m^2	66.8 ± 17.1	68.9 ± 15.2	*0.432*
BNP, pg/mL	98 ± 174	91 ± 112	*0.790*

Data are expressed as mean ± SD or percentage. *P* values represent data comparisons between the CB and RF groups. CB, cryoballoon; RF, radiofrequency; FBS, fasting blood sugar; eGFR, estimated glomerular filtration rate; BNP, brain natriuretic peptide.

Methods

Patient selection

We enrolled 138 patients with Paf (82 men; mean age, 67 years) who consecutively underwent single RF (n=69) or CB (n=69) ablation and an echocardiographic examination between August 2014 and August 2018. The patients had symptomatic Paf that was refractory to drug treatment. We excluded patients with significant mitral annular calcification, mitral stenosis, or moderate/severe mitral regurgitation. Oral anticoagulation therapy was necessary for at least 1 month before and 3 months after ablation and was omitted only on the morning of the ablation procedures. Computed tomography was performed before ablation in all patients to visualize the anatomy of the pulmonary veins (PVs) and guide the procedure. Blood samples were obtained before and on the day after ablation. The investigation conformed with the principles outlined in the Declaration of Helsinki and was approved by the Institutional Review Board of our hospital. Written informed consent was obtained from all patients before catheter ablation.

Ablation procedure

The ablation procedure used in the study was performed as reported previously [11, 12]. In cases undergoing RF ablation, three-dimensional (3-D) electroanatomical maps created with a NavX system (St. Jude Medical, MN, USA) or the CartoSound module of a CARTO 3 system (Biosense Webster, CA, USA) were used. We performed an extensive encircling pulmonary vein isolation (EEPVI) procedure using a circular mapping catheter (OPTIMA, St. Jude Medical or Lasso, Biosense Webster). Continuous circumferential ablation lines were created around the left- and right-sided PVs using a FlexAbility catheter (St. Jude Medical) at a maximum power of 30 W for 30 s at each site or a ThermoCool SmartTouch catheter (Biosense Webster) in the range of the ablation index determined in advance. In case undergoing CB ablation, an inner lumen mapping catheter (Achieve, Medtronic, MN, USA) was advanced into each PV ostium. Then, a 28-mm cryoballoon (Arctic Front Advance, Medtronic) was advanced, inflated, and positioned sequentially in the PV ostium of each vein. The freeze duration was reduced to 3 min because of the short time required to isolate numerous PVs [13]. Complete PV isolation was achieved in both ablation groups. The patients were treated according to the physicians' discretion and current guidelines.

Echocardiographic examination

Transthoracic echocardiography (Aplio 400, Canon Medical Systems, Tokyo, Japan) was performed before, 3 days after, and 6 months after ablation under sinus rhythm. Measurements of echocardiographic parameters such as chamber size (LA dimension [LAD], LA volume index [LAVI], and LV dimension), LV ejection fraction (LVEF), SV, tricuspid regurgitation pressure gradient (TRPG), transmitral flow velocity (E/A), and tissue Doppler images of the mitral annular septal and lateral areas (mean e') were obtained in accordance with the American or European Society of Echocardiography criteria [1, 2]. All patients exhibited an LVEF of >50%. We calculated Ea [3, 14], Ed [4], and Ed/Ea [5, 6]. Echocardiographic measurements were compared between patients with and without recurrence after the RF and CB ablation procedures. Transesophageal echocardiography was performed in all patients before ablation to exclude the presence of LA thrombus [15].

Table 2. Changes in echocardiographic data between before and 3 days after ablation

	CB		*P value*	RF		*P value*
	Before	3 days after		Before	3 days after	
LVDd, mm	46 ± 4	46 ± 4	*0.864*	47 ± 5	46 ± 4	*0.103*
LVDs, mm	29 ± 5	29 ± 5	*0.627*	30 ± 4	29 ± 4	*0.056*
LVEF, %	66 ± 9	67 ± 10	*0.616*	65 ± 6	68 ± 7	*0.067*
SVI, mL/m^2	38 ± 8	38 ± 7	*0.751*	40 ± 7	40 ± 6	*0.608*
LAD, mm	39 ± 6	40 ± 5	*0.316*	39 ± 6	39 ± 6	*0.695*
LAVI, mL/m^2	31 ± 10	30 ± 11	*0.537*	33 ± 10	31 ± 9	*0.525*
TRPG, mmHg	22 ± 6	23 ± 8	*0.614*	22 ± 5	21 ± 4	*0.745*
Ea, mmHg*m^2/mL	3.16 ± 0.71	3.06 ± 0.67	*0.415*	2.95 ± 0.69	3.02 ± 0.71	*0.544*

Data are expressed as mean ± SD. *P* values represent data comparisons between before and 3 days after ablation. CB, cryoballoon; RF, radiofrequency; LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; LVEF, left ventricular ejection fraction; SVI, stroke volume index; LAD, left atrial dimension; LAVI, left atrial volume index; TRPG, tricuspid regurgitation pressure gradient; Ea, effective arterial elastance.

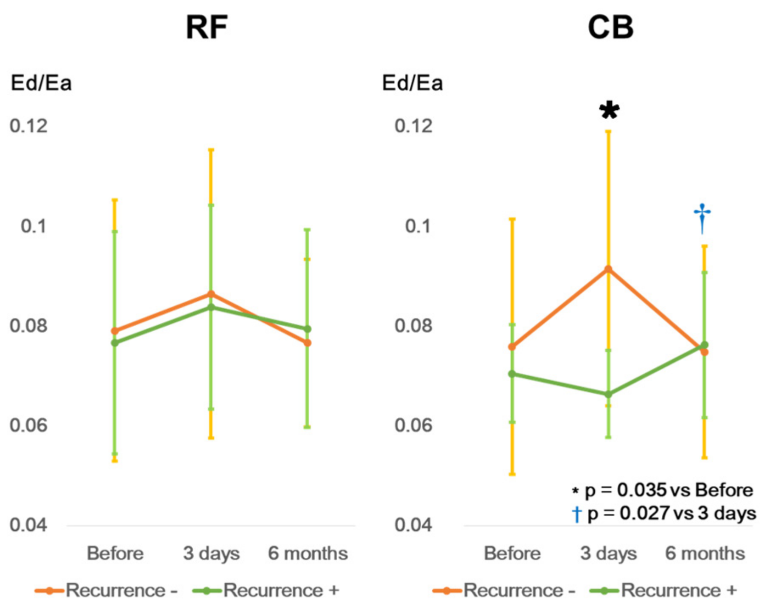

Figure 1. Serial changes in the ratios of diastolic elastance, Ed [(*E/e'*)/(stroke volume index)], to arterial elastance, Ea [(0.9 × systolic blood pressure)/(stroke volume index)] before and after radiofrequency (RF) and cryoballoon (CB) ablations in patients with paroxysmal atrial fibrillation. Between-group differences were assessed by one-way analysis of variance for three comparisons, and differences between pairs of each group were assessed using post hoc Bonferroni tests. A significant difference in Ed/Ea is observed only in patients without recurrence after CB ablation (one-way analysis of variance, P=0.016).

Evaluation of recurrence

The incidence of clinical recurrence was evaluated as follows: follow-up 12-lead ECG results obtained at 1, 3, 6, 9, and 12 months after the initiation of the assigned intervention were analyzed. Twenty-four-hour Holter monitoring was performed at 3, 6, and 12 months of follow-up. The time to the first documented AF or atrial tachyarrhythmia after the 3-month blanking period that lasted >30 s was defined as recurrence.

Statistical analysis

Continuous variables were expressed as means ± standard deviation, while categorical variables were presented as percentage. Between-group differences in categorical and continuous variables were compared using chi-square and Student's t-tests, respectively. Between-group differences for three comparisons were assessed using one-way analysis of variance, while differences between pairs of groups were assessed with the post hoc Bonferroni tests. Correlations were tested using Pearson's coefficient and *P* values were examined using regression analysis. *P* values <0.05 were considered significant.

Results

Clinical and laboratory data before ablation

The differences in clinical and laboratory data before ablation in patients in the RF and CB ablation groups are shown in **Table 1**. No significant differences in age, sex, and blood pressure were observed between the two ablation

Table 3. Differences in clinical and laboratory characteristics between patients with and without recurrence

	CB			RF		
	Recurrence- n=59	Recurrence+ n=10	*P value*	Recurrence- n=57	Recurrence+ n=12	*P value*
Age, years	68 ± 12	65 ± 12	0.431	67 ± 10	67 ± 11	*0.942*
Men, %	58	100	*0.013*	56	52	*0.472*
Systolic blood pressure, mmHg	128 ± 16	135 ± 17	*0.166*	127 ± 16	130 ± 19	*0.572*
Diastolic blood pressure, mmHg	68 ± 12	76 ± 14	*0.066*	74 ± 10	72 ± 10	*0.653*
Heart rate, bpm	63 ± 12	66 ± 8	*0.375*	68 ± 12	67 ± 18	*0.941*
Laboratory data						
FBS, mg/dL	107 ± 30	103 ± 18	*0.703*	104 ± 16	107 ± 16	*0.563*
eGFR, mL/min/1.73 m^2	66.0 ± 15.2	71.9 ± 25.6	*0.307*	70.0 ± 13.7	64.1 ± 20.7	*0.224*
BNP, pg/mL	99 ± 186	90 ± 88	*0.879*	82 ± 100	132 ± 151	*0.161*

Data are expressed as mean ± SD or percentage. *P* values represent data comparisons between the patients with and without recurrence in each ablation procedure. CB, cryoballoon; RF, radiofrequency; FBS, fasting blood sugar; CB, cryoballoon; RF, radiofrequency; FBS, fasting blood sugar.

Table 4. Differences in echocardiographic findings between before and after CB ablation in patients with and without recurrence

	Recurrence -		*P value*	Recurrence +		*P value*
	Before	3 days after		Before	3 days after	
LVDd, mm	46 ± 4	46 ± 4	*0.757*	45 ± 5	46 ± 3	*0.842*
LVDs, mm	29 ± 5	29 ± 5	*0.571*	28 ± 4	29 ± 3	*0.898*
LVEF, %	66 ± 9	67 ± 10	*0.565*	68 ± 5	67 ± 3	*0.833*
SVI, mL/m^2	38 ± 8	38 ± 7	*0.709*	37 ± 7	36 ± 5	*0.937*
LAD, mm	38 ± 5	40 ± 5	*0.299*	40 ± 10	43 ± 7	*0.650*
LAVI, mL/m^2	31 ± 10	30 ± 11	*0.470*	31 ± 9	33 ± 9	*0.696*
TRPG, mmHg	21 ± 6	23 ± 8	*0.458*	24 ± 5	20 ± 5	*0.352*
Ea, mmHg*m^2/mL	3.13 ± 0.73	3.06 ± 0.70	*0.645*	3.39 ± 0.57	3.01 ± 0.19	*0.217*

Data are expressed as mean ± SD. *P* values represent data comparisons between before and 3 days after ablation. CB, cryoballoon; LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; LVEF, left ventricular ejection fraction; SVI, stroke volume index; LAD, left atrial dimension; LAVI, left atrial volume index; TRPG, tricuspid regurgitation pressure gradient; Ea, effective arterial elastance.

groups. Likewise, no significant differences were observed in the estimated glomerular filtration rates and brain natriuretic peptide levels between the two procedures.

The echocardiographic data before ablation showed no significant differences in LAD, LAVI, LVEF, SV index (SVI), E/e', and TRPG between the two ablation groups. No significant changes were observed in LA size, LV size, LVEF, SVI, and TRPG between before and 3 days after ablation in patients in both ablation groups (**Table 2**). Furthermore, Ea did not differ significantly between before and 3 days after ablation in both ablation groups. The systolic blood pressure did not differ significantly between the two ablation groups 3 days after ablation (126 ± 13 vs. 129 ± 15 mmHg, P=0.347).

Recurrence-related alterations in echocardiographic data after ablation

Recurrence-related differences in the alteration of LV diastolic function before and after the two ablation procedures are shown in **Figure 1**. Ed/Ea was significantly increased at 3 days after CB ablation (P=0.035) but not after RF ablation in patients without recurrence. No alterations were observed in the Ed/Ea of patients with recurrence in both ablation groups (**Figure 1**). The index of LV diastolic function was restored to baseline levels at 6 months

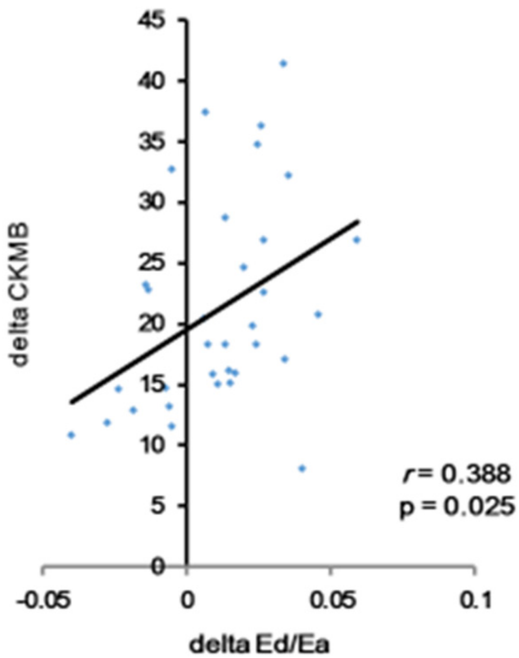

Figure 2. The relationship between the changes in left ventricular diastolic function and myocardial injury shortly after cryoballoon ablation. A positive correlation is observed between the changes in the ratio of diastolic elastance (Ed) to arterial elastance (Ea) (delta Ed/Ea) and the changes in the creatine kinase-myocardial band release (delta CKMB).

after CB ablation in patients without recurrence. Other indexes of LV diastolic function, such as E/A and deceleration time, were not altered after ablation in either treatment group (data not shown). No significant differences were observed in clinical data between the patients with and without recurrence (**Table 3**). In addition, no significant differences in ordinal echocardiographic data before and after CB ablation were observed in those with and without recurrence (**Table 4**).

Modulating factors for altered diastolic function

Significant differences in serum levels of creatine kinase (RF vs. CB ablation: 139 ± 61 vs. 303 ± 99 IU/L, P<0.001) and creatine kinase-MB isoenzyme (16 ± 6 vs. 30 ± 9 IU/L/37°C, P<0.001) at 24 hours after ablation were observed between the two ablation groups; however, no significant differences were observed before ablation. Regarding the relationship between the changes in LV diastolic function and myocardial injury after CB ablation, a positive correlation was observed between the changes in Ed/Ea and myocardial injury, the extent of which was evaluated according to the changes in CK-MB release (**Figure 2**). Though not shown, no positive correlation was observed between the changes in Ed/Ea and MB-CK release in patients with RF ablation.

Figure 3 shows the relationship between LV diastolic function and LA pressure before and after CB ablation. The Ed/Ea 3 days after ablation was positively and significantly correlated with LA pressure immediately after, but not before, CB ablation. The right atrial pressure immediately after CB ablation showed no correlation with the Ed/Ea 3 days after ablation (data not shown).

Discussion

Ed/Ea, an afterload-integrated LV diastolic index, increased significantly 3 days after CB but not RF ablation in Paf patients without recurrence and was correlated with LA pressure immediately after ablation. The transient manifestation of LV diastolic dysfunction after CB ablation in relation to the extent of myocardial injury was observed only in patients without recurrence. In patients with RF ablation, no difference was observed in Ed/Ea 3 days after ablation between those with and without recurrence.

Protracted impairment of LA compliance and recurrence

Impaired LA compliance leading to relatively increased volume may induce a transient progression of LV diastolic dysfunction that is not evident before ablation [9, 16]. The increased LA pressure immediately after CB ablation may persist after 3 days because impaired LV diastolic function was still observed in this phase. An important finding of our study was that the transient progression of LV diastolic dysfunction occurred only in patients without recurrence after CB ablation, which was associated with the extent of myocardial injury in the evaluation of CK release. In patients with Paf, the speed of LA function restoration after sinus conversion remains undefined. As the grade of the impaired LV diastolic function 3 days after CB ablation was significantly correlated with LA pressure immediately after ablation, protracted impairment of LA compliance after CB ablation

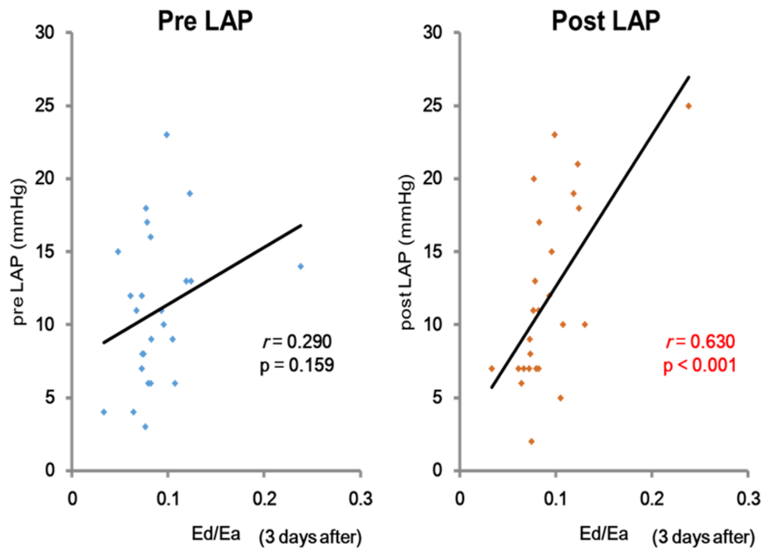

Figure 3. Relationships between left ventricular diastolic function and left atrial (LA) pressure before and after cryoballoon ablation. The ratio of diastolic elastance (Ed) to arterial elastance (Ea) (Ed/Ea) 3 days after ablation is positively and significantly correlated with the LA pressure immediately after (Post LAP), but not before (Pre LAP), cryoballoon ablation.

may occur only in patients without recurrence. In other words, to secure LA damage to some extent, recurrence must be avoided in cases undergoing CB ablation.

As visualization of acute edema in the LA myocardium after RF ablation was recently reported by application of a novel high-resolution 3-D magnetic resonance imaging sequence [17], defining the difference in the edematous change of the LA myocardium during the acute phase between the two ablation procedures is important. In contrast, the difference in the manifestation of LV diastolic dysfunction may be due to the different isolation areas of each PV antrum between CB and RF ablation. The extents of the immediate [18] and protracted (shown in this study) LA injury differ between the CB and RF ablation procedures.

The ablation procedure for persistent AF in patients with LV diastolic dysfunction was associated with increased short- or long-term recurrence risk [19, 20]. In patients with RF ablation, a higher LA pressure after sinus conversion was related to the incidence of recurrence [21]. We observed no significant difference in Ed/Ea 3 days after RF ablation between patients with and without recurrence. During the chronic phase, no significant differences in recurrence rates have been observed between the CB and RF ablation procedures [22, 23], as also shown in the present study. The LV diastolic dysfunction at baseline was a risk factor for late recurrences (first recurrence >12 months after the last catheter ablation) after AF ablation [24], although most patients with Paf had normal systolic and diastolic LV functions.

Ablation-induced LV diastolic dysfunction

Although AF, per se, is a well-known risk factor of HFpEF [25], not all patients with Paf with ablation procedures show LV diastolic dysfunction shortly after ablation. In our previous study, patients with Paf and preserved LVEF were at risk of impaired LV diastolic function after CB ablation [11]; however, the impaired LV diastolic function grade was lower at 3 days in patients in the present study with CB ablation (Ed/Ea, 0.087 ± 0.024) than that in patients with stable HFpEF before discharge (Ed/Ea, 0.156 ± 0.071) [7]. As the LV diastolic dysfunction observed after CB ablation was moderate and returned to the baseline level 6 months after the procedure, the alteration of LV diastolic function observed in this study may not be related to the occurrence of heart failure. However, the short-term incidence of HFpEF may be high when LA compliance is greatly and/or persistently impaired for any reason. The ablated lesions leading to impaired LA compliance differ between CB and RF ablation. Thus, it is important to clarify the lesions in patients without recurrence after CB ablation. Further study of the relationship between the protracted impairment of LA compliance and cryoablation lesions within the left atrium is needed. As patients who were elderly, female, or with hypertension showed impaired LV diastolic function after ablation [11], a long-term follow-up study to elucidate the differences in the future incidence of HFpEF and their related factors among patients with Paf is warranted.

Conclusions

The transient manifestation of LV diastolic dysfunction after CB ablation, as evaluated by a new echocardiographic index, was observed only in recurrence-free patients with Paf. Protracted impairment of the LA compliance due to ablation-induced myocardial injury may be related to the lack of recurrence in patients after CB ablation.

Disclosure of conflict of interest

None.

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References

[1] Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, Flachskampf FA, Foster E, Goldstein SA, Kuznetsova T, Lancellotti P, Muraru D, Picard MH, Rietzschel ER, Rudski L, Spencer KT, Tsang W and Voigt JU. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2015; 28: 1-39.

[2] Nagueh SF, Smiseth OA, Appleton CP, Byrd BF 3rd, Dokainish H, Edvardsen T, Flachskampf FA, Gillebert TC, Klein AL, Lancellotti P, Marino P, Oh JK, Popescu BA and Waggoner AD. Recommendations for the evaluation of left ventricular diastolic function by echocardiography: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr 2016; 29: 277-314.

[3] Kelly RP, Ting CT, Yang TM, Liu CP, Maughan WL, Chang MS and Kass DA. Effective arterial elastance as index of arterial vascular load in humans. Circulation 1992; 86: 513-521.

[4] Redfield MM, Jacobsen SJ, Borlaug BA, Rodeheffer RJ and Kass DA. Age- and gender-related ventricular-vascular stiffening. A community-based study. Circulation 2005; 112: 2254-2262.

[5] Hoshida S, Shinoda Y, Ikeoka K, Fukuoka H, Inui H and Watanabe T. Age- and sex-related differences in diastolic function and cardiac dimensions in a hypertensive population. ESC Heart Fail 2016; 3: 270-277.

[6] Hoshida S, Shinoda Y, Ikeoka K, Minamisaka T, Fukuoka H, Inui H and Watanabe T. Fluctuation of dynamic diastolic function relative to static cardiac structure - New insights into the underlying mechanism of heart failure with preserved ejection fraction in elderly patients. Circ J 2017; 81: 755-758.

[7] Hoshida S, Watanabe T, Shinoda Y, Ikeoka K, Minamisaka T, Fukuoka H, Inui H, Ueno K, Suna S, Nakatani D, Hikoso S, Yamada T, Yasumura Y, Fuji H and Sakata Y. Sex-related differences in left ventricular diastolic function and arterial elastance during admission in patients with heart failure with preserved ejection fraction: the PURSUIT HFpEF study. Clin Cardiol 2018; 41: 1529-1536.

[8] Hoshida S, Watanabe T, Shinoda Y, Minamisaka T, Fukuoka H, Inui H, Ueno T, Yasumura Y, Yamada T, Uematsu M, Tamaki S, Higuchi Y, Abe H, Hikoso S and Nakatani D; Sakata Y on behalf of the OCVC Investigators. A single factor for prognosis in patients with heart failure with preserved ejection fraction. ESC 2019; abstract.

[9] Witt CM, Fenstad ER, Cha YM, Kane GC, Kushwaha SS, Hodge DO, Asirvatham SJ, Oh JK, Packer DL and Powell BD. Increase in pulmonary arterial pressure after atrial fibrillation ablation: incidence and associated findings. J Interv Card Electrophysiol 2014; 40: 47-52.

[10] Miyazaki S, Kuroi A, Hachiya H, Nakamura H, Taniguchi H, Ichihara N, Takagi T, Iwasawa J and Iesaka Y. Early recurrence after pulmonary vein isolation of paroxysmal atrial fibrillation with different ablation technologies - Prospective comparison of radiofrequency vs. second-generation cryoballoon ablation. Circ J 2016; 80: 346-353.

[11] Minamisaka T, Watanabe T, Shinoda Y, Ikeoka K, Fukuoka H, Inui H, Ueno K, Inoue S, Mine K and Hoshida S. Transient manifestation of left ventricular diastolic dysfunction following ablation in patients with paroxysmal atrial fibrillation. Clin Cardiol 2018; 41: 978-984.

[12] Tanaka N, Tanaka K, Ninomiya Y, Hirao Y, Oka T, Okada M, Inoue H, Nakamaru R, Takayasu K, Kitagaki R, Koyama Y, Okamura A, Iwakura K, Sakata Y, Fujii K and Inoue K. Comparison of the safety and efficacy of automated annotation-guided radiofrequency ablation and 2-nd generation cryoballoon ablation in paroxysmal atrial fibrillation. Circ J 2019; 83: 548-555.

[13] Chierchia GB, Di Giovanni G, Sieira-Moret J, de Asmundis C, Conte G, Rodriguez-Mañero M, Casado-Arroyo R, Baltogiannis G, Paparella G, Ciconte G, Sarkozy A and Brugada P. Initial experience of three-minute freeze cycles using the second-generation cryoballoon ablation: acute and short-term procedural outcomes. J Interv Card Electrophysiol 2014; 39: 145-151.

[14] Sunagawa K, Maughan WL, Burkhoff D and Sagawa K. Left ventricular interaction with ar-

terial load studied in isolated canine ventricle. Am J Physiol 1983; 245: H773-H780.

[15] Watanabe T, Shinoda Y, Ikeoka K, Inui H, Fukuoka H, Sunaga A, Kanda T, Uematsu M and Hoshida S. Dabigatran exhibits low intensity of left atrial spontaneous echo contrast in patients with nonvalvular atrial fibrillation as compared with warfarin. Heart Vessels 2017; 32: 326-332.

[16] Shoemaker MB, Hemnes AR, Robbins IM, Langberg JJ, Ellis CR, Aznaurov SG, Fredi JL, Slosky DA, Roden DM, Murray KT, Piana RN, Mendes LA and Whalen SP. Left atrial hypertension after repeated catheter ablations for atrial fibrillation. J Am Coll Cardiol 2011; 57: 1918-1919.

[17] Zghaib T, Malayeri AA, Ipek EG, Habibi M, Huang D, Balouch MA, Bluemke DA, Calkins H, Nazarian S and Zimmerman SL. Visualization of acute edema in the left atrial myocardium after radiofrequency ablation: application of a novel high-resolution 3-dimensional magnetic resonance imaging sequence: visualization of post-ablation LA edema using T2-SPACE. Heart Rhythm 2018; 15: 1189-1197.

[18] Miyazaki S, Taniguchi H, Hachiya H, Nakamura H, Takagi T, Iwasawa J, Hirao K and Iesaka Y. Quantitative analysis of the isolation area during the chronic phase after a 28-mm second-generation cryoballoon ablation demarcated by high-resolution electroanatomic mapping. Circ Arrhythm Electrophysiol 2016; 9: e003879.

[19] Cha YM, Wokhlu A, Asirvatham SJ, Shen WK, Friedman PA, Munger TH, Oh JK, Monahan KH, Haroldson JM, Hodge DO, Herges RM, Hammill SC and Packer DL. Success of ablation for atrial fibrillation in isolated left ventricular diastolic dysfunction: a comparison to systolic dysfunction and normal ventricular function. Circ Arrhythm Electrophysiol 2011; 4: 724-732.

[20] Kosiuk J, Breithardt OA, Bode K, Kornej J, Arya A, Piorkowski C, Gaspar T, Sommer P, Husser D, Hindricks G and Bollmann A. The predictive value of echocardiographic parameters associated with left ventricular diastolic dysfunction on short- and long-term outcomes of catheter ablation of atrial fibrillation. Europace 2014; 16: 1168-1174.

[21] Kishima H, Mine T, Takahashi S, Ashida K, Ishihara M and Masuyama T. The impact of elevated left atrial pressure in sinus rhythm after cardioversion on outcomes after catheter ablation for atrial fibrillation. J Cardiovasc Electrophysiol 2016; 27: 813-819.

[22] Chierchia GB, Di Giovanni G, Ciconte G, de Asmundis C, Conte G, Sieira-Moret J, Rodriguez-Mañero M, Casado R, Baltogiannis G, Namdar M, Saitoh Y, Paparella G, Mugnai G and Brugada P. Second-generation cryoballoon ablation for paroxysmal atrial fibrillation: 1-year follow-up. Europace 2014; 16: 639-644.

[23] Ciconte G, Baltogiannis G, de Asmundis C, Sieira J, Conte G, Di Giovanni G, Saitoh Y, Irfan G, Mugnai G, Hunuk B, Chierchia GB and Brugada P. Circumferential pulmonary vein isolation as index procedure for persistent atrial fibrillation: a comparison between radiofrequency catheter ablation and second-generation cryoballoon ablation. Europace 2015; 17: 559-565.

[24] Onishi N, Kaitani K, Amano M, Imamura S, Sakamoto J, Tamaki Y, Enomoto S, Miyake M, Tamura T, Kondo H, Izumi C and Nakagawa Y. Relationship between left ventricular diastolic dysfunction and very late recurrences after multiple procedures for atrial fibrillation ablation. Heart Vessels 2018; 33: 41-48.

[25] Rusinaru D, Leborgne L, Peltier M and Tribouilloy C. Effect of atrial fibrillation on long-term survival in patients hospitalised for heart failure with preserved ejection fraction. Eur J Heart Fail 2008; 10: 566-572.