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Left Atrial Ejection Force (LAEF) in Patients With Hypertension: LAEF Is Decreased in Hypertensive Patients With Left Ventricular Failure Or Atrial Fibrillation

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Background: Left atrial (LA) contraction is an important parameter in hypertensive (HT) patients. However, it is difficult to evaluate LA contraction non-invasively. Recently, a Doppler echocardiogram derived left atrial ejection force (LAEF) method was introduced for evaluating LA contraction. We studied LAEF in patients with HT. Subjects: One hundred and twenty-four patients with HT were studied. There were 74 men and 50 women. Age ranged 35–77 years. Thirty-five normal subjects and 20 patients with congestive heart failure (CHF) or paroxysmal atrial fibrillation (PAF) were also studied. Principle: According to Newton’s law of motion, LAEF is calculated as LA ejection volume × acceleration of flow. LA ejection volume = mitral valve area (MVA) × time velocity integral of mitral flow. Acceleration is the slope of atrial flow velocity. Methods: (1) MVA was calculated by 2-D echo. Mitral flow velocity was recorded by pulsed Doppler. (2) LAEF was calculated as 1/3 area (MVA) / Newton’s law of motion, LAEF is calculated as LA ejection volume / time. (3) LAEF was compared with WHO stage and period of HT. (4) LAEF was compared between patients with and without CHF or PAF. Results: (1) In normal subjects, LAEF correlated with age (r = 0.74, p < 0.001). Therefore, age corrected %LAEF was used for analysis. %LAEF = (actual LAEF) / (normal LAEF) × 100. (2) In patients with HT, %LAEF was 107.8 ± 5.7 % in WHO stage I, 111.6 ± 8.0 % in stage II and 105.7 ± 13.5 % in stage III (n.s.). %LAEF was higher in patients with WHO stage I and II than normal subjects. (3) %LAEF was 111.6 ± 6.0 % in patients with period < 5 years, 108.6 ± 9.0 % in period 10–20 years and 105.8 ± 11.2 % in period > 20 years. %LAEF had a tendency to decrease with period of HT (n.s.). (4) %LAEF was 50.3 ± 22.4 % in patients with PAF, and was 64.3 ± 31.8 % in patients with CHF. %LAEF was lower in hypertensive patients with CHF or PAF than without CHF or PAF (p < 0.001). Conclusions: LAEF may be compensated in mid stage of hypertension and decompensated in late stage of hypertension. LAEF is decreased in hypertensive patients with paroxysmal atrial fibrillation or congestive heart failure. J Clin Basic Cardiol 2002; 5: 237–40.

Key words: left atrial contraction, left atrial ejection force, hypertension, atrial fibrillation, congestive heart failure

Left ventricular hypertrophy causes left ventricular diastolic dysfunction in patients with hypertension, and left atrial contraction is affected by left ventricular diastolic dysfunction. It is important to gauge the left atrial contraction for evaluating the haemodynamic changes in hypertensive patients. However, it is difficult to evaluate non-invasively left atrial contraction. Recently, Manning et al. reported a non-invasive method “Left atrial ejection force (LAEF)” using pulsed wave Doppler applying Newton’s second law of motion: force equals mass times acceleration [1]. LAEF is reported to be decreased in patients with paroxysmal atrial fibrillation or dilated cardiomyopathy [1–2]. In this study, we have analyzed the left atrial contraction using LAEF in patients with hypertension.

The purpose of this study was to evaluate the usefulness of the left atrial ejection force (LAEF) for assessing the left atrial contraction in patients with hypertension. We also evaluated LAEF in hypertensive patients with paroxysmal atrial fibrillation or congestive heart failure.

Subjects

Study I

One hundred twenty-four patients with hypertension, who were referred to our out-patient clinic from April, 1990 to March, 1997, were entered into this study. Age ranged from 35 to 77 (61.4 ± 9.35) years. There were 74 men and 50 women. Patients with mitral regurgitation were excluded because the regurgitant flow affects the atrial ejection flow. Patients with atrial fibrillation were also excluded because of absence of mitral A-velocity. Complications were diabetes mellitus in 25 pts, hyperlipidaemia in 15 pts, cerebral haemorrhage in 1 pt, cerebral infarction in 7 pts, angina pectoris in 4 pts, and none in 63 pts. Medications were Ca-antagonist in 38 pts, beta-blocker in 5 pts, ACE inhibitor in 19 pts, alpha-blocker in 3 pts, combination of these drugs in 26 pts, and none in 37 pts. All patients had normal left ventricular systolic function.

Study II (Follow-up Study)

Forty patients with hypertension who were admitted to our hospital from January, 1989 to December, 1998 were also entered into this study. These patients were also included in Study I. Patients complicated with other heart diseases such as coronary and valvular heart disease were excluded. Patients were treated with life style modification and medications. LAEF was measured in the follow-up period. Eleven patients complicated with paroxysmal atrial fibrillation (PAF). Nine patients complicated with congestive heart failure (CHF) in the follow-up period, and LV ejection fraction decreased in these patients.

Methods

Principle of Left Atrial Ejection Force (LAEF)

According to Newton’s law of motion, force equals mass times acceleration. Therefore, Manning et al. [1] hypothesized that LAEF equals left ejection volume times acceleration of left atrial flow. In hydrodynamics, force equals consistency of the fluid (ρ) times area of spouting out (s) times squared flow velocity (q). Because the velocity of A wave changes with time in transmitral flow, mean force is calculated as follows:

\[ \text{LAEF} = \frac{\text{MVA} \times \int v(t) \, dt}{\text{A}} \times \text{acceleration} \]
Therefore, the final formula is as follows; LAEF = 1/3 \times \text{MVA}.  
Actually, Manning used the coefficient “1/2” in his original formula, however, as shown in our formula, we used the coefficient “1/3” because the law of motion was applied to fluid.

**Echocardiogram**

Echocardiogram was recorded in a left decubitus position using SSH-160A ultrasonic machine (Toshiba Co., Ltd., Tokyo, Japan) with a 2.5 MHz transducer. Mitral valve diameter (MVD) was measured from a four chamber view using manual tracing. Mitral valve area (MVA) was calculated as $3.14 \times (\text{MVD}/2)^2$. Pulsed Doppler transmitral flow was obtained at the mitral ring level from a four chamber view with a paper speed of 50 mm/sec. Three consecutive beats were recorded to measure the peak velocity of A wave.

**Calculation of LAEF**

Figure 1 shows the method for calculating the LAEF. Left upper panel shows the schema of four chamber view of two-dimensional echocardiogram. As indicated by arrow, mitral valve dimension (MVD) was measured, and mitral valve area (MVA) was calculated as a circle. Right upper panel shows the schema of transmitral flow velocity on the pulsed wave Doppler (PWD). Left atrial ejection force (LAEF) was calculated using the final equation.

Because the LAEF directly correlated with age in normal subjects, following analysis was performed using the age corrected %LAEF [2].

**Parameters of Hypertension**

We have evaluated the relationship between %LAEF and following parameters; 1) Cardiac Mass Index, 2) WHO Stage of Hypertension, 3) Periods of Hypertension, 4) Paroxysmal Atrial Fibrillation and Heart Failure. The cardiac mass index was calculated using M-mode echocardiographic cubic method: LV mass index = $1.05 \times [(\text{LVDd} + \text{IVS} + \text{PW})^3 - (\text{LVDd})^3] / \text{BSA}$ g/m² (where LVDd is LV diastolic dimension, IVS is thickness of interventricular septum, PW is thickness of posterior wall, and BSA is body surface area). The LV mass was also calculated using the following equation (Devereux’s method): LV mass = $0.80 \times (\text{cube LV mass}) + 0.6$ g [3].

**Statistical Analysis**

Data were expressed as mean ± standard deviation (SD). Student’s t-test and ANOVA were used for unpaired data. Linear regression analysis was performed for scattered data by using the least squares methods. Statistical significance was defined as $p < 0.05$.

**Results**

**Relationship Between LAEF and Age in Normal Subjects**

Figure 2 shows the relationship between left atrial ejection force (LAEF) and age. LAEF positively correlated with age. R-value was 0.74 ($p < 0.0001$), and regression line was LAEF = 0.098 × age − 0.74.

**Relationship Between Cardiac Mass Index and %LAEF in Hypertensive Patients**

Figure 3 shows the relationship between cardiac mass index and %LAEF. Cardiac mass index ranged from 50 to 270 g/m² (cube method). There were no significant correlations between cardiac mass index (cube method) and corrected left atrial ejection force (%LAEF) ($r = 0.11$, n.s.). There were also no significant correlations between cardiac mass index (Devereux’s method) and corrected left atrial ejection force (%LAEF) ($r = 0.08$, n.s.).

**Relationship Between Left Atrial Diameter and %LAEF in Hypertensive Patients**

Figure 4 shows the relationship between left atrial diameter and corrected left atrial ejection force (%LAEF). LA diameter ranged from 20 to 55 mm. There were no significant correlations between two parameters ($r = 0.01$, n.s.).
WHO Stage and %LAEF
Figure 5 shows the %LAEF in WHO stages of hypertension I, II and III. WHO stage was I in 61 patients (50%), II in 44 patients (36%), and III in 18 patients (14%). %LAEF was 107.8 %, 111.6 % and 105.7 % (on average), respectively. %LAEF was slightly higher in stage II than in stage I, and was slightly lower in stage III than stage II (n.s.).

Period of Hypertension and %LAEF
Figure 6 shows the %LAEF in 3 period groups of hypertension. Periods of hypertension were less 9 years in 69 patients (58%), 10 through 19 years in 27 patients (22%), and over 20 years in 24 patients (20%). %LAEF was 111.6 %, 108.6 % and 105.8 % (on average), respectively. %LAEF had a tendency of decreasing with period of hypertension, however, there were no statistically significant differences among the three groups (n.s.).

%LAEF in Hypertensive Patients with Paroxysmal Atrial Fibrillation (PAF) or Congestive Heart Failure CHF)
Figure 7 shows the %LAEF of 6–12 months before PAF or CHF in hypertensive patients. %LAEF was 50.5 ± 22.4 % in patients with PAF, and was significantly lower in hypertensive patients without PAF (p < 0.001). %LAEF was 64.3 ± 31.8 % in patients with CHF, and was significantly lower in hypertensive patients without CHF (p < 0.001).

Discussion
Left Atrial Size and Function in Hypertensive Patients
Left atrial enlargement is a common finding in patients with arterial hypertension. This is provoked by long-term elevated left atrial afterload due to the left ventricular diastolic dysfunction. It is reported that high average nighttime blood pressure is a powerful marker of left atrial enlargement [4]. In our study, left atrial diameter ranged from 20 to 55 mm, and many patients had enlarged LA diameter.

Elevated left atrial afterload also affects the left atrial contraction in hypertension. Left atrial pump function is reported to be augmented in essential hypertension [5]. Our results also showed that LAEF, which is a left atrial systolic function, is augmented in hypertensive patients. The atrial function can also be evaluated by electrocardiogram. Electrocardiographic signs of atrial overload are an index of abnormality of atrial function in hypertensive patients [6].
Left Atrial Systolic Function and Left Ventricular Diastolic Function

It is difficult to evaluate the left atrial systolic function non-invasively. Previously, many techniques were used; posterior aortic echocardiogram to calculate left atrial volume change [7], the left atrial pressure-dimension relation [5], systolic time intervals [8]. Recently, Manning et al. have reported that atrial ejection force provides a physiologic assessment of atrial systolic function [1]. This method using Doppler echocardiography is simple and easy for evaluating the left atrial systolic function non-invasively. Mattioli et al. have reported the findings of atrial ejection force in healthy subjects [9].

They showed that the LA ejection force correlated with age (r = 0.90), and discussed the fact that the age-corrected normogram is essential when assessing atrial ejection force in individual patients. This result was similar to our study as shown in Figure 2 (r = 0.74).

Left ventricular diastolic function affects the left atrial contraction because LV diastolic function is the LA afterload. It is reported in subjects with normal relaxation that increasing chamber stiffness was associated with an enhanced peak early filling velocity and decreased filling during atrial systole [10]. LAEF directly correlated with age in our study. LA contraction may be augmented by age related LV diastolic dysfunction. Appleton et al. have reported that mitral flow velocity recordings have clinical potential in assessing left ventricular diastolic dysfunction that merits further investigation [11].

Left Atrial Ejection Force (LAEF) and Hypertension

We used LAEF by Doppler echocardiography for evaluating the LA systolic function in patients with hypertension. Although age corrected LAEF (%LAEF) widely scattered from 20 to 220 %, %LAEF was higher in hypertension than in normal, on average (108.4 vs. 100.0 %). %LAEF was lower in hypertensive patients with period over 20 years and WHO stage III than period less than 19 years and WHO stage II. Otherwise, %LAEF had no significant correlation with left cardiac mass index. Left atrial ejection force is influenced by many factors such as LV diastolic function, period of hypertension, WHO stage, atrial fibrillation, congestive heart failure.

Arterial hypertension affected the left atrial function. LA reservoir function increases and LA conduit function decreases, while LA ejection force increases in hypertensive patients [12]. Patients with hypertensive heart disease had impaired left ventricular diastolic filling before atrial contraction, which resulted in the decreased left atrial conduit volume [13]. These changes may affect the LAEF in hypertensive patients. We speculated that compensated versus decompensated LA function can be discriminated by monitoring the %LAEF.

%LAEF and WHO Stage and Period of Hypertension

Matsuzaki et al. have reported that the increased pump function of the left atrium may be attributed not only to Staring’s effect but also to the enhanced inotropic state of the left atrium in patients with hypertension [5]. In our study, %LAEF was less than 100 % in 8/18 hypertensive patients with WHO stage III and was lower in patients with over 20 years than less than 20 years of the period of hypertension. These findings suggest that the left atrial contraction is compensated in the early to mid stage of hypertension, however, decompensated in the late stage of hypertension.

%LAEF is Decreased in Congestive Heart Failure and Atrial Fibrillation

%LAEF was higher in early to mid stage of hypertension than in normal controls, however, %LAEF was lower in late stage than mid stage of hypertension. %LAEF was also significantly lower in hypertensive patients with CHF than those without CHF in our retrospective study. Although it takes a long time, monitoring of %LAEF may be useful for predicting the CHF in hypertensive patients [14].

Hypertensive cardiovascular disease reported to be the most common antecedant disease of atrial fibrillation [15]. Occurrence of paroxysmal atrial fibrillation in hypertension is associated with left atrial function and ventricular filling [16]. Manning et al. have reported that LAEF was significantly lower in patients with Paf [1]. %LAEF was, indeed, significantly lower in hypertensive patients with Paf than those without Paf in our study. Monitoring of %LAEF may be useful for predicting atrial fibrillation in hypertensive patients.

References


Figure 7. %LAEF in hypertensive patients with paroxysmal atrial fibrillation (PAF) or congestive heart failure (CHF). %LAEF of 6–12 months before CHF or PAF are shown. %LAEF was significantly lower in patients with PAF than in those without PAF. %LAEF was significantly lower in patients with CHF than those without CHF.
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