The Role of the Left Atrial Appendage A Volume Loading Study in Open-chest Dogs

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SUMMARY

Although the left atrial appendage has a quite unique structure, its function remains unclear. To clarify the function of the left atrial appendage, changes in its anteroposterior, transverse and longitudinal dimensions, and in the anteroposterior dimension of the left atrial body were measured by a sonomicrometer during volume loading in open chest dogs. In the control state, fractional shortening of the transverse dimension of the appendage was greater than that of the atrial body. After dextran infusion, each dimension of the appendage and body, measured just before atrial contraction, increased curvilinearly. The percent increase in appendage dimensions was greater than that of the atrial body dimension ($p < 0.05$). Systolic shortenings of the appendage increased until mean left atrial pressure reached approximately 15 mmHg but after further pressure elevation, it decreased. In postmortem isolated hearts, the appendage volume was $17.2 \pm 4.4\%$ of the whole left atrial volume. These findings indicate that the appendage has a considerable volume with a greater compliance and assists left ventricular filling during atrial contraction by a Frank-Starling mechanism. (Jpn Heart J **36**: 225-234, 1995)

Key words: Systolic shortening of the left atrial appendage Left atrial function Sonomicrometer

GREAT attention has been paid to the left atrial appendage, particularly in patients with mitral diseases, for diagnosis^{1,2)} and as the location of thrombus formation.³⁾ Although the appendage functions may differ from those of the atrial body because of its unique structure, few studies of the appendage functions have been performed because of methodological limitations.⁴⁾

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Received for publication June 10, 1994.

Accepted December 7, 1994.

Using a sonomicrometer,⁵⁾ multiple dimensional changes can be measured simultaneously during a cardiac cycle. Although changes in the left atrial appendage dimensions have been measured by Zucker et al,⁶⁾ Linderer et al,⁷⁾ and Hintze et al⁸⁾ using a sonomicrometer, they did not compare those changes with changes in the atrial body dimension. The purpose of this study was to clarify the function of the left atrial appendage by comparing changes in the appendage dimensions with those in the atrial body during volume loading.

METHODS

Ten mongrel dogs (body weight 6–27 kg) were anesthetized with 10 mg/kg i.m. of ketamine and 25 mg/kg i.v. of pentobarbital. The trachea was intubated and ventilation maintained by a respirator (R-60, Aika, Tokyo, Japan). Following left fifth intercostal thoracotomy, the pericardium was widely opened. The sinus node was ablated by injecting 10% formalin into the right atrial wall, and right atrial appendage pacing was set at a rate of 80 per minute (pacing generator 5320, Medtronic, Minneapolis, MN). Two short catheters were inserted in the pulmonary vein and the left ventricular apex and then connected to a pressure transducer (Statham P23XL, Spectramed, Wingham, UK) to measure left atrial and ventricular pressures. Four pairs of sonomicrometer crystals, about 1.5 mm in diameter, were sutured externally to the anterior edge, the posterior edge, the right side wall, the left side wall, the base and the tip of the left atrial appendage, and the anterior wall and posterior wall of the left atrial body. These crystals were connected to a sonomicrometer (Triton Technology, San Diego, CA) and were oriented to obtain the anteroposterior, transverse, and longitudinal dimensions of the appendage and the anteroposterior dimension of the atrial body (Figure 1). After waiting about 30 minutes for stabilization, control recordings were obtained. Then, 10 or 20 ml/kg of 6% dextran solution was infused stepwise via the femoral vein until the mean left atrial pressure reached 20 to 30 mmHg. The electrocardiogram, the dimensions of the left atrial appendage and body, and left atrial and ventricular pressures were recorded by a Mingograph 804 (Simens-Elema, Stockholm, Sweden) at a paper speed of 100 mm/sec during a brief interruption of respiration.

Measurements: Just before atrial contraction, the anteroposterior, transverse and longitudinal dimensions of the left atrial appendage (APDpre, TRDpre and LNDpre) and the anteroposterior dimension of the left atrial body (LADpre) were measured. Systolic shortening of each diameter of the left atrial appendage and body was also measured and the ratio of each systolic shortening to dimension just before atrial contraction was calculated as fractional shortening (%FS).

The appendage volume was calculated in six dogs as follows: after the

Figure 1. Diagram of the experimental preparation. AO = ascending aorta; PA = pulmonary artery; LA = left atrium; LAA = left atrial appendage; LAP = left atrial pressure; LVP = left ventricular pressure; APD, TRD and LND = anteroposterior, transverse and longitudinal dimension of the left atrial appendage, respectively.

volume loading protocol was completed, the left atrium was isolated, and the pulmonary veins were ligated at their junction to the atrium. The left atrium was suspended upside down with the mitral orifice upward. Saline was poured through the mitral orifice to fill the whole atrium, and the volume was measured. The appendage was then resected and its orifice sutured. The atrial body volume was measured in the same manner. The average of five measurements was used. Atrial appendage volume was calculated as the difference between the whole atrial volume and the body volume.

Statistics: The values are expressed as mean $\pm$ standard deviation. Statistical analyses were performed using Wilcoxon's signed-rank test or Scheffe's multiple comparison. A p value of less than 0.05 was considered significant.

RESULTS

Baseline morphometry and dynamics of the left atrial appendage: Figure 2 shows a representative recording of the electrocardiogram, atrial dimensions and left atrial and left ventricular pressures. Each dimension of the appendage increased during ventricular systole along with the V wave of atrial pressure, and decreased during rapid ventricular filling and atrial contraction, forming two

Figure 2. Recording of electrocardiogram (ECG), APD, TRD, LND, anteroposterior dimension of the left atrial body (LAD), LAP and LVP. See Figure 1 for abbreviations.

descents. This pattern was basically the same as that of the atrial body.

APDpre, TRDpre, LNDpre and LADpre were 14.6 ± 2.4 mm, 7.6 ± 1.4 mm, 19.2 ± 3.2 mm, and 25.2 ± 3.4 mm, respectively. The ratios of APDpre, TRDpre, LNDpre to LADpre were 0.59 ± 0.14 , 0.31 ± 0.06 , and 0.77 ± 0.13 , respectively. The left appendage had a pyramidal form with an elliptical basal section.

%FS of the anteroposterior, transverse and longitudinal dimensions of the left appendage and of the anteroposterior dimension of the left atrial body were $10.0 \pm 6.8\%$, $12.3 \pm 6.9\%$, $3.8 \pm 2.7\%$ and $5.4 \pm 2.7\%$, respectively. %FS of the transverse dimension of the appendage was significantly greater than those of the longitudinal dimension of the left appendage and the anteroposterior dimension of the body ($p < 0.05$)

Left appendage dynamics during volume loading: Mean left atrial pressure increased from 5.6 ± 1.3 mmHg to 28.9 ± 6.0 mmHg after dextran infusion. Figure 3 shows one example of changes in the left atrial body and the appendage dimensions just before contraction. APDpre, TRDpre, LNDpre and LADpre increased curvilinearly to reach 21.2 ± 4.2 mm, 13.3 ± 2.3 mm, 29.9 ± 5.2 mm and 33.7 ± 4.2 mm, increases of $45.5 \pm 13.6\%$, $75.0 \pm 18.9\%$, $57.1 \pm 22.6\%$ and

Figure 3. Changes in dimensions just before atrial contraction during volume loading. See Table for the abbreviations.

Figure 4. Increment ratio of APDpre, TRDpre, LNDpre and LADpre to each control value at the end of volume loading. See Table for the abbreviations.

$34.4 \pm 5.5\%$, respectively (Figure 4). The ratios of APDpre, TRDpre and LNDpre to LADpre increased from 0.59 ± 0.14 to 0.64 ± 0.16 ($p < 0.05$), from 0.31 ± 0.06 to 0.40 ± 0.07 ($p < 0.05$), and from 0.77 ± 0.13 to 0.90 ± 0.19 ($p < 0.05$), respectively. Thus, the left appendage was more compliant than the left atrial body and changed its form from pyramidal to a more spherical one.

The systolic shortenings of the atrial appendage and the body initially increased, but decreased with further infusion. Figure 5 shows the changes in systolic shortening of the appendage and body during volume loading. The baseline values, maximum values and the values obtained after volume loading are presented. The systolic shortenings of the anteroposterior, transverse and longitudi-

Figure 5. Changes in systolic shortening of (a) APD, (b) TRD, (c) LND and (d) LAD during volume loading.

Table. Changes in Each Dimension just before Atrial Contraction by Volume Loading

	Control (mm)	After infusion (am)	(percent increase)
APDpre	14.6 ± 2.4	$21.2 \pm 4.2^*$	$(45.5 \pm 13.6\%)$
TRDpre	7.6 ± 1.4	$13.3 \pm 2.3^*$	$(75.0 \pm 18.9\%)$
LNDpre	19.2 ± 3.2	$29.9 \pm 5.2^*$	$(57.1 \pm 22.6\%)$
LADpre	25.2 ± 3.4	$33.7 \pm 4.2^*$	$(34.4 \pm 5.5\%)$

Values are mean $\pm$ SD. APDpre, TRDpre, LNDpre and LADpre = anteroposterior, transverse and longitudinal dimensions of left appendage and left atrial dimension just before atrial contraction, respectively. $*p < 0.01$ compared with control.

nal dimensions of the left appendage, and of the anteroposterior dimension of the left atrial body reached maximum values of 3.3 ± 1.5 mm, 2.4 ± 0.6 mm, 2.7 ± 0.8 mm, and 3.2 ± 1.0 mm at mean left atrial pressures of 14.7 ± 3.0 mmHg, 14.6 ± 3.5 mmHg, 15.6 ± 3.4 mmHg, and 14.2 ± 3.3 mmHg, respectively. There were no differences among these pressures and among the increment ratios of the systolic shortenings of the appendage and the body.

Left atrial appendage volume: The left appendage accounts for $17.2 \pm 4.4\%$ of the whole isolated atrial volume.

DISCUSSION

Although great attention has been paid to the left atrial appendage, its physiological significance has been disregarded. Furthermore, the left atrial appendage has often been ignored when the whole atrial volume is measured by angiography.⁹⁾ In the present study, ratios of the left atrial appendage dimensions to the body dimensions were calculated in the beating heart, while the volume was determined in the postmortem isolated atrium. The anteroposterior, transverse, and longitudinal dimensions of the appendage were approximately 60, 31, and 77% of atrial body dimension and the appendage volume was about 17% of the whole left atrial volume. Archilla et al,⁹⁾ and Graham et al¹⁰⁾ reported that the left atrial appendage volume determined by angiography was about 11 and 14% of the whole atrial volume. Yamamoto¹¹⁾ reported that the residual left atrial volume after appendage clamp was 70% of baseline, and thus the appendage volume accounted for 30% of the whole atrial volume. The left appendage can not be disregarded.

During a cardiac cycle, changes in the left atrial appendage dimensions showed a characteristic pattern involving an increase during ventricular systole and two decreases during ventricular diastole. This pattern was concordant with previous findings by Zucker et al,⁶⁾ Linderer et al⁷⁾ and Hintze et al⁸⁾ in which dimensional changes of the appendage were studied using a sonomicrometer. Dimensional changes of the appendage during a cardiac cycle were basically the same as those of the left atrial body. However, the pattern of change was not consistent with the flow pattern previously described by Suetsugu et al,¹²⁾ who reported a biphasic flow pattern following the P wave in the ECG by transesophageal pulsed Doppler flowmetry, but did not describe any flow in the appendage during the rapid ventricular filling phase. In their study the mean age of patients was 65 years. Since left ventricular filling during the rapid filling phase decreases with age, the appendage flow during rapid filling might decrease the same as the mitral flow. In addition, mitral flow during rapid filling consists of both released volume from the left atrium and conduit volume through the left

atrium, but the appendage does not act as a conduit. These facts may explain the inconsistency between appendage dimensional changes in the present study and the flow pattern described by Suetsugu et al.¹²⁾

Some previous studies have shown that left atrial appendectomy caused few hemodynamic changes.^{13,14)} The left appendage may not be important in hearts with an intact left ventricle. In this study, however, the appendage clearly acted as a booster pump showing greater fractional shortening than the atrial body, and moreover, the appendage had a Frank Starling mechanism during volume loading similar to that of the atrial body. Thus, the left atrial appendage contributed to the late diastolic filling of the left ventricle. It is known that left atrial contraction plays an important role in increasing ventricular filling and maintaining cardiac output in patients with impaired left ventricles, such as following myocardial infarction.^{15,16)} Left atrial appendage may also be important in such cases.

A recent study demonstrated that the appendage was more compliant than the atrial body in the isolated heart, and it was suggested that the left appendage played an important role in hemodynamic homeostasis in patients with elevated atrial pressure.⁴⁾ Moreira et al¹⁷⁾ suggested that the appendage had a buffer-like function during acute pressure elevation. In our study, percent increases in left appendage dimensions after volume loading were greater than those of the atrial body. These findings indicate that the left atrial appendage functions as a reservoir during acute volume loading in the beating heart, and support the concept that the appendage acts as a buffer to prevent an elevation of the left atrial pressure.

The left atrium not only has hemodynamically important functions such as acting as a reservoir and a booster pump, but also secretes atrial natriuretic peptide (ANP). Recent physiological studies have shown that appendectomy attenuated or abolished ANP secretion in rats¹³⁾ and monkeys.¹⁴⁾ Hintze et al⁸⁾ showed that ANP secretion was related to appendage wall stress, and the highest ANP content of the heart is found in the appendage. Furthermore, it is known that atrial stretch is more important than atrial pressure in stimulating ANP secretion.¹⁸⁾ It may be reasonable to consider that the atrial appendage is more likely to stretch than the atrial body and thus more sensitive to atrial overload.

Limitation: We used dimensional changes of the left atrial body and appendage as indicators of contractile functions. As the geometries of the left atrial body and appendage are complicated, dimensional changes may not accurately reflect volume changes. As for the left atrial body, Tsakiris et al¹⁹⁾ reported that the changes in atrial circumference were, in general, symmetrical, while the dorsal part of the wall was seen to participate little in atrial systole. As for the left atrial appendage, we measured three dimensions, and the results indicated that the left

atrial appendage was more compliant and more dynamic than the left atrial body.

The left atrial appendage may act as a booster pump, especially in hearts with an impaired left ventricle, and as a buffer during acute elevation of left atrial pressure. Both functions may be important in understanding clinical changes in left atrial hemodynamics.

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