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Smoke-Like Echo in the Left Atrial Cavity in Mitral Valve Disease: Its Features and Significance

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In some patients with mitral stenosis, a smoke-like echo is observed in the left atrial cavity. The present study in 116 consecutive patients with rheumatic mitral valve disease investigated the echocardiographic features and clinical significance of this echo. The smoke-like echo is characterized by the following echocardiographic features: 1) it is composed of numerous microechoes; 2) it curls up slowly in the enlarged left atrial cavity; and 3) it vanishes as soon as it pours into the ventricular cavity. Hemostasis in the left atrial cavity was considered to be an important underlying condition for development of the echo. Hemorheologic conditions indicated that the shear rate of blood flow in the left atrial cavity was calculated to be low enough for the development of red blood cell aggregation.

These conditions suggest that the source of the smoke-like echo might be aggregated cells due to hemostasis in the left atrial cavity. Left atrial thrombi were detected in many patients who had this echo in the left atrial cavity. Although it has not been conclusively determined that the presence of the smoke-like echo is a necessary condition for thrombus formation, this echo appears to be closely related to thrombus formation in the left atrial cavity. It is concluded that the presence of this echo indicates severe left atrial hemostasis and is a warning for thrombus formation.

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In general, the cardiac cavity is echo-free on the echocardiogram, because the ultrasound reflection from the intracardiac blood is not dense enough to appear on the screen. However, we have observed a smoke-like or cloud-like echo in the left atrial cavity in certain patients with mitral stenosis (1). The characteristics of this echo have not been previously reported. The purpose of the present study was to investigate the echocardiographic features of the smoke-like echo in the left atrial cavity and its clinical significance.

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Methods

Study patients. The subjects were 116 consecutive patients with rheumatic mitral valve disease, 40 men and 76 women whose age ranged from 24 to 74 years (average 49). The left atrium was clearly imaged on the echocardiogram without noise echo. Nine patients whose echocardiogram was not recorded clearly enough to examine the fine and weak echoes were excluded in advance. Forty of the 116 patients were also examined for the smoke-like echo after cardiac surgery. The maximal period from cardiac surgery to the echocardiographic examination was 45 days.

Echocardiography. The equipment and recording materials used were the same in all patients. The echocardiograph was a commercially available wide angle phased array system (Toshiba SSH-11A). The ultrasound frequency was 2.4 MHz with a pulse repetition rate of 4,500 Hz. Two-dimensional echocardiograms were recorded on Polaroid film or 8 mm cine film. M-mode echocardiograms were recorded on Kodak Linagraph type 1930 paper using a Honeywell FR-06A line scan recorder in all except two post-

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operative patients. These two patients were examined in the intensive care unit, where the recorder was not available, and the M-mode record was recorded on Polaroid film. The echocardiographic examinations were performed in the semi left lateral or supine position with normal breathing. The entire left atrial cavity was rigorously searched for the abnormal echo, which is described later. The gain of the echograph was set high enough to detect faint echoes.

The left atrial and ventricular dimensions were measured from the M-mode echocardiogram as usual. The rate of left ventricular fractional shortening was derived from the end-diastolic and end-systolic dimensions. Mitral valve area was measured from a two-dimensional echocardiogram in early diastole (2,3). The echocardiogram was projected onto the digitizer and the orifice outline was traced by a sonic pen connected to a desktop computer (Hewlett-Packard 9845T).

Cardiac catheterization. Cardiac catheterization and left ventriculography were performed in 84 of the 116 patients. The cardiac index was evaluated by the thermodilution method. Patients with severe tricuspid regurgitation diagnosed by right ventriculography or the Doppler method were excluded from the cardiac output evaluation. The diastolic filling period was measured from the left ventricular pressure tracing using the Hewlett-Packard Cath Lab Computer system (model HP 5600B) adapted for the calculation of cardiac catheterization data with an on-line computer system according to Harrison et al. (4). The presence and severity of mitral regurgitation were assessed using Sellers' criteria (5) from the left ventriculogram in 66 patients.

The left atrial cross-sectional area (LACSA) was approximately calculated from the formula: LACSA = $\pi \times$ $(LAD/2)^2$, where LAD is the left atrial dimension from the M-mode echocardiogram. Blood volume flowing through the mitral orifice was measured as total stroke volume from left ventricular end-diastolic and end-systolic volumes. The mean velocity of the blood flow through the left atrial cross section in diastole was calculated from the formula: mean velocity = total stroke volume/LACSA/DFP, where DFP is the diastolic filling period. The shear rate of the blood in the left atrial cavity was roughly calculated by the following formula (6) derived from Poiseuille's law: shear rate = 4 $\times$ mean velocity/(LAD/2).

Left atrial thrombus was diagnosed by two-dimensional echocardiography (7,8). The size of the thrombus, when diagnosed, was roughly estimated by the maximal area of its cross section, in which a thrombus with an area less than 10 cm^2 was designated as small, between 11 and 20 cm^2 as medium and greater than 21 cm^2 as large.

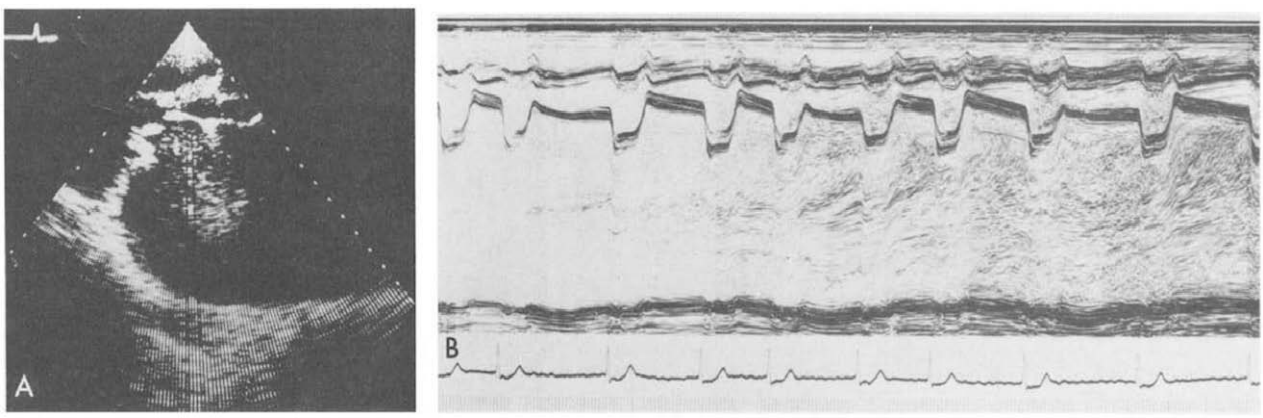
Statistics. Statistical analyses were performed, using the *t* test and chi-square test. A probability value of less than 0.05 was considered statistically significant.

Results

Echocardiographic features of the smoke-like echo. The smoke-like echo was echocardiographically characterized by an amorphous echo, composed of numerous microechoes, which curled up slowly in the enlarged left atrial cavity like billows of smoke or clouds (Fig. 1A). It resembled stirred sludge. On the M-mode echocardiogram, it appeared as wavy curvilinear echoes resembling brush drawings (Fig. 1B). It moved slowly toward the anterior mitral leaflet in diastole. This characteristic motion of the smoke-like echo differentiated it from white noise echo. In the ventricular filling phase, part of the smoke-like echo poured into the left ventricular cavity, like water sprayed from a narrow nozzle, and then immediately vanished (Fig. 2).

To observe the echo, attention was given to the gain control of the equipment (Fig. 1B). When the microechoes composing the smoke-like echo were concentrated, it was easily visible at normal gain or even at low gain. For con-

Figure 1. Smoke-like echo in the left atrial cavity. **A**, The smoke-like echo is shown near the mitral orifice in the left atrial cavity. On the real-time image it is recognized easily, although it is difficult to distinguish from noise or artifact echo on this still image. **B**, Amorphous and nonuniform echoes curl up slowly toward the anterior mitral valve leaflet on the M-mode echocardiogram. This echocardiogram was recorded using the gain control technique. The gain of the equipment was low on the **left** and high on the **right**.



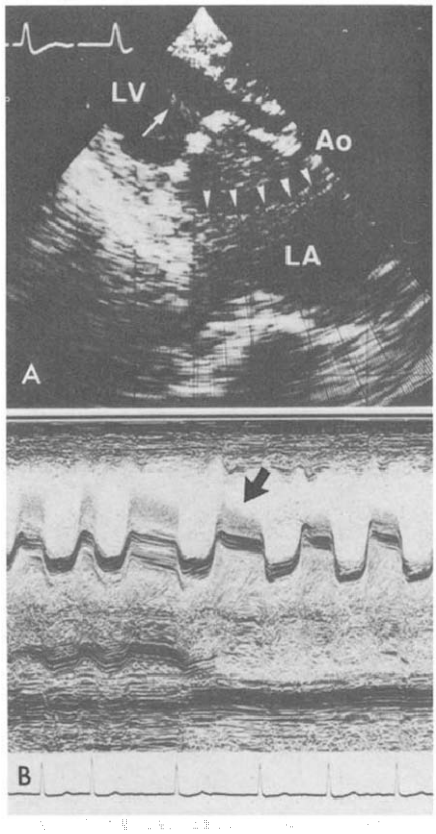


Figure 2. A, The smoke-like echo is noted behind the anterior mitral valve leaflet. It is ejected from the mitral orifice to the left ventricular (LV) cavity **(arrow)**. The echo **(arrowheads)** in the left atrial (LA) cavity is an artifact echo generated by the side lobe of the ultrasound. **B**, An M-mode scan from the apical site to the basal site of the mitral orifice. The smoke-like echo ejected into the left ventricular cavity is in front of the anterior mitral valve leaflet during diastole **(arrow)**. Ao = aorta.

venience of description, such an intensity was designated "severe." When the microechoes were not so concentrated, the smoke-like echo could be just barely discerned at high gain. Such an intensity was designated "mild." In this case, the smoke-like echo was observed only near the mitral orifice, showing multiple but scattered and thin curvilinear echoes on the M-mode echocardiogram (Fig. 3). In some patients, the echocardiogram was so rich in white noise as to obscure the smoke-like echo, making it virtually undetectable. These patients were excluded in advance from the present study.

Prevalence and underlying conditions of the smoke-like echo. In the subsequent study, the patients examined were classified in groups with severe, mild or absent smoke-like echo. Classification of patients was performed by two independent observers. In patients with some white noise, the separate judgments were incompatible. The echocardiograms in question were reviewed until a consensus was reached. Thus, the absent group should be considered to include both patients with a truly absent and patients with

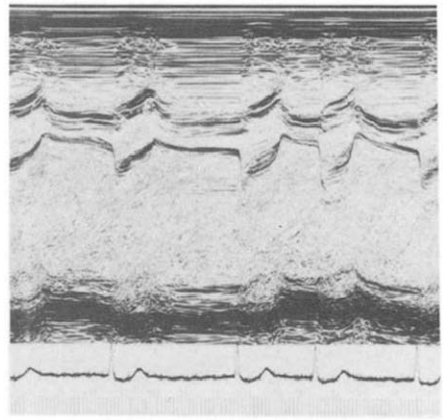


Figure 3. Smoke-like echo of low concentration. The echo is observed only near the mitral valve orifice in the left atrial cavity, showing sparse upward brush-like linear echoes. The echo lines are thin and slender and the echo intensity is weak.

an apparently absent (not detectable) smoke-like echo. Of the 116 patients, 10 patients were included in the severe group, 27 in the mild group and 79 in the absent group.

To investigate the development of the smoke-like echo, common underlying conditions were considered with reference to hemodynamic and echocardiographic data (Table 1). All patients in the severe and mild groups exhibited atrial fibrillation. In the absent group, 17 of the 79 patients showed normal sinus rhythm.

Mean cardiac index was 1.8, 2.4 and 3.1 liters/min per

Table 1. Echocardiographic and Hemodynamic Data Among Three Groups of Patients With Absent, Mild or Severe Smoke-Like Echo

	Absent	Mild	Severe
Patients (no.)	79	27	10
Atrial fib (no.)	62	27	10
CI (liters/min per m^2)	3.1 ± 0.9	2.4 ± 0.6*	1.8 ± 0.4*
No.	41	20	7
LAD (mm)	54 ± 13	66 ± 10*	76 ± 12*
No.	79	27	10
MVA (cm^2)	1.5 ± 0.8	1.1 ± 0.4*	0.7 ± 0.2*
No.	64	23	9
LVDd (mm)	51 ± 11	49 ± 8	48 ± 6
No.	55	19	8
LVFS	0.32 ± 0.09	0.28 ± 0.11	0.30 ± 0.05
No.	51	18	8
Thrombus	6 of 79	7 of 27	6 of 10
Small	3	2	0
Medium	2	2	2
Large	1	3	4

*$p < 0.05$ for the *t* test compared with the absent group. Hemodynamic and echocardiographic data are expressed as mean values ± standard deviation. Atrial fib = atrial fibrillation; CI = cardiac index; LAD = left atrial dimension; LVDd = left ventricular diastolic dimension; LVFS = left ventricular fractional shortening; MVA = mitral valve area; no. = number of patients.

m^2 in the severe, mild and absent group, respectively, showing significant differences among the groups (Table 1).

Mean left atrial dimension was 76, 60 and 54 mm in the severe, mild and absent group, respectively. The differences among the three groups were statistically significant.

Left ventricular dimension and fractional shortening did not statistically differ among the groups (Table 1).

Mean mitral valve area was 0.7, 1.1 and 1.5 cm^2 in the severe, mild and absent group, respectively. These differences were statistically significant.

The severity of mitral regurgitation varied among the groups. A graph showing the relation of the left atrial dimension to the severity of mitral regurgitation in individual patients in each group revealed the effect of mitral regurgitation (Fig. 4). Although the smoke-like echo was observed mostly in patients with a left atrial cavity greater than 60 mm in diameter, massive mitral regurgitation of more than third degree appeared to preclude the development of the smoke-like echo. Conversely, even among patients without massive mitral regurgitation, those without a large left atrial cavity tended not to have the smoke-like echo.

The shear rate of the blood in the left atrial cavity was 2.9 and 6.0 $second^{-1}$ in the severe and mild group, respectively, which was significantly lower than 12.5 $second^{-1}$ in the absent group (Table 2).

Left atrial thrombus was found in six (60%), seven (26%) and six (8%) patients in the severe, mild and absent group, respectively (Table 1). The prevalence of thrombus in patients with a smoke-like echo was significantly greater than that in patients without the echo. The size of the thrombus, moreover, tended to be large in the severe group.

Figure 4. Effect of the left atrial diameter (LAD) and mitral regurgitation on development of the smoke-like echo. Note that the smoke-like echo is observed in most patients with a left atrial cavity greater than 60 mm in diameter without mitral regurgitation greater than grade III. The high prevalence of the echo in these patients is statistically significant ($p < 0.001$ by the Kruskal-Wallis test).

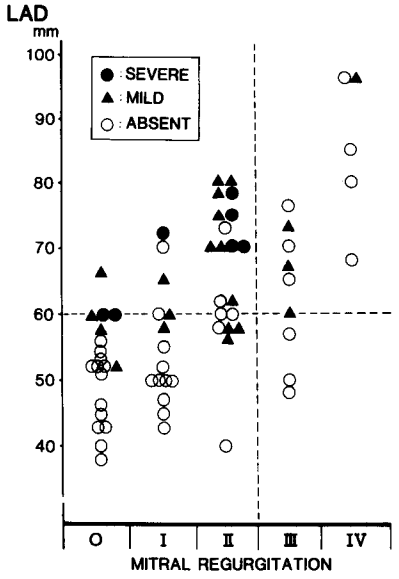


Table 2. Hemorheologic Data Among the Three Groups

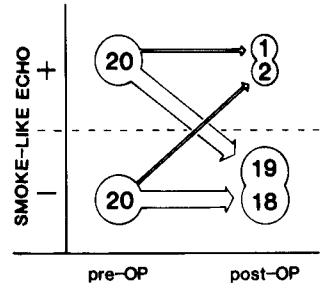
	Absent	Mild	Severe
TSV (ml)	77 ± 27	77 ± 40	53 ± 13
No.	40	19	4
DFP (s/beat)	0.47 ± 0.19	0.46 ± 0.14	0.45 ± 0.07
No.	32	18	6
LACSA (cm^2)	24 ± 12	35 ± 11*	46 ± 15*
No.	75	23	9
U (cm/s)	7.7 ± 3.4	4.8 ± 1.8*	2.7 ± 0.2*
No.	28	16	3
SR ($second^{-1}$)	12.5 ± 6.8	6.0 ± 2.5*	2.9 ± 0.2*
No.	28	16	3

*$p < 0.05$ for the t test compared with the absent group. DFP = diastolic filling period in one cardiac beat; LACSA = left atrial cross-sectional area; SR = shear rate; TSV = total stroke volume from the left ventriculogram; U = mean velocity of the blood through the left atrial cross section in diastole.

Blood in the left atrial cavity. In two patients in the severe group, one with left atrial thrombus, the blood of the left atrial cavity was sampled during cardiac surgery. The blood was smeared on a glass slide and examined microscopically. No unusual features were observed concerning the shape and distribution of the red and white blood cells.

Effect of cardiac surgery. Of the 40 patients examined before and after mitral valve surgery, 20 had exhibited the smoke-like echo before surgery. After surgery, the smoke-like echo could not be detected in 37 patients (Fig. 5). In these patients, a thrombus echo was not observed in the left atrial cavity. The smoke-like echo was demonstrated in the remaining three patients (Fig. 6), two of whom had not manifested the smoke-like echo before surgery. The postoperative findings in these three patients was similar. All three had atrial fibrillation and a left atrial cavity greater

Figure 5. Effect of cardiac surgery on development of the smoke-like echo. Most of the 40 patients did not exhibit the smoke-like echo postoperatively (post-OP). Three patients with a giant left atrium, who had low output syndrome after surgery, showed the smoke-like echo. pre-OP = preoperatively.



JACC Vol. 6, No. 4
October 1985:744-9

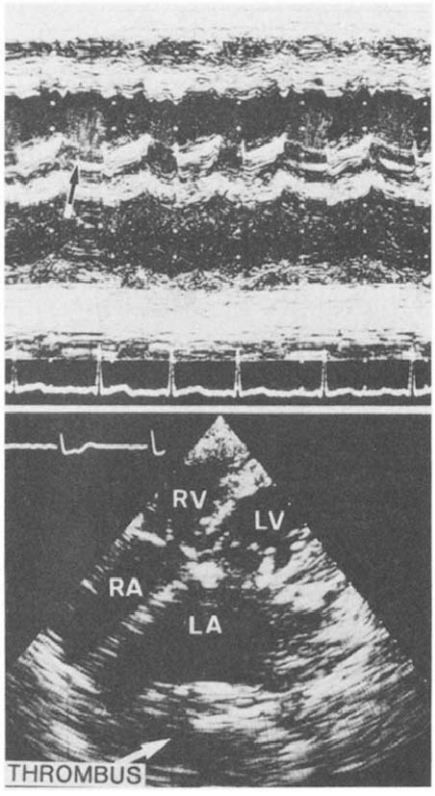


Figure 6. A patient with a smoke-like echo after surgery. **Top**, The echo was ejected from the prosthetic mitral valve into the left ventricular cavity as indicated by an **arrow**. The smoke-like echo in the left atrial cavity was not obvious in this image. **Bottom**, Apical four chamber view demonstrated a large thrombus **(arrow)** in the left atrium (LA) on the 23rd postoperative day. LV = left ventricle; RA = right atrium; RV = right ventricle.

than 60 mm in diameter. Although the mitral valve was replaced by an artificial valve, the patients were suffering from low cardiac output syndrome. A large thrombus was observed to have already formed in the left atrial cavity in all three patients on the 8th, 16th and 23rd postoperative day, respectively (Fig. 6). In two patients, autopsy revealed that the thrombus was jelly-like and composed of red blood cells.

Discussion

Development of the smoke-like echo. Although the smoke-like echo resembles the noise echo on the still view of the two-dimensional echocardiogram, it is easily differentiated because the smoke-like echo is characterized by its sludge-like motion. It is obvious that the smoke-like echo is not noise but an echo reflected from some unknown substance.

The smoke-like echo might also resemble the contrast echo. However, the contrast echo is characterized by intense microechoes that resemble twinkling particles and remain in the ventricular cavity. These differences indicate that the source of the smoke-like echo is not microbubbles.

The following clinical conditions appeared common among patients exhibiting the smoke-like echo: atrial fibrillation, low cardiac output syndrome, giant left atrium, small mitral valve area and absence of severe mitral regurgitation. Therefore, we believe that the origin of the smoke-like echo is generated in conditions of hemostasis. This reasoning is also supported by the findings that the smoke-like echo was not demonstrated when the blood was stirred by severe mitral regurgitation and that it disappeared with the elimination of hemostasis, as it did in the left ventricular cavity or after cardiac surgery in the patients without impaired cardiac function. A condition of hemostasis might implicate aggregated red blood cells as the possible source of the echo. Although each particle of red blood cell is too small to be shown as an echo, aggregated red cells may be large enough to reflect the ultrasound (9). In light of the following hemorheologic considerations, such a possibility might be considered.

Although the actual shear rate in the left atrial cavity cannot be evaluated accurately, the roughly calculated shear rate was significantly lower in the group of patients with the smoke-like echo. It is known that the red blood cells aggregate if the shear rate is lower than 10 second^{-1} (6), and the calculated shear rate in the left atrial cavity with smoke-like echo was in that range. This hypothesis should be compatible with the finding that the smoke-like echo vanished immediately after entering the left ventricular cavity. The flow velocity of the blood flowing through the narrowed mitral orifice is markedly fast and the shear rate is high enough to shatter the clumps of red blood cells. The absence of specific findings in the microscopic examination of the left atrial blood also might result from the release of red cell aggregates during the process of sucking blood into a syringe and smearing it onto a glass slide.

There have been reports of unusual echoes in the ventricular chamber (1,10,11). The "dynamic intracavitary echoes," observed in the left ventricular cavity in an experimental study of myocardial infarction by Mikell et al. (11), are worth special notice in light of the present study. If these echoes are attributable to left ventricular congestion due to the impaired ventricular function or to regional congestion due to asynergy of the infarcted area, or both, they may be qualitatively the same as the present smoke-like echo.

Clinical significance of the smoke-like echo. The prevalence of the left atrial thrombus was high in the patients with the smoke-like echo, and a large thrombus was formed in the early postoperative days in this group. Thus, it is possible that red cell aggregation promotes the growth of thrombus. This assumption is supported by our pathologic finding that the thrombus formed in the early postoperative days was soft, like gelatin and composed of red blood cells. If the red blood cell aggregation is markedly dense and becomes a thrombus, a transitional stage from red cell ag-

gregation to solid thrombus may occur. In an experimental study (12) of left ventricular thrombus formation after myocardial infarction, a soft amorphous mass echo called the "tail of thrombus" was demonstrated adjacent to the rigid thrombus echo. Pathologic examination revealed that the tail of thrombus was a fresh blood clot formed by red blood cells. The tail observed in that study may be the transitional stage from blood sludge to thrombus. It has not yet been determined conclusively whether the presence of the smoke-like echo is a necessary precursor of thrombus formation. However, it is certain that the smoke-like echo has some close relation to thrombus formation in the left atrial cavity.

Implications. Thrombus formation in the left atrial cavity is one of the major complications in mitral valve disease. It should be emphasized again that even a large thrombus can form very quickly, even within a few days after surgery, as shown in our patients with the smoke-like echo. Because of the close relation between the smoke-like echo and thrombus formation, it may be prudent to require early, intensive follow-up examinations to diagnose left atrial thrombus whenever the smoke-like echo is observed, even if no thrombus echo can be detected. In this sense, the presence of the smoke-like echo may be considered as a warning of left atrial thrombus formation.

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