Noninvasive pulsed Doppler echocardiographic detection of the direction of shunt flow in patients with atrial septal defect: usefulness of the right parasternal approach

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ABSTRACT Noninvasive pulsed Doppler echocardiography combined with two-dimensional echocardiography by the right parasternal approach was performed to detect the shunt flow through the defect in 31 patients with suspected secundum atrial septal defect (ASD). A defect of the interatrial septum was seen on the two-dimensional echocardiograms of 30 of 31 patients. In all the 30 patients, Doppler signals of shunt flow could be recorded by placing the sample volume in the center of the defect on the two-dimensional echocardiogram. Neither a defect nor Doppler signal indicating shunt flow were demonstrated in any of 15 normal control subjects. Cardiac catheterization indicated significant shunt flow in all the 31 patients with suspected ASD. Doppler signals obtained from the center of the defect showed left-to-right and/or right-to-left shunt flow patterns. The direction of the shunt flow was mainly left to right, with its peak in late systole and atrial systole in 28 of 30 patients; mainly right-to-left flow was present in the remaining two patients, who had Eisenmenger’s syndrome. The direction of flow as predicted by the Doppler signal was confirmed by the coincidence of direction of flow as seen on the contrast two-dimensional echocardiogram. In 22 patients for whom the measurement of the pulmonary-to-systemic flow ratio by oximetry was believed to be reasonably accurate, the ratio was fairly well correlated with Doppler-determined left-to-right shunt flow velocity (r = .71, SEE = 6.7 cm/sec). In 13 patients with ASD who underwent surgical repair of the defect, postoperatively the defect on the two-dimensional echocardiogram and the Doppler signals indicating shunt flow disappeared. In conclusion, noninvasive pulsed Doppler echocardiography by the right parasternal approach is useful in the assessment of the direction of shunt flow in patients with ASD.


NONINVASIVE DOPPLER echocardiographic detection of shunt flow in patients with atrial septal defect (ASD) has been performed indirectly by the detection of flow velocity in the jugular vein or right atrium.1-4 Although pulsed Doppler echocardiography in combination with two-dimensional echocardiography has provided us a means to noninvasively examine the intracardiac flow velocity at the optimal portion of the cardiac cavity, very few studies of direct detection of shunt flow through a defect have been reported.5,6 Sakakibara et al.5 detected shunt flow in 24 patients with ASD by placing the sample volume near the defect in the right atrium using the parasternal four-chamber view. Shub et al.6 used a similar technique and a subcostal view in seven patients with ASD. However, the direction of the shunt flow is not described in detail by these authors. Although Shub’s subcostal method provided good imaging of the defect on the two-dimensional echocardiogram, they did not discuss the sensitivity of the Doppler method for detection of shunt flow and an 11% false-negative rate was demonstrated for two-dimensional echocardiography alone.

On the other hand, we reasoned that the right parasternal approach in which the transducer is placed to the right of the sternum was a method that might provide better evaluation of the structure and function of the interatrial septum (IAS) because the ultrasound beam passes in a plane perpendicular to the IAS.7-10 In

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this study we applied this method to the detection of shunt flow through a defect in 31 patients with secundum ASD.

The purpose of this study was therefore to evaluate the usefulness of the right parasternal view and the pulsed Doppler technique in detecting the presence and direction of shunt flow in patients with secundum ASD.

Methods

Patient selection. The study groups consisted of 31 patients with suspected secundum ASD and 15 normal control subjects. The patients ranged in age from 4 to 68 years (mean ± SD, 30 ± 22 years); eight were male and 23 female. The normal control subjects ranged in age from 7 to 56 years (32 ± 16 years) and 10 were male and five female. All 31 patients had evidence of right ventricular volume overload, ejection systolic flow, and wide splitting of the second heart sound. Two-dimensional and Doppler echocardiographic studies by the right parasternal approach were carried out within the 48 hr before cardiac catheterization. After the Doppler echocardiographic study, a peripheral contrast echocardiogram was obtained from each subject. Cardiac catheterization was performed by individuals having no knowledge of the echocardiographic results. Thus, the two-dimensional and Doppler echocardiographic studies were done prospectively in a blind fashion before cardiac catheterization.

Of seven patients with atrial fibrillation, six also had tricuspid regurgitation. The diagnosis of tricuspid regurgitation was made by phonocardiography and peripheral contrast echocardiography14–16 or pulsed Doppler echocardiography.14

Apparatus. The instruments used in this study were a commercially available bidirectional ultrasonic pulsed Doppler flowmeter (Toshiba SDS-10A) combined with a phased-array two-dimensional echocardiograph (Toshiba SSH-11A), or a pulsed Doppler flowmeter (Aloka UGR-23) combined with a mechanical sector-scanning, two-dimensional echocardiograph (Aloka SSD-720). The frequency of the pulsed Doppler flowmeter was 2.4 to 3.0 MHz and the pulse repetition rate was 6 kHz. Frequency analysis of the Doppler signals was carried out in real time by fast-Fourier transform for both instruments. The site of the sample volume could be set at any depth from 0 to 15 or 18 cm from the transducer and was displayed on the M mode echocardiograph. The length of the sample volume varied between 2 and 10 mm and was usually 2 to 3 mm in this study.

Doppler examination. A cross-sectional two-dimensional echocardiogram was first obtained by the right parasternal approach to demonstrate the defect of the IAS. The transducer was placed in the third, fourth, or fifth intercostal space to the right of the sternum and was directed posteroomedially and superiorly with respect to the horizontal plane (figure 1).7,8 After imaging the IAS, we looked for the defect in the IAS on the two-dimensional echocardiogram by tilting the transducer back and forth.8 In cases in which the defect was visualized (figure 2, A), a pulsed Doppler echocardiographic study was performed by passing the cursor line in a plane perpendicular to the defect and then placing the sample volume in the center of the defect. An example of display of the sampling site on the two-dimensional echocardiogram is as shown in figure 2, B. In the one case in which the defect was not visualized from this view, the Doppler study was performed by placing the sample volume near the surface of the IAS in the right atrium.

The Doppler signal was passed through a high-pass filter (400 Hz in Toshiba SDS-10A and 300 Hz in Aloka UGR-23) to eliminate the influence of movements of the intracardiac structures.

Doppler recording. Doppler signals were recorded simultaneously during held expiration without Valsalva on a strip-chart recorder (Toshiba line-scan recorder LSR 20 A or Aloka ultrasonorcer recording SSZ-93) at a paper speed of 50 or 100 mm/sec with an M mode echocardiograph, electrocardiograph, or phonocardiograph. Doppler signals toward the transducer were represented by the sound spectrogram above the baseline (positive deflection), indicating left-to-right shunt flow, and Doppler signals away from the transducer were below the baseline (negative deflection), indicating right-to-left shunt flow.

Contrast two-dimensional echocardiogram examination. After recording the Doppler echocardiogram, we obtained a contrast two-dimensional echocardiogram by injecting saline into the antecubital vein to confirm that the defect in the midportion of the IAS was a true ASD. The confirmation of the defect on the contrast two-dimensional echocardiogram was made when a negative contrast echo flowing from the defect into the right atrium (figure 2, C, arrow) or a flow of positive contrast echoes from the right atrium into the left atrium was visualized.10,15,16 These images were displayed on an oscilloscopic screen at 30 frames/sec and recorded on a movie camera at a rate of 15 frames/sec. We then also analyzed the phases of the appearance of negative and positive contrast echoes in the right atrium and left atrium on the two-dimensional echocardiogram.

Measurement of velocity of left-to-right shunt flow by the Doppler method. Mean Doppler-derived velocity of left-to-

FIGURE 1. Schematic representation of right parasternal approach. Placing the transducer to the right of the sternum, the ultrasound beam passes in a plane perpendicular to the defect in the IAS. The Doppler signal was obtained by placing the sample volume in the center of the defect in a plane perpendicular to the defect. RA = right atrium; LA = left atrium; RV = right ventricle; St = sternum; Th = thoracic spine; L = left; P = posterior; SV = sample volume; LV = left ventricle; T = transducer; A = anterior; R = right.
right shunt flow was obtained by measurement of the left-to-right shunt flow area on the Doppler echocardiogram by planimetry and dividing by the duration of left-to-right shunting. Measurements were obtained for 3 consecutive beats and the result was divided by three. Of 30 patients with ASD in whom Doppler-determined shunt velocities were detected by the right parasternal approach, two who had Eisenmenger’s syndrome were excluded because of obscurity of left-to-right shunt flow.

Comparison of mean Doppler-derived left-to-right flow velocities and pulmonary-to-systemic flow (Qp:Qs) ratios obtained at cardiac catheterization. Measurement of Qp:Qs ratio was obtained at cardiac catheterization by Grossman’s formula. For six of the 30 patients with ASD in whom Doppler-determined shunt flow velocities were obtained from the right parasternal approach, measurements of O₂ saturation in the superior vena cava and the inferior vena cava were inadequate. Data from these six patients and the two patients with Eisenmenger’s syndrome were therefore excluded from the comparison of mean left-to-right Doppler-determined flow velocity and Qp:Qs ratio obtained at cardiac catheterizations so that the comparison was carried out with data from 22 patients.

Results

Detection of the defect and shunt flow. In all 31 patients and 15 normal control subjects two-dimensional echocardiographic imaging of the IAS from the right parasternal approach was successful. The defect in the midportion of the IAS on the two-dimensional echocardiogram could be observed clearly in 30 of 31 patients with suspected secundum ASD, as shown in figure 2, A. The defect of the IAS on the two-dimensional echocardiogram was confirmed as being a true secundum ASD by observing the positive and/or negative contrast echoes for flow through the defect in each of the 30 patients. Cardiac catheterization indicated that all 31 patients with suspected ASD had significant shunt flow at the atrial level. Of the 31 patients, 13 underwent surgery and the diagnosis was confirmed in all 13. In the one patient in whom a defect could not be demonstrated on the two-dimensional echocardiogram and in all of the normal control subjects there were no negative or positive contrast echoes in the right atrium or left atrium.

Abnormal Doppler signals in the center of the defect were observed in all 30 patients whose defects were demonstrated on two-dimensional echocardiograms (figure 3) and there was no abnormal Doppler signal on the surface of the IAS in the right atrium of the one patient in whom a defect was not observed on the two-dimensional echocardiogram.

In all of the 13 patients who underwent surgical closure of their defects, the abnormal Doppler signals observed before the operation disappeared afterward (figure 4).
Abnormal Doppler signals were also not observed on the surface of the IAS in the right atria of normal control subjects. In the one patient in whom a defect could not be observed on the two-dimensional echocardiogram and in whom no abnormal Doppler signal was noted in this study, the defect was confirmed during surgery to have been situated in the lower part of the IAS near the entrance of the inferior vena cava.

**Direction of Doppler signal.** Directions of abnormal Doppler signals derived from the sampling site in the center of the defect showed mainly left-to-right shunt flow (positive deflected Doppler signal representing flow toward the transducer) in 28 patients with secundum ASD (figure 3 and table 1). In two other patients, the direction of the Doppler signal showed only right-to-left shunt flow from early systole to mid-diastole (figure 5 and table 1). Cardiac catheterization indicated that both of these patients had Eisenmenger’s syndrome.

However, in three of the 28 patients in whom mainly left-to-right shunt flow was observed, the direction of the Doppler signal pattern showed, in addition, definite right-to-left shunt flow in systole (figure 6, top, and table 1).

**Doppler signal showing left-to-right shunt flow.** The left-to-right shunt flow pattern demonstrated by Doppler signal featured one positively deflected signal appearing during midsystole to early diastole (with its peak mainly in late systole) and a second positive signal during atrial systole in patients in sinus rhythm (figure 3). In patients in atrial fibrillation, the number and contour of the positive signals as well as the timing of the peaks were more variable. However, these patients tended to have tricuspid or mitral regurgitation, which might also have altered the patterns of flow (see figure 6, top, and figure 7, top).

**Doppler signal showing right-to-left shunt flow.** Although a small right-to-left shunt flow signal was observed in atrial systole, early ventricular systole, and/or midventricular diastole in almost all patients, a definite right-to-left pattern of shunt flow in systole was observed in only five patients, all of whom had tricuspid regurgitation (compare the negative signal on figure 3 to that on figure 6, top). Characteristic turbulent flow from early systole to mid-diastole was observed in two patients, both of whom had Eisenmenger’s syndrome (figure 5 and table 1).

**Contrast echocardiography.** Of the 30 patients in whom a defect was detected on the two-dimensional echocardiogram, flow was recognized as a negative contrast echo (figure 2, C) in 28 and as a positive contrast echo (No. 1 in figure 6, bottom) in 27 of 28. In the remaining two patients with Eisenmenger’s syndrome, contrast material crossed the defect from the right atrium and filled the left atrium completely.

**Correlation between Doppler and contrast echocardiographic findings.** Doppler signals suggesting left-to-right and right-to-left shunt flows coincided with the direction of flow as suggested by the negative and positive contrast echocardiographic results. Figure 6

**TABLE 1**

<table>
<thead>
<tr>
<th>Direction of Doppler signal</th>
<th>No. of patients</th>
<th>Definite R-L shunt flow in systole</th>
<th>Complication of TR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predominant L-R shunt</td>
<td>28</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Predominant R-L shunt</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

R-L = right-to-left; L-R = left-to-right; TR = tricuspid regurgitation.
shows a Doppler recording and contrast echocardiogram from a patient with secundum ASD complicated by tricuspid regurgitation. In this figure, the right-to-left pattern of shunt flow indicated by the Doppler signal in systole coincides with the flow indicated by positive contrast echoes, which demonstrate flow from the right atrium into the left atrium on the two-dimensional echocardiogram. The left-to-right pattern of shunt flow indicated by the Doppler signal in diastole coincides with that indicated by negative contrast echoes on the two-dimensional echocardiogram, which demonstrate left-to-right flow from the left atrium into the right atrium.

In other cases, especially in patients without tricuspid regurgitation, the magnitude of the Doppler signals, as well as the amount of flow seen on the contrast two-dimensional echocardiogram, were much smaller than in this example, especially for right-to-left shunt flow.

**Relationship between Doppler-determined flow patterns and interatrial pressure gradient.** The pressures in the right atrium and left atrium were recorded simultaneously with two catheter-tipped manometers in the one patient with atrial fibrillation and mitral regurgitation in whom the Doppler signal showed only a left-to-right pattern of shunt flow throughout the entire cardiac cycle (figure 7, top). The pressure tracings demonstrate a positive left-to-right pressure gradient throughout the entire cycle (figure 7, bottom). The pattern of variation in the pressure gradient between

**FIGURE 5.** Doppler echocardiogram from a patient with secundum ASD complicated with Eisenmenger’s syndrome. Doppler signal demonstrates predominant negative flow pattern (right-to-left shunt) during early systole to mid-diastole. These characteristic flow patterns were observed in two patients with Eisenmenger’s syndrome. Abbreviations are as in figure 1.

**FIGURE 6.** Doppler echocardiogram (top) and contrast two-dimensional echocardiogram (bottom) during one cardiac cycle in a patient with secundum ASD complicated with atrial fibrillation and tricuspid regurgitation. Direction of Doppler signal that demonstrates right-to-left shunting in systole (away from the transducer, arrow in No. 1 in top panel) and left-to-right shunt in diastole (arrows in No. 2 and No. 3 in top panel) is confirmed by the coincidence with the positive contrast echo in systole (arrow in No. 1 in bottom panel) and negative contrast echo in diastole (arrows in Nos. 2 and 3 of bottom), respectively. Abbreviations are as in figure 1.
FIGURE 7. Doppler echocardiogram (top) and pressure tracing of the right atrium and left atrium and the pressure gradient across the defect (bottom) in a patient with secundum ASD complicated with atrial fibrillation and mitral regurgitation. Doppler echocardiogram demonstrates predominant left-to-right shunt flow throughout the entire cardiac cycle with its peaks in early, mid, and late diastole. Pressure tracing also demonstrates the dominant left atrial pressure throughout the entire cardiac cycle and the shape of the pressure gradient between the two atria is very similar to that of Doppler signal. ECG = electrocardiogram. Other abbreviations are as in figure 1.

the two atria showed almost the same configuration as that of the Doppler-determined flow pattern.

Relationship between mean Doppler-derived left-to-right flow velocities and Qp:Qs ratios obtained at cardiac catheterization. In the 22 patients for whom reasonably accurate measurements of Qp:Qs ratio were obtained, the mean flow velocity of the left-to-right shunt as determined by the Doppler method was 43.8 ± 9.4 (mean ± SD) cm/sec (range = 31 to 56.2) and the mean Qp:Qs ratio was 4.4 ± 2.1 (range = 2.2 to 7.6). The correlation between mean velocity of shunt flow as determined by Doppler echocardiography and Qp:Qs ratio was $r = 0.71$ (SEE = 6.7 cm/sec).

Discussion

Recently Kitabatake et al. and Valdes-Cruz et al. have demonstrated, by recording flow with the Doppler method in the main pulmonary artery and aorta, that the two-dimensional Doppler echocardiographic method is useful in the estimation of shunt flow in patients with ASD.

The aim of this study was to determine if pulsed Doppler echocardiography combined with two-dimensional echocardiography by a right parasternal approach could provide a noninvasive method for detecting the direction of the shunt flow directly through the defect in patients with suspected secundum ASD.
In this study we were able to demonstrate the defect by both two-dimensional and Doppler echocardiography with high sensitivity. The sensitivity of the Doppler signal for detecting shunt flow was 100% if the defect could be observed on the two-dimensional echocardiogram. Thus, in this study the Doppler method had the same value as the addition of the contrast method to two-dimensional echocardiography in the confirmation of the presence of the defect.

The subcostal approach has been successfully used by Shub et al. to directly visualize ASDs on two-dimensional echocardiograms. However, they describe false-negative results in the detection of secundum ASD that they attribute to one of the following causes: (1) multiple small or fenestrated defects, (2) associated aneurysm of the IAS with distortion of normal anatomy, (3) small defect size, and (4) incomplete scanning of the IAS. The most important of these factors according to these authors was the potential for incomplete scanning of the IAS. We performed two-dimensional echocardiographic detection of the defect from the subcostal approach in only seven patients in our study, and could not detect the defect in two. However, we did detect the defect in all seven patients when using the right parasternal approach. This indicated to us that the right parasternal approach might be helpful in reducing the incidence of false-negative results in detection of ASD by two-dimensional echocardiography.

The Doppler results obtained in this study showed signals for shunt flow above and below the zero line. The positive or negative direction of the Doppler flow signal through the defect coincided with the direction of the contrast echocardiographic flow on the two-dimensional echocardiogram. These findings suggest that the pulsed Doppler method can directly detect the direction of both left-to-right and right-to-left shunt flow when the sample volume is placed in the defect and when viewed from the right parasternal approach.

Shunt flow was mainly left to right in almost all patients with secundum ASD. The pattern of this flow for the most part showed a peak in late ventricular systole and again during atrial systole in patients in sinus rhythm. Concerning the pattern of shunt flow through a defect in ASD, Levin et al. have reported the shunt dynamics in 26 patients with secundum ASD and in sinus rhythm with the use of biplane cineangiography and simultaneous right and left atrial pressures. Alexander et al. also have described the shunt dynamics in seven awake dogs by examining the interatrial pressure gradient and blood flow across a surgical-ly created defect with an electromagnetic flowmeter probe. Both of these groups report that the major left-to-right shunt occurs during the latter half of ventricular systole and during atrial contraction. Therefore, the timing of the peak velocity of Doppler-determined left-to-right shunt flow in patients in sinus rhythm without Eisenmenger's syndrome in our study was similar to that found in previous invasive clinical and experimental studies. Furthermore, in a patient with atrial fibrillation, we observed that the pattern of the pressure gradient across the ASD was almost the same as that of the Doppler-determined flow.

In patients in sinus rhythm without Eisenmenger's syndrome, the Doppler signals suggest that right-to-left shunt flow appeared in atrial systole, early ventricular systole, and/or midventricular diastole and was of low amplitude and short duration. In a previous article we have reported that motion of the IAS is determined by the interatrial pressure gradient through each cardiac cycle. We showed that the IAS moves posteriorly from the right atrium to the left atrium during right atrial systole, early ventricular systole, and midventricular diastole. The timing of a small signal for right-to-left shunt flow observed in atrial systole, early ventricular systole, or midventricular diastole therefore coincides with the motion of the IAS as it moves from the right atrium to the left atrium, and both may be a result of the interatrial pressure gradient. Thus, Doppler signals showing a small amount of right-to-left shunt flow may indicate real shunt flow. However, extreme care must be taken to differentiate these signals from "noise," especially in atrial systole, since the sample volume placed in the center of the defect may touch the margin of the defect during contraction of the IAS.

The accuracy of the Doppler signal in detecting the presence and direction of flow was confirmed by the following: (1) The direction of flow suggested by Doppler results coincides with that seen on contrast two-dimensional echocardiograms. (2) The flow pattern in patients in sinus rhythm, except those with Eisenmenger's syndrome, was similar to that found in previous invasive clinical and experimental studies of shunt flow and in the one patient in this study with atrial fibrillation in whom pressures were recorded, the flow pattern was similar to the variation in the pressure gradient between the atria. (3) Doppler signals obtained before surgery for ASD in 13 patients disappeared after closure of the defect at surgery.

The usefulness of the right parasternal approach used in this study for detection of shunt flow through a defect may be considered as follows: First, the clear
identification of the defect on the two-dimensional echocardiogram by passing the ultrasound beam perpendicular to the IAS provided accuracy and simplicity in placing the sample volume in the center of the defect. Second, a perpendicular angle between the cursor line and the defect provided identification of the sample volume in a plane parallel to the shunt flow and made it possible to detect not only left-to-right but also right-to-left shunt flow through the defect with a high-quality Doppler shift. Third, use of the right parasternal approach results in no increase in the distance from transducer to the defect such as that produced by the right ventricle in the left parasternal view or by the liver in the subcostal view. In general, the short distance between the sample volume and the transducer is helpful in obtaining a clear Doppler signal since the power of the Doppler transmission is limited. These three factors seem to have contributed to the good result in detection of the shunt flow by use of the right parasternal approach in this study.

A definite right-to-left pattern of shunt flow in systole was observed in five patients who had complicating tricuspid regurgitation (figures 5 and 6), even though in three the flow was predominantly left to right. Variations in the direction and severity of the regurgitant jet may be important, however, since there were two patients in whom no right-to-left shunt flow was demonstrated in systole in spite of complicating tricuspid regurgitation (table I). Thus, a definite right-to-left pattern of shunt flow would appear to be associated with tricuspid regurgitation, although the influence of regurgitation on the shunt flow requires further study. In the analysis of flow, the Doppler technique has a definite advantage over contrast two-dimensional echocardiography in that, in the presence of a large right-to-left shunt flow, the contrast tended to occupy all four chambers within the first few beats after injection, making further observations impossible. Doppler measurements, on the other hand, can be made continuously. Therefore, this technique may be useful not only in the diagnosis but also in hemodynamic analysis of shunt flow in patients with secundum ASD.

Shub et al. also attempted to detect the ASD in seven patients with pulsed Doppler echocardiography using the subcostal view and placing the sample volume in the right atrium over the site of the presumed defect. Although we did not perform Doppler studies from the subcostal approach, the Doppler signal pattern they noted differs slightly from that in patients in sinus rhythm in our study. This probably results from the differences in the location of the sample volume and the different relationship of the ultrasound beam to the plane of the defect with the two methods. Since we had difficulty visualizing the defect on two-dimensional echocardiograms from the subcostal view, further study is warranted for comparison of the relative value of the right parasternal and subcostal views in two-dimensional and Doppler echocardiographic examinations.

More recently, Marx et al. have reported that velocities of transatrial septal flow determined from the subcostal view had a good correlation with Qp:Qs ratios obtained by cardiac catheterization in seven children with ASD. We compared our measurement of velocity of left-to-right shunt flow obtained from the right parasternal view with the Qp:Qs ratios obtained at cardiac catheterization in 22 adults with ASD (in these patients the oxygen saturation determinations were performed in a rigorous enough fashion that reasonable estimates of pulmonary and systemic blood flows could be made). Our results also showed a good correlation between Qp:Qs and the Doppler-determined velocity of flow, in agreement with the aforementioned study.

In conclusion, noninvasive pulsed Doppler echocardiography combined with two-dimensional echocardiography by a right parasternal approach is useful in the assessment of the presence and direction of shunt flow in patients with secundum ASD.

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