Evaluation of Right Atrial Appendage Blood Flow by Transesophageal Echocardiography in Subjects with a Normal Heart

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SUMMARY

Right atrial appendage (RAA) blood flow pattern was analyzed in 42 normal subjects without cardiovascular disease (aged 30 to 48 years, mean 40 ± 6) who underwent transesophageal echocardiography. RAA flow pattern was demonstrated to be bi-, tri- or quadriphasic and heart rate dependent (p < 0.01) in this study. In 15 subjects (36%), a biphasic pattern was observed. A triphasic pattern was observed in 12 subjects (28%). Fifteen subjects (36%) had a quadriphasic pattern. In these subjects, we observed a pattern consisting of two diastolic forward flow waves, each followed by a backward flow wave. Mean heart rates among subjects with bi-, tri- and quadriphasic patterns were 110 ± 6, 91 ± 4 and 72 ± 13 beats/min, respectively. In the triphasic pattern, the onset of superior vena cava diastolic forward flow began 18 ± 4 ms after the onset of tricuspid E wave, whereas the first diastolic forward flow wave in the RAA began 40 ± 7 ms after onset of the tricuspid E wave. A similar relation was also noted in the quadriphasic pattern. This sequence was constant and independent of heart rate (p < 0.05), suggesting a temporal relation between right ventricular relaxation and the first diastolic forward flow wave in the RAA.

In normal subjects, the RAA flow pattern is heart rate dependent and three distinct flow patterns can be differentiated. Right ventricular relaxation appears to induce both the superior vena cava diastolic forward flow wave and the first diastolic forward flow wave of the RAA. These results can be used for comparison with patterns found in disease states. (Jpn Heart J 1999; 40: 599–607)

Key words: Right atrial appendage blood flow, Transesophageal echocardiography

The role of transesophageal echocardiography (TEE) in the evaluation characteristics of normal left atrial appendage (LAA) blood flow is well
established. In patients with sinus rhythm, LAA Doppler velocity waveforms are generally biphasic or quadrifasic. In the biphasic pattern, the diastolic forward flow wave is produced by LAA contraction, whereas the systolic backward flow wave has been attributed to LAA relaxation. These two waves occur subsequent to the electrocardiographic P wave. The quadrifasic pattern was described by Kortz et al., and a relatively lower velocity diastolic forward flow wave and backward flow wave are also present before the electrocardiographic P wave.

Although the LAA lends itself to accurate interrogation by TEE, right atrial appendage (RAA) has not received as much attention. This was probably because of its location. It is hard to image consistently by TEE and almost impossible to image by transthoracic echocardiography. To our knowledge, there is no report regarding the RAA blood velocity pattern in human subjects. The present study was therefore designed to determine the characteristics of normal blood flow in the RAA by TEE.

**Methods**

**Subject population:** The study group consisted of 42 subjects (27 men and 15 women; average age 40 ± 6 years [range 30 to 48]) with a structurally normal heart who underwent TEE. Eleven subjects were healthy volunteers without any history of systemic or cardiopulmonary disease. Indications for the TEE study in the remaining subjects included suspected congenital heart disease (13 subjects), fever of unknown origin (10 subjects) and suspected aortic disease (8 subjects).

All subjects were in normal sinus rhythm and were not receiving any medication at the time of the study. Before beginning TEE, informed consent was obtained from each subject.

**Transesophageal echocardiographic study:** Studies were performed using a multiplane 5 MHz TEE probe (Vingmed CFM 725 Vingmed Sound Horten, Norway). Subjects were studied in the fasting state using 10% lidocaine spray for posterior pharyngeal anesthesia. No sedation or atropine was administered. The TEE probe was inserted with the subject lying in the left lateral position. During echocardiography, a one lead electrocardiogram was recorded continuously. All images were recorded on Super VHS videotapes.

The RAA was identified in the longitudinal planes. With the transducer tip in the midesophagus, progressive rightward rotation of the endoscope shaft (the array was 90° throughout this maneuver) developed a long-axis view of the superior and inferior vena cava entering the right atrium. In this position, images of the RAA were obtained in a continuum of angles from 90° to 140° and were determined anteriorly (Figure 1). Peak RAA forward and backward velocities
Figure 1. A: The view of the RAA, seen in the longitudinal plane (the array is 108°), shows the pectinate muscles (arrows) lining the appendage. This frame shows the RAA during diastole (lower small arrow points to ECG prior P wave). B: After atrial systole, RAA is virtually obliterated. Lower small arrow points to ECG just after QRS complex. RA = right atrium, RAA = right atrial appendage, IAS = interatrial septum.

were measured by placing a pulsed wave Doppler sample volume just inside the base of the appendage. Velocities of RAA Doppler flow were obtained using pulsed Doppler with the lowest possible cut off filter settings (5 or 10 cm/sec). At 90 degrees (longitudinal plane), a long-axis view of the vena cava superior was visualized. Superior vena cava flow velocities were obtained with the sample volume placed 1 to 2 cm into the superior vena cava.

To record the right ventricular inflow velocities, the transverse view was used and the pulsed Doppler sample volume was placed at the level of the leaflet tips of the tricuspid valve. Since right ventricular filling is significantly affected by respiration, all measurements of right ventricular filling dynamics were obtained during apnea. Doppler flow velocity patterns were recorded on videotape (Panasonic AG-7350) at a chart speed of 100 mm/sec with simultaneous tracing of electrocardiogram for subsequent analysis.

**Doppler analysis and timing:** From the videotapes, all measurements were analyzed by hand with a computer-interlaced digitizing tablet. Because Doppler flow tracing could not be recorded simultaneously, the temporal relations among diastolic flow waves were analyzed by matching records at approximately the same RR intervals (intraindividual variation < 100 ms). To minimize the effect of respiration on ventricular filling dynamics, Doppler measurements were obtained from 7 to 10 consecutive cardiac cycles and averaged. Moreover, right ventricu-
lar filling dynamics were obtained during apnea in all subjects.

The time intervals measured were the time from the onset of the QRS complex to the onset of tricuspid flow; the onset of superior vena cava diastolic flow; the onset of the first diastolic forward flow in the RAA.

**Statistical analysis:** Values are expressed as mean ± SD. Mean peak velocities and heart rates were compared using an independent t test. P value < 0.05 was considered significant. Regression analysis of the relation between the onset of diastolic flow velocity waves and heart rate in the tri- and quadrifasic flow patterns was performed.

**RESULTS**

No echocardiographic cardiac abnormalities were observed in any subject, except for mild mitral and tricuspid regurgitation in four.

The RAA was best appreciated in the longitudinal planes (from 90 to 140°). The RAA was triangular in shape and vigorous contractile activity was seen in nearly all subjects. In most subjects, pectinate muscles were clearly seen (Figure 1).

**Right atrial appendage flow pattern:** Analyzable RAA flow velocity tracings were recorded from all subjects. Three different flow patterns were identified within the RAA; bi-, tri- and quadrifasic. In 15 subjects (36%), the RAA flow pattern was characterized by a biphasic flow of clearly defined waves of diastolic forward and systolic backward flow. These two waves occurred subsequent to the electrocardiographic P wave. Mean heart rate in these subjects was 110 ± 6 beats/min (Table I).

In 12 subjects (28%), a triphasic flow pattern was noted. A relatively lower velocity diastolic forward flow wave was present also before the electrocardio-

**Table I.** Right Atrial Appendage Flow Patterns and Velocities in 42 Normal Subjects

<table>
<thead>
<tr>
<th></th>
<th>Biphasic pattern</th>
<th>Triphasic pattern</th>
<th>Quadrifasic pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>15</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>110 ± 6</td>
<td>91 ± 4*</td>
<td>72 ± 13*</td>
</tr>
<tr>
<td>Peak first diastolic forward flow (cm/s)</td>
<td>NA</td>
<td>25 ± 3</td>
<td>24 ± 3</td>
</tr>
<tr>
<td>Peak diastolic backward flow (cm/s)</td>
<td>NA</td>
<td>NA</td>
<td>22 ± 2</td>
</tr>
<tr>
<td>Peak second diastolic forward flow (cm/s)</td>
<td>79 ± 7</td>
<td>66 ± 7**</td>
<td>64 ± 7**</td>
</tr>
<tr>
<td>Peak systolic backward flow (cm/s)</td>
<td>55 ± 12</td>
<td>59 ± 17</td>
<td>54 ± 15</td>
</tr>
</tbody>
</table>

Data are means ± SD. NA = not applicable. *p < 0.01, **p < 0.001 versus biphasic flow pattern, *p < 0.05 versus triphasic flow pattern. Biphasic flow pattern has 1 diastolic forward flow wave (with peak velocity represented by peak second diastolic forward flow) and 1 systolic backward flow.
Figure 2. Pulsed Doppler recording of RAA flow in subject showing triphasic pattern; a relatively lower velocity diastolic forward flow (DF1) is present also before the electrocardiographic P wave (small arrow points to P wave on ECG). DF1 = first diastolic forward flow, DF2 = second diastolic forward flow, SBF = systolic backward flow.

Figure 3. A quadriphasic flow pattern consisting of two diastolic forward flow waves, each followed by a backward flow wave (the same patient as in Figure 1). DF1 = first diastolic forward flow, DF2 = second diastolic forward flow, DBF = diastolic backward flow, SBF = systolic backward flow.
Table II. RAA Blood Flow Pattern in Relation to Time Intervals in Transtricuspid, Superior Vena Cava and RAA Flows

<table>
<thead>
<tr>
<th>Interval</th>
<th>Biphasic ((n = 15))</th>
<th>Triphasic ((n = 12))</th>
<th>Quadrifasic ((n = 15))</th>
</tr>
</thead>
<tbody>
<tr>
<td>RR</td>
<td>525 ± 40</td>
<td>687 ± 134</td>
<td>812 ± 105</td>
</tr>
<tr>
<td>P → DF2</td>
<td>NA</td>
<td>57 ± 7</td>
<td>60 ± 7</td>
</tr>
<tr>
<td>Q → E</td>
<td>296 ± 49</td>
<td>398 ± 36</td>
<td>408 ± 27</td>
</tr>
<tr>
<td>Q → D</td>
<td>317 ± 44</td>
<td>415 ± 42</td>
<td>429 ± 34</td>
</tr>
<tr>
<td>Q → DF1</td>
<td>NA</td>
<td>432 ± 43</td>
<td>447 ± 42</td>
</tr>
<tr>
<td>Q → DF</td>
<td>338 ± 43</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>E → D</td>
<td>21 ± 12</td>
<td>18 ± 4</td>
<td>21 ± 3</td>
</tr>
<tr>
<td>E → DF1</td>
<td>NA</td>
<td>40 ± 7</td>
<td>49 ± 7</td>
</tr>
<tr>
<td>E → DF</td>
<td>42 ± 14</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

RR = time from R wave to R wave, P = electrocardiographic P wave, Q = electrocardiographic Q wave, Q → E = time to onset of tricuspid E wave, Q → D = time to onset of superior vena cava diastolic forward flow, Q → DF1 = time to onset of the first diastolic forward flow, Q → DF=time to onset of diastolic forward flow in biphasic pattern, E → D = (Q → E) - (Q → D), E → DF1 = (Q → E) - (Q → DF1), E → DF = (Q → E) - (Q → DF), DF2 = second diastolic forward flow. Mean values ± SD in ms. NA = not applicable.

graphic P wave (Figure 2). Mean heart rate in subjects with this flow pattern was 91 ± 4 beats/min (Table I).

Fifteen subjects (36%) with a mean heart rate of 72 ± 13 beats/min had a quadrifasic flow pattern (Table I). In these subjects, we observed a quadrifasic pattern consisting of two diastolic forward flow waves, each followed by a backward flow wave (Figure 3).

In subjects with the quadrifasic flow pattern, the maximal flow waves occurred just before and after the QRS complex with a mean peak diastolic forward flow velocity of 64 cm/sec and a mean peak systolic backward flow velocity of 54 cm/sec. In the triphasic flow pattern, similar mean peak velocities were obtained (Table I). The additional forward and backward flow waves showed lower velocities, and their presence was dependent on the heart rate.

As did the peak flow velocities of the second diastolic forward flow in the quadrifasic and biphasic patterns, the mean heart rates corresponding to three different RAA flow patterns differed significantly (Table I).

**Tricuspid flow pattern:** Analyzable tricuspid flow velocity tracings were obtained from all subjects. Pulsed Doppler recordings showed a biphasic flow pattern in 27 subjects. In 15 subjects with sinus tachycardia, the tricuspid flow pattern was monophasic.

**Superior vena cava flow pattern:** Analyzable superior vena cava flow velocity tracings were recorded from all subjects. Pulsed Doppler recordings showed a biphasic forward flow and atrial reverse flow in all subjects.

**Time relation of onset of diastolic flow waves (Table II):** In subjects with a
biphasic flow pattern, the onset of superior vena cava diastolic forward flow began 21 ± 12 ms after the onset of tricuspid E velocity, whereas the diastolic forward flow wave in the RAA began 42 ± 14 ms after the onset of tricuspid E velocity. In subjects with a triphasic flow pattern, the onset of superior vena cava diastolic forward flow began 18 ± 4 ms after onset of the E wave, whereas the first diastolic forward flow wave in the RAA began 40 ± 7 ms after onset of the E wave. In subjects with a quadriphasic pattern, onset of the E' wave was followed at 21 ± 3 ms by that of the superior vena cava diastolic forward flow wave and at 49 ± 7 ms by that of the first diastolic forward flow wave in the RAA.

In regression analysis, there were small slopes for time delays of both the superior vena cava diastolic forward flow and the first diastolic forward flow waves in comparison to the tricuspid E wave (calculated slope −0.07 ± 0.10 and −0.13 ± 0.17, p < 0.01 and p < 0.05 respectively). This relation pointed out that the sequence of onset of early diastolic flow is constant and heart rate independent.

**DISCUSSION**

The appendages are the cardiac structures that remain difficult to examine thoroughly by transthoracic echocardiography. However, TEE is a minimally invasive technique allowing imaging of the appendages. Various different blood flow patterns have been observed on LAA Doppler tracings in patients with sinus rhythm and atrial fibrillation. However, the characteristics of normal blood flow pattern in the RAA have not yet been reported.

The RAA blood flow pattern was demonstrated to be bi-, tri- or quadriphasic and heart rate dependent in this study. In the biphasic pattern, two waves occurred subsequent to the electrocardiographic P wave. The diastolic forward flow wave was produced by RAA contraction, whereas the systolic backward flow was attributed to RAA relaxation. This description is comparable to the finding of Pollick and Taylor who first described a biphasic LAA blood flow velocity pattern in patients having sinus rhythm. Kortz et al. found that the LAA blood flow pattern in healthy subjects was variable, changing from quadri- to tri- and biphasic with increasing heart rate. In our study, a similar relation was also observed in the RAA. In contrast, Jue et al. found no differences in heart rate between patients with a biphasic pattern and those with a quadriphasic pattern.

In the quadriphasic pattern, we observed a relatively lower velocity forward and backward wave which were present also before the electrocardiographic P wave. The onset of the first RAA diastolic forward flow wave in the tri- and quadriphasic pattern coincided with the onset of the tricuspid E wave and superior vena cava diastolic forward flow. Similar temporal relations were reported
for LAA flow patterns in several studies. In light of these observations, the first diastolic forward flow might be an initial phase of passive emptying of the RAA before its active contraction.

The origin of the diastolic backward flow after the first forward flow can either be explained by elastic recoiling of the appendage wall or by passive filling during diastasis, or both. The second forward flow wave began 60 ± 7 ms after the P wave on the electrocardiogram in the quadruphasic pattern. This wave and its systolic backward flow are due to appendage contraction and relaxation, respectively. These observations imply that right ventricular relaxation induce both the superior vena cava diastolic forward flow wave and the first diastolic RAA forward flow wave.

In a recent study, Tabata et al. reported that aging could reduce LAA emptying velocities. Our study primarily described normal RAA blood flow patterns in a middle age population. Therefore, the results cannot be generalized to all age groups.

Limitations of the study: A major limitation is the lack of simultaneous invasive right heart hemodynamic data and Doppler recordings. Another source of error is the beat-to-beat variability in flow dynamics, especially in the right side, caused by respiration. However, to minimize the effect of respiration on ventricular filling dynamics, Doppler measurements were obtained from 7 to 10 consecutive cardiac cycles and were averaged. Moreover, right ventricular filling dynamics were obtained during apnea in all subjects, as previously described. Finally, right atrial compliance or function and right ventricular specific properties were not measured in this study; therefore, the role of these factors is unknown.

Conclusions: In normal subjects, the RAA blood flow pattern is heart rate dependent and three distinct blood flow patterns can be differentiated. Right ventricular relaxation appears to induce both the superior vena cava diastolic forward flow wave and the first diastolic RAA forward flow wave. We believe that the results of this study can be used as baseline information for current as well as future studies. Additional studies are needed to further elucidate the relations between flow patterns and anatomic or functional features of this structure.

REFERENCES
71: 976–81.