Study of the Cardiac Arrhythmias by the Ultrasonic Doppler Method

By Samuel Bellet, M.D., and John Kostis, M.D.

SUMMARY

The Doppler tracing is a sensitive method for depicting movement of the heart wall, valves, and blood flow. This communication reports the authors’ experience with the Doppler method in normal persons and patients with various cardiac arrhythmias.

Three main components are recognized in the Doppler tracing: the presystolic component, \( a \); component \( v_s \) due to systolic movement of the ventricles; and component \( v_d \) corresponding to the movement of ventricles during early diastole. Evidence is presented that component \( a \) is due to atrial contraction. This has been substantiated in this study by the simultaneous recording of the Doppler tracing with the electrocardiogram, phonocardiogram, apex cardiogram, jugular venous tracing, right atrial pressure tracing, and the inscription of the Doppler tracing frame by frame in the right atrial cineangiogram.

These findings are of interest since they introduce a relatively new method of studying cardiac wall movement, particularly that of the right atrium. In addition, simultaneous recording of the Doppler tracing of the atria with the electrocardiogram may be of help in the diagnosis of certain cardiac arrhythmias.

Additional Indexing Words:
Atrial movement Ventricular movement

Although considerable data relative to the use of ultrasound in the study of many aspects of cardiac function are available, the Doppler method has been used only infrequently for this purpose.

Ultrasound has been employed for the study of many aspects of cardiac function. It can be emitted in narrow beams, aimed in a precise direction, reflected at interfaces between media of different densities, and can penetrate most mammalian tissues to an adequate depth.\(^1\)\(^-\)\(^8\) The commonly used method of application of ultrasound in the study of the cardiovascular system is the “pulse method” (echo-ranging technique) based on the time lapse between emission of ultrasound and the reception of its reflection from the heart. Since its first application in cardiology by Edler and Hertz,\(^4\) this technique has been used for the demonstration of pericardial effusion,\(^5\),\(^6\) the study of mitral valve abnormalities, especially in mitral stenosis and mitral regurgitation,\(^7\)\(^-\)\(^12\) the diagnosis of tricuspid stenosis,\(^13\) the analysis of prosthetic ball valve function,\(^14\) and the diagnosis of aneurysms of the abdominal aorta.\(^15\) A different technique of application of ultrasound in cardiology is the Doppler method first employed by Yoshida and associates,\(^16\)\(^-\)\(^19\) Satomura,\(^20\) and Nimura and associates\(^21\) in the study of cardiovascular dynamics and valve motion. The Doppler effect is the apparent change in frequency of sound when the sound source or the observer or both move. The general principles of the method relative to this technique are given below.

Ultrasound is emitted by an ultrasound

\(^{From the Division of Cardiology, Philadelphia General Hospital, and the Division of Graduate Medicine, University of Pennsylvania, Philadelphia, Pennsylvania.\)

\(^{This work was aided by Grant TO1-HE-05165-11 from the National Institutes of Health, Grant 68-589-1 from the Commonwealth of Pennsylvania, and by the Foundation for Cardiovascular Research, Philadelphia, Pennsylvania.\)
source applied on the chest wall, reflected by the heart (heart wall, vessel, valve) and sensed by a receiver on the chest wall near its source. Because of the movement of the reflecting surface, the frequency of the ultrasound sensed by the receiver will be different from the frequency of the emitted ultrasound; that is, the ultrasound will undergo a "Doppler shift." If the reflected wave is mixed together with the initial wave emitted from the source of ultrasound, a signal proportional in frequency to the velocity of the reflecting target will appear. We have called this the "raw" (that is, "unmodified") Doppler tracing of the heart (see fig. 3R).

The amplitude of the Doppler signal depends, among other things, on the distance of the transducer from the reflecting target, the angle at which the ultrasound reaches the reflecting surface, and the absorption characteristics of the intervening tissues.

Yoshida and associates\textsuperscript{16} classified the Doppler signals of the heart according to their frequency. During the early stages of this investigation, we employed the low frequency component of the raw Doppler signal, which is probably due to the movement of the walls of the heart\textsuperscript{19} (see fig. 3R). However, in the course of the study, we observed that the envelope of the raw Doppler signal (displaying the amplitude of the Doppler raw signal versus time) was more satisfactory for the study of cardiac arrhythmias. We have called this "the amplitude Doppler tracing of the heart" (see fig. 3A). By this improved technique, we can more clearly delineate atrial activity (see fig. 2B).

In this paper, the term "Doppler tracing" is used to refer to the "raw" or the "amplitude" Doppler tracing.

The object of this communication is to report our experience with the Doppler method in the study of normal subjects and patients with cardiac arrhythmias.

**Methods**

An ultrasound apparatus\textsuperscript{*} was employed for


\textsuperscript{‡}Twin-Viso Recorder, Sanborn Co., Waltham, Massachusetts.
Figure 2

Tracings from A to E are taken from normal subjects. The distance between the thick lines represents 0.2 sec in A, B, C, and D.

(A) Normal sinus rhythm. Upper tracing: ECG, lead II. Lower tracing: Doppler tracing taken at the fourth right intercostal space close to the sternum. Note the components of the Doppler tracing ("a," "v_8," and "v_d") and their relationship to the P, QRS, and T waves of the electrocardiogram.

(B) Tracings taken on the same patient as A. The patient has been placed in the right lateral decubitus position. Note the increased amplitude of the atrial component ("a") of the Doppler tracing.

(C) Upper strip: Esophageal lead with electrode at atrial level. Lower strip: Doppler tracing. Note the consistent relationship of the P wave to component "a" of the Doppler tracing.

(D) Sinus tachycardia. The three components of the Doppler tracing are in their normal sequence.

(E) Respiratory variations in the Doppler tracing. Distance between thick time lines represents 2.0 sec to illustrate the variations of the amplitude of the Doppler tracing with the phases of respiration. I = inspiration; E = expiration; arrow = held inspiration.
Figure 3

Tracing taken from an 18-year-old male with rheumatic heart disease, slight cardiac enlargement, and aortic insufficiency. Simultaneous recording of the electrocardiogram, raw Doppler, and amplitude Doppler tracings. Distance between time lines represents 0.04 sec. (Upper strip) ECG, lead II showing normal sinus rhythm. (R) “Raw” Doppler signal. Note the sequential recordings of “a”, “v”, and “v_d”. These deflections show multiple vibrations which are somewhat similar to those observed in heart sound tracings. Compare this with the “amplitude” Doppler tracing (A) which shows clear-cut deflections for “a”, “v”, and “v_d”. The last group are sharper and more clearly identifiable than those observed with the raw tracings.

Table 1

<table>
<thead>
<tr>
<th>Arrhythmia</th>
<th>Amplitude tracing</th>
<th>“Raw” tracing</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinus rhythm</td>
<td>11</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Sinus tachycardia</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Atrial premature contractions</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>7</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Atrial flutter</td>
<td>2</td>
<td>–</td>
<td>2</td>
</tr>
<tr>
<td>Premature ventricular contractions</td>
<td>8</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Intermittent sino-atrial block</td>
<td>–</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1st Degree A-V heart block</td>
<td>1</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td>2nd Degree A-V heart block</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Complete heart block</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Atrioventricular dissociation</td>
<td>–</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Marked sinus bradycardia with nodal escapes</td>
<td>1</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>42</strong></td>
<td><strong>23</strong></td>
<td><strong>65</strong></td>
</tr>
</tbody>
</table>
Figure 4

Relationship of the components of the Doppler tracing (D) to phonocardiogram at apex (PCG) and waves of the electrocardiogram. (ECG, lead II) Tracings were taken from a man, 36 years old, with cardiac enlargement due to alcoholic cardiomyopathy. Time lines are every 0.04 sec. Note that component "a" is simultaneous with the fourth heart sound.

Records signals with frequencies up to 150 cps with decreased amplitude and does not respond to signals above 200 cps. Recordings were also made with an eight-channel photographic recorder* with frequency limits set at 0.1 and 200 cps. In order to study specifically the production of the a wave, the Doppler tracing was recorded simultaneously with the electrocardiogram, phonocardiogram, apexcardiogram, jugular venous tracing, and right atrial pressure tracings. In addition, the amplitude Doppler tracing together with the electrocardiogram or the intracardiac right atrial pressure tracing, or both, was inscribed simultaneously frame by frame on a 35 mm cineangiogram using a Cine-trace control unit.* Recordings were made with or without injection of methylglucamine diatrizoate (70% Renografin) into the right atrium in order to establish the time relationships between the atrial contraction as seen on the cineangiogram and the occurrence of the a wave of the Doppler tracing.

Table 1 shows the types of arrhythmias studied and the number of subjects with each arrhythmia. All subjects were patients in the Philadelphia General Hospital. Most of the tracings were made at the bedside. Only one person was needed to apply the transducer and operate the recorder. The time of the actual application of the ultrasound approximated 5 minutes. Proper application of the transducer to the chest wall necessitated shaving a portion of the chest wall of a few patients.

Although an atrial (a) and two ventricular components (v_a and v_d) are recorded in normal subjects, in this study, we concentrated on the

---

*Electronics for Medicine, Inc., White Plains, N. Y.

Circulation, Volume XXXVIII, October 1968
atrial component. The transducer thus was applied over the right atrium, that is, at the fourth to sixth right intercostal space close to the sternum (fig. 1). A coupling medium* was employed to assure good contact between the transducer and the skin. The direction of the transducer and its position on the chest wall was then slowly changed in order to obtain maximum amplitude of the Doppler tracing. The signal was observed on the recorder and heard with the help of the audiophone until the optimum amplitude of the atrial component (a) was attained. Recordings were made at that time. Turning the patient to the right lateral decubitus position (figs. 1 and 2B) markedly accentuated the atrial component.

Results

The Doppler Tracing

This study includes a total of 65 subjects; amplitude tracings (figs. 2, 4 to 10, and C) were recorded on 42 patients and raw tracings (figs. 3R, and 11B and C) on 23 patients. Analysis of the tracings shows that they are composed of three main components: the atrial component, a, starts 0.05 to 0.11 sec after the onset of the P wave of the electrocardiogram; it has a duration of 0.06 to 0.12 sec and is related to atrial contraction. The ventricular systolic component, v., starts 0.03 to 0.09 sec after the onset of the QRS complex and lasts 0.12 to 0.20 sec. The ventricular, early diastolic component, v.d, starts almost immediately after the end of the T wave and has a duration of 0.06 to 0.14 sec. In some tracings one or more of the components were bifid. Component a of the Doppler tracing precedes the a wave of the jugular venous tracing (fig. 6) and the a wave of the displacement apex cardiogram (fig. 5) by 0.06 to 0.09 sec. It is simultaneous with the fourth heart sound (fig. 4) and the a wave of the right atrial pressure tracing (fig. 7). It is simultaneous with the atrial contraction as

---

* Aquasonic 100 (R), Parker Laboratories, Inc., Irvington, New Jersey.
documented by frame-by-frame analysis of cineangiocardiograms with the Doppler tracing inscribed on them. Component $v_s$ precedes the point E of the apex cardiogram and the c wave of the jugular venous tracing and is almost simultaneous with the first heart sound (figs. 4 to 6). Component $v_d$ precedes point O of the apex cardiogram and the v wave of the jugular venous tracing (figs. 5 and 6) and is almost simultaneous with the second heart sound. The relative amplitude of the individual components depends on the site of application and direction of the transducer. Thus, by applying the transducer at the fifth or sixth right intercostal space near the sternum, atrial components of increased amplitude are obtained. The amplitude of the atrial component is further increased by turning the patient to the right lateral decubitus position. This results in a higher ratio of signal to noise and thus in clearer definition of the wave form (fig. 2A and B). This probably is due to the decreased absorption of the ultrasound because of the smaller distance between the right atrial wall and the transducer. The amplitude of the ventricular components is increased when the transducer is placed on the left fourth intercostal space. The amplitude of the tracing depends on the distance of the heart from the chest wall and thus is decreased in patients with emphysema. The amplitude of the tracing is affected by the phases of respiration; the deflections are generally more prominent during expiration and smaller during inspiration. This probably is due to an increased amount of lung tissue between the transducer and the heart during inspiration (decreased in expiration) and to changes in the angle between the ultrasound beam and the reflecting heart surface (fig. 2E).
By applying the transducer to special sites on the chest wall and directing the ultrasound beam at certain angles, we obtained tracings consisting of only the atrial or only the ventricular components. In certain cases, this facilitated the diagnosis of the arrhythmia. Tracings containing only the atrial deflection were obtained when the transducer was applied at the third right intercostal space near the sternum (fig. 12C and D). However, the exact site and direction varied to some degree with each patient.

Studies of Normal Persons and Subjects with Arrhythmias

Normal Sinus Rhythm

Twenty subjects with normal sinus rhythm were studied. The tracings of 10 additional patients with normal sinus rhythm and occasional premature contractions were also analyzed. In all subjects, the tracings consisted of the three main deflections described above. They form a pattern that can be clearly identified and easily interpreted (figs. 2 to 7).

Sinus Tachycardia

In three patients with sinus tachycardia, the Doppler tracing consisted of the same three components (presystolic, \(a\); systolic, \(v_s\); and early diastolic, \(v_d\)) in normal sequence as above (fig. 2D).

Atrial Premature Contractions

The Doppler tracing in six subjects with atrial premature contractions showed an atrial component, \(a\), preceding the ventricular contraction. In the electrocardiogram, the P wave was not clearly observed in three cases (two manifested aberrant QRS complexes). In figure 9B, premature atrial beats with a widened QRS are seen on the electrocardiogram (at arrows). The atrial component, \(a\), is clearly seen on the Doppler tracing preceding the premature beat; it is not clearly delineated on the electrocardiogram. The

Figure 7

Amplitude Doppler tracing (D), right atrial pressure curve (RAP), and ECG, lead aVF, from same patient as figure 4. Time lines appear every 0.04 sec. The component "a" of the Doppler tracing is practically simultaneous with the a wave of the right atrial pressure. The slight delay of the latter is probably due to the relatively slow (in comparison with the velocity of ultrasound in tissue) pulse wave velocity in our catheter-pressure transducer system.
ventricular diastolic component, $v_d$, is not recognized in this tracing. Similar sequences are displayed in figure 9A (at arrows) taken on the same patient. The normal configuration of the QRS and the presence of a P wave preceding the QRS is evidence for the supraventricular origin of this premature beat.

Atrial Fibrillation

In 11 patients with atrial fibrillation, absence of the presystolic (a) component of the Doppler tracing was noted. The tracings were composed of the two ventricular deflections ($v_s$ and $v_d$) only. This observation is consistent with the physiological fact that there is no gross movement of the atrial wall in atrial fibrillation. As expected, the time intervals of the cardiac cycles on the Doppler tracing were irregularly irregular (fig. 8C to E).

Atrial Flutter

In two cases of atrial flutter, regular a waves corresponding to the flutter waves of the electrocardiogram are seen on the Doppler tracing. The systolic, $v_s$, and early diastolic, $v_d$, components of the ventricular

Figure 8

(A and B) Atrial flutter. Tracings from man, 70 years old, with arteriosclerotic heart disease and congestive failure. The distance between the thick time lines represents 0.2 sec. The “a” wave (at arrows) on the Doppler tracing corresponds to the P waves of the electrocardiogram. Components “$v_s$” and “$v_d$” are also recognized.

(C, D, and E) Atrial fibrillation. Tracings from patients with hypertensive and arteriosclerotic heart disease and congestive failure. The Doppler tracing consists of deflections “$v_s$” and “$v_d$” only. The atrial component (“a”) is absent.

Circulation, Volume XXXVIII, October 1968
beats are also recognized in their normal relation to the deflections (QRS-T) of the electrocardiogram. Depending on the exact position of the transducer on the chest wall and the direction of the ultrasound beam, the ventricular components of the Doppler tracing were inscribed with higher or lower amplitude than the atrial component (fig. 8A and B).

Premature Ventricular Contractions

In nine patients with premature ventricular contractions, the abnormal beats were composed of components vₐ or vₛ, or both. Component a occurred at the time when it would be expected in the presence of an undisturbed sinus rhythm. It was recognized even in cases in which the corresponding P wave could not be identified on the electrocardiogram (figs. 9C and 10A and B). In figure 10A, the a wave is clearly identified in the Doppler tracing at the fourth and fifth arrows and is not observed in the electrocardiogram. The same is true for the fifth and eighth beats in figure 10B.
CARDIAC ARRHYTHMIAS

Figure 10

Premature ventricular beats. Tracings from a 67-year-old woman with chronic bronchitis, emphysema, arteriosclerotic and coronary artery disease, cardiac enlargement, and congestive failure.

(A) The “a” waves (arrows) on the Doppler tracing have a constant configuration and amplitude. The P waves are not clearly seen in the second and third premature beats.

(B) The “a” component of the Doppler tracing is shown at arrows. No P waves are discernible in the fifth and eighth cycles. The atrial contractions are clearly delineated on the Doppler tracing (fifth and eighth arrows).

Sinoatrial Block

One patient with intermittent sinoatrial block was studied. The Doppler tracing indicates that there was no atrial or ventricular movement during that short interval (fig. 11B). Thereafter, the three components occurred in their normal sequence. The interval between the component a following the long pause and the previous one was slightly shorter than twice the normal R-R interval.

Atrioventricular Dissociation

Two patients with atrioventricular (A-V) dissociation were studied. In both, the presystolic component, a, of the Doppler tracing related to atrial contraction, manifested a rhythm independent of the systolic, v_s, and early diastolic, v_d. The a-v_s interval changed in a progressive manner. A dissociation between the presystolic component, a, and the systolic and early diastolic components, v_s and v_d, respectively, of the Doppler tracing, corresponding to the dissociation between the P wave and QRS in the electrocardiogram, was demonstrated (fig. 11C).

First Degree A-V Heart Block

As seen in figure 12A in first degree A-V heart block, the distance between component a and v_s of the Doppler tracing is increased. The three components (a, v_s, and v_d) are easily recognized.

Second Degree A-V Heart Block

In the four cases of second degree A-V heart block, the component a of the Doppler tracing manifests the close relationship to the P wave of the electrocardiogram. The tracing of a patient with acute myocardial infarction is displayed in figures 12C and D. The electrocardiographic diagnosis was first degree A-V heart block (fig. 12C). The Doppler
tracing was taken with the transducer placed in the third right intercostal space in such a direction that only the atrial component is displayed; this shows two atrial deflections corresponding to each QRS. The atrial components have a regular rate of about 120 per minute. We suspected from the Doppler tracing that the patient had a 2:1 A-V heart block. This was not clearly shown in the standard electrocardiogram, although small notches were observed on the ascending limb of the T wave. The electrocardiographic diagnosis became obvious during spontaneous transient increase in the degree of block from 2:1 to 3:1 (fig. 12D).

**Complete A-V Heart Block**

In five patients with complete heart block the atrial and ventricular components of the Doppler tracing were clearly recognized. Their respective relationship to the P wave and QRS complex was maintained (fig. 12B).

![Figure 11](image)

(A) A-V nodal escape beats. Tracings from a 43-year-old woman with rheumatic heart disease, mitral insufficiency, and digitalis toxicity. Interval between thick time lines is 0.2 sec. Note the relationship of the components of the Doppler tracing to the deflections of the electrocardiogram. The arrow points at a sequence where the P wave is hidden in the T but the "a" wave is easily recognized in the Doppler tracing.

(B) Intermittent sino-atrial block. Tracings from a 56-year-old woman with arteriosclerotic heart disease. (Upper strip) ECG, lead II. (Lower strip) Raw Doppler tracing. Note the three components of the Doppler tracing ("a", "v_d", and "v_o"). There are two periods of inactivity on the Doppler tracing corresponding to the pauses of the electrocardiogram.

(C) A-V dissociation with periods of idioventricular rhythm. Tracings from a 75-year-old man with hypertension and a cerebrovascular accident who was taking digitalis. Note the gradual decrease in the P-R interval. The QRS complex is widened after the second cycle. The P wave apparently is buried in the QRS in the last two complexes. The three Doppler components ("a", "v_d", and "v_o") appear regularly in the initial part of the tracing. These components continue in a regular manner. In the sixth complex, where the P wave is buried in the QRS, three oscillations are observed in the initial Doppler complex. The second oscillation apparently corresponds to the atrial complex (see arrow); the first oscillation is due to ventricular systole ("v_o"). The tracings in this strip represent raw Doppler beats. Interval between thick time lines is 0.2 sec.
Distance between thick time lines represents 0.2 sec. (A) First degree A-V heart block. Tracings from a 55-year-old man with coronary artery disease, healed infarction, and congestive heart failure. Note the increased interval between components “a” and “v_8”.

(B) Complete A-V heart block. Tracings from a 70-year-old woman with diabetes and coronary artery disease. Note the complete dissociation between the atrial (arrow) and ventricular (“v_8”, and “v_d”) components of the Doppler tracing. Their relationship to the electrocardiographic waves remains unchanged.

(C) Second degree A-V heart block. Tracings from a 53-year-old man with acute inferior infarction. The original electrocardiographic diagnosis was first degree A-V heart block. The Doppler tracing shows large “a” waves with a rate double that of the QRS. Careful inspection shows slight notching in the T wave due to a superimposed P wave (at arrow). The ventricular components of the Doppler tracing have been eliminated by a change in the direction of the ultrasound beams.

(D) Tracings from same patient as C. A transient increase in block from 2:1 to 3:1 revealed more distinctly the atrial rate and rhythm.

Discussion

The Doppler method is a relatively new method for the study of heart action and as such is an offspring of the “pulse” ultrasonic method. In our study, we have employed this procedure on normal subjects and on
Because of the frequency limits of our recorders, the raw tracings correspond to the low-pitched Doppler signals of the heart which have been attributed to the motion of the heart wall.\textsuperscript{19} Analysis of the frequency of the unfiltered Doppler signal has revealed that most of its energy is displayed at frequencies below 200 cps\textsuperscript{21} which corresponds again to signals originating from the movement of the walls of the heart.\textsuperscript{19} Thus, the amplitude tracing employed by us contains signals due mainly to the movement of the heart walls. The movement of the valves and blood flow which constitute components of low energy contribute to a much lesser degree to the amplitude of the deflections. The presystolic component a on which we concentrated our attention in this study has been attributed to the “motion of the heart wall that accompanies the atrial contraction”\textsuperscript{19} because “its timing and duration are similar to the fourth (atrial) sound.”\textsuperscript{19}

Analysis of our tracings lends further support to this interpretation. They demonstrate the features of component a as follows: 

1. It occurs 0.05 to 0.11 sec after the onset of the P wave (figs. 2 to 7) as expected because the mechanical events of the heart follow the electrical events by a time lag of that order.\textsuperscript{22, 23}

2. It disappears in cases of atrial fibrillation (fig. 8C to E) when there is no significant atrial motion.

3. It maintains its close relationship to the P wave of the electrocardiogram and occurs independently of the QRS-T in cases of A-V dissociation (fig. 11C) and in second degree and complete A-V heart block (fig. 12).

4. It precedes the a wave of the jugular venous tracing by 0.06 to 0.09 sec, the time necessary for the transmission of the pressure wave from the right atrium to the neck.\textsuperscript{24, 25} (fig. 6).

5. It precedes the a wave of the displacement apexcardiogram by 0.06 to 0.09 sec, a time interval probably required for blood to flow from the atria into the ventricles and for the apex of the heart to displace the chest wall (fig. 5).

6. It is simultaneous with the fourth heart sound (fig. 4).

7. It is

patients with various cardiac arrhythmias, particularly those in which delineation of the atrial component is of importance.

Figure 13

Diagram displaying the temporal relationships of the amplitude (AD) and the raw (RD) Doppler tracing to the electrocardiogram (ECG), right atrial pressure (RAP) wave, phonocardiogram (PCG), jugular venous tracing (JVT), and apexcardiogram (ACG). Redrawn from actual tracings after correction for cycle length and change in amplification. Distance between time lines represents 0.04 sec.

The component “a” of the Doppler tracing follows the onset of the P wave by 0.05 to 0.11 sec. It is simultaneous with the fourth heart sound and the “a” wave of the right atrial pressure tracing and precedes the “a” wave of the apexcardiogram and the “a” wave of the jugular venous tracing by 0.06 to 0.09 sec. Component “v\textsubscript{s}” follows the onset of the Q wave by 0.03 to 0.09 sec and is almost simultaneous with the second heart sound and precedes the “c” wave of the jugular venous tracing and the E wave of the apexcardiogram. Component “v\textsubscript{d}” precedes the O point of the apexcardiogram and the v wave of the jugular venous tracing and is simultaneous with or immediately follows the second heart sound and the end of the T wave.
CARDIAC ARRHYTHMIAS

simultaneous with the \( a \) wave of the intracardiac right atrial pressure tracing (fig. 7). (8) It is simultaneous with atrial contraction as visualized on cineangiocardiograms.

It is further suggested that the \( a \) deflection is due mainly to the movement of the atrial wall itself and not to other factors associated with atrial contraction because most of its energy content has a frequency (100 to 200 cps) which corresponds to a target velocity similar to that of the walls of the heart.\(^\text{19-21}\)

Moreover, its amplitude increases when the transducer is placed over the right atrium and the patient is turned to the right lateral decubitus position, which brings the anterior wall of the right atrium close to the transducer and perpendicular to the ultrasound beam. The movements of the atroventricular valves during atrial contraction and blood flow through the tricuspid orifice contribute little to its genesis.\(^\text{17, 18, 26}\)

Component \( v_a \) is probably due to the movement of the ventricular wall during systole, the closing of the atroventricular valves and the opening of the semilunar valves. Component \( v_d \) is due to the movement of the ventricular wall during early diastole, the closing of the semilunar valves, and the opening of the atroventricular valves. Blood flow probably contributes to both ventricular components. The fact that each of the ventricular components is due to several physiological events with slightly different timing explains the variation of their duration, time of occurrence, and configuration. Because of these factors, the amplitude tracing has not been very helpful in studying ventricular dynamics. It cannot be used for measurements of velocities of heart structures which can be studied by tracings displaying the frequency of the Doppler beat.

When taken simultaneously with the electrocardiogram, the "amplitude" Doppler tracing may often help in the demonstration and timing of atrial activity when the \( P \) wave is not easily recognized in the ECG, and thus, the amplitude tracing facilitates the study of arrhythmias. In nine of the 45 cases studied, the Doppler tracing provided some information that could not be obtained from the standard electrocardiogram.

The technique is simple and not time consuming. The tracings can be made at the bedside by one person, and no photographic development is required when the direct writer recorder is used. There is no discomfort to the patient as when esophageal or intracardiac electrocardiographic leads are employed. The energy emitted by the transducer (20 to 30 mw/cm\(^2\)) is far below the levels used in ultrasound treatment or those considered harmful.

In the latter stages of this study, only the amplitude tracing was used because it consists of more clearly defined deflections, has a higher amplitude, and a more even base line.

In summary, this study constitutes a relatively new application of the ultrasonic Doppler method in the study of cardiac arrhythmias. More studies using this technique or other methods of processing and modes of display of the Doppler signal are needed in the further study of the clinical disorders of the heart beat.

References

8. Effert, S.: Registration of Movement of Cardiac Walls Using an Ultrasonic Reflection Pro-

Circulation, Volume XXXVIII, October 1968


21. Nimura, Y., Matsuo, H., Mochizuki, S., Aoki, K., Wada, O., and Abe, H.: Analysis of the cardiac cycle of the left side of the heart in cases of left ventricular overloading or damage with the ultrasonic Doppler method. Amer Heart J 75: 49, 1968.


Study of the Cardiac Arrhythmias by the Ultrasonic Doppler Method
SAMUEL BELLET and JOHN KOSTIS

_Circulation_. 1968;38:721-736
doi: 10.1161/01.CIR.38.4.721

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1968 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/38/4/721

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in _Circulation_ can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to _Circulation_ is online at:
http://circ.ahajournals.org//subscriptions/