Characterization of Atrial Flutter

Studies in Man After Open Heart Surgery Using Fixed Atrial Electrodes

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SUMMARY  Studies were performed using bipolar atrial wire electrodes to record atrial electrograms and to pace the atria in 27 patients who developed atrial flutter after open heart surgery. Two types of atrial flutter, classic or type I atrial flutter, and type II atrial flutter, were identified. Both types of atrial flutter were characterized by uniformity of the beat-to-beat atrial cycle length, morphology, polarity, and amplitude of the recorded bipolar atrial electrogram. Both types sometimes manifested a beat-to-beat electrical alternans, which in turn was sometimes associated with an alternans in beat-to-beat cycle length. The initial basis of separation of types I and II atrial flutter was that type I atrial flutter was always influenced by rapid atrial pacing from the high right atrium, and type II atrial flutter was not. Two additional observations suggested that types I and II atrial flutter were different, although related, rhythms: 1) In four patients, type II atrial flutter was present after termination of rapid atrial pacing used to treat type I atrial flutter; 2) in two patients, type II atrial flutter changed to type I atrial flutter in a one-step fashion. The range of rates of the two types of atrial flutter were also different — type I atrial flutter was slower (range 240–338 beats/min) than type II (range 340–433 beats/min). We concluded that type II atrial flutter is a distinct rhythm which may be intermediate between classic, or type I, atrial flutter and atrial fibrillation.

ATRIAL FLUTTER is a supraventricular arrhythmia which has long been recognized in man, although its underlying mechanism has not been explained. Based on the ECG, it has been characterized as a regular, rapid atrial rhythm, most often with an atrial rate close to 300 beats/min, with the upper and lower limits of its range uncertain and variously stated. At our institution, at the time of open heart surgery, bipolar wire electrodes are routinely placed on the right atrial epicardium for possible diagnostic or therapeutic use in the immediate postoperative period. Since many patients develop atrial flutter spontaneously during this latter period, this was an opportunity to use these electrodes to characterize and define this rhythm better while providing patient care.

Methods

Twenty-seven patients who developed atrial flutter in the immediate period after open heart surgery were studied. The atrial flutter was identified initially from a standard or monitored ECG, or from bipolar atrial electrograms recorded from a pair of atrial wire electrodes placed routinely 0.5–1.0 cm apart on the epicardial surface of the superior portion of the right atrium. The atrial electrograms were used to distinguish atrial flutter from atrial fibrillation when this differentiation was not clear from the ECG recording alone. After identifying atrial flutter, bipolar atrial electrograms were recorded simultaneously with ECG leads II and III for as long as 15 minutes with an Electronics for Medicine Model DR-12 switched beam oscilloscopic recorder. In one patient, the recordings were made using a Medical Systems Corporation Model DU-35 three-channel ECG machine and in two patients using a Hewlett-Packard Model 1151B ECG machine. Then, the atria were paced rapidly at rates up to 600 beats/min in an attempt to interrupt the atrial flutter. All data were recorded on magnetic FM tape (Honeywell Model 5600) for later playback and analysis, except in three patients. In the 24 patients in whom recordings were made using the Electronics for Medicine DR-12 machine, all ECGs and atrial electrograms were recorded between a bandpass of 0.1–500 Hz, and the atrial electrograms also were recorded between a bandpass of 12–500 Hz. In the other three patients, ECGs and electrograms were recorded between a bandpass of 0.1–100 Hz. All electrodes in contact with the heart were electrically isolated.

The bipolar atrial electrograms initially stored on magnetic tape were later played back into a Sigma-7 computer for analysis. The computer was programmed to identify atrial electrogram complexes and to measure beat-to-beat atrial cycle lengths. The program identified the onset of an atrial electrogram complex by scanning the differentiated electrogram signal for a value which exceeded a predetermined threshold. The beat-to-beat intervals measured by the computer represented the intervals between atrial electrogram complexes identified in this manner. The Sigma-7 computer also was programmed to measure differences between successive beat-to-beat intervals.
The computer then created histogramic plots of all measured cycle length intervals and changes in beat-to-beat cycle lengths. These data were randomly cross-checked from bipolar atrial electrograms recorded on photographic paper at speeds of 100 mm/sec using a vernier measuring device with an accuracy of ±1 msec. In three patients all measurements were made using the vernier device.

Results

Type I (Classic) Atrial Flutter

In 18 patients who had a rapid, regular supraventricular tachyarrhythmia conforming to the commonly accepted definition of atrial flutter,4,8 the atrial flutter always was interrupted by rapid atrial pacing. We have labeled the atrial flutter in this group of patients as type I, or classic atrial flutter. Type I atrial flutter also was characterized by a strikingly constant beat-to-beat cycle length, morphology, polarity, and amplitude of the recorded bipolar atrial electrogram (fig. 1). Clinical information for all 18 patients in this group is contained in table 1.

A summary of electrophysiologic data for each example of type I atrial flutter is presented in table 2. Included separately for each patient is the mean atrial rate; the mean, longest and shortest atrial cycle length; and the mean, longest, and shortest change in beat-to-beat atrial cycle length. The mean atrial cycle length for each patient ranged from 177 msec in the fastest example of type I atrial flutter to 250 msec in the slowest example (mean 205 msec). The corresponding atrial rates ranged from 338-240 beats/min (mean 293 beats/min).

The mean beat-to-beat change in atrial cycle length for each patient was small, ranging from 1.4 msec per beat in the least variable case (i.e., most regular case) to 12.5 msec per beat in the most variable (table 2). The overall mean beat-to-beat change in atrial cycle length, obtained by averaging the mean from all patients, was 4.3 msec per beat. This characteristic narrow range in beat-to-beat atrial cycle lengths is illustrated by the histogram in figure 2. Although the beat-to-beat atrial cycle length was remarkably constant for all patients, the mean maximal change in atrial cycle length for all patients was 19 msec (range 6-42 msec). Thus, for most patients, a rare or occasional cycle length change considerably exceeded the mean (table 2).

In three patients, bipolar atrial electrograms demonstrated a consistent beat-to-beat electrical alternans. The recording in figure 3 is from the patient with the greatest beat-to-beat variability (mean 12.5 msec) in atrial cycle length (table 2) and is also representative of this electrical alternans. Subtle alternations in the amplitude of the atrial electrogram complexes are emphasized by the line connecting the negative amplitudes of greater magnitude, and the subtle alternations in atrial cycle length are illustrated by the S for short and L for long cycles of the atrial electrogram. Figure 4 is a histogram from the same patient as in figure 3, and shows a bimodal distribution of cycle lengths. Thus, the relatively great change in atrial beat-to-beat intervals demonstrated by this patient is rather misleading, as the atrial cycle lengths are actually remarkably constant for each alternans population. More pronounced electrical alternans were recorded from the two other patients in this group; one example is given in figure 5. In this patient, the morphological alternans was not associated with marked alternation in cycle length.

Type II Atrial Flutter

In seven patients with rapid, regular supraventricular tachycardia in whom the atrial rates ranged from 340-433 beats/min, faster than the rate generally given for atrial flutter,4,8 the atrial rhythm could not be interrupted by rapid atrial pacing. We have labeled this rhythm type II atrial flutter. Two other patients, each with a regular atrial rhythm of 404 and 413 beats/min, were included in this group, although atrial pacing was not performed, because in each instance, the rapid, regular atrial rhythm was well within the apparent range of type II atrial flutter.

![ECG leads II and III recorded simultaneously with bipolar atrial electrograms (AEG) illustrating a representative example of type I atrial flutter. Paper recording speed is 50 mm/sec. Time lines are at 1-second intervals.](image-url)
As with type I atrial flutter, type II atrial flutter also was characterized by a strikingly constant beat-to-beat cycle length, morphology, polarity, and amplitude of the recorded bipolar atrial electrogram (fig. 6). Clinical information for all patients with type II atrial flutter is contained in table 3.

Table 4 is a summary of electrophysiologic data for patients with type II atrial flutter. The mean atrial cycle length for each patient ranged from 139 msec in the fastest example to 176 msec in the slowest example (mean 157 msec), with corresponding atrial rates ranging from 433 beats/min to 340 beats/min (mean 384 beats/min). The mean beat-to-beat change in atrial cycle length for each patient ranged from 1.2 msec/beat in the least variable case to 16.7 msec/beat in the most variable (table 4). The overall mean change in atrial cycle length for all patients was 6.4 msec/beat. Although the beat-to-beat atrial cycle length was remarkably constant, the mean maximal change in atrial cycle length (table 4) for this group of nine patients was 24 msec (range 12–42 msec). Thus, for patients with type II atrial flutter, much as for patients with type I atrial flutter, a rare or occasional cycle length change considerably exceeded the mean.

Electrical alternans also occurred in two patients with type II atrial flutter. In one of these patients, it was associated with a beat-to-beat alternans in cycle length such that the beat-to-beat variability in cycle length was actually less than suggested by the beat-to-beat interval measurements (16.7 msec).

### Rapid Atrial Pacing

Overdrive rapid atrial pacing was performed in 24 patients. In all 18 cases of type I atrial flutter, rapid atrial pacing changed the rhythm. In 14 of the 18 cases, the rhythm was changed by rapid atrial pacing to either normal sinus rhythm directly or to atrial fibrillation. In four patients, however, at the termination of rapid atrial pacing, a sustained rhythm identical to type II atrial flutter was present. We could not tell if a transient period of atrial fibrillation preceded the development of type II atrial flutter or whether it developed immediately after terminating rapid pacing. Thus, whether this period represents sustained entrainment of type I atrial flutter to type II atrial flutter or whether pacing produced a transient and unrecognized period of atrial fibrillation which then evolved into type II atrial flutter is unclear.

In seven of the nine cases of spontaneous type II atrial flutter, rapid atrial pacing at rates up to 600 beats/min was performed, but in each case the rhythm remained unchanged. In three of the four patients in whom type II atrial flutter developed after rapid atrial pacing treatment for type I atrial flutter, rapid atrial pacing at rates up to 600 beats/min failed to interrupt the new, more rapid atrial flutter. Thus, while rapid atrial pacing always influenced type I atrial flutter, it never influenced type II atrial flutter.

### Relationships Between Types I and II Atrial Flutter

As indicated above, type I atrial flutter was con-
converted to type II atrial flutter in four patients by rapid atrial pacing. In addition, spontaneous, abrupt conversion from type II to type I atrial flutter occurred twice. An example is shown in figure 7.

![Diagram](image)

**Figure 2.** A histogram of atrial cycle lengths from a representative case of type I atrial flutter. These data represent 508 beats recorded over 100 seconds. Note the narrow range of atrial cycle lengths, extending from 194-204 msec.

### Table 2. Data—Patients with Type I Atrial Flutter

<table>
<thead>
<tr>
<th>Pt</th>
<th>Mean atrial rate (beats/min)</th>
<th>Mean atrial CL (msec)</th>
<th>Max atrial CL (msec)</th>
<th>Min atrial CL (msec)</th>
<th>Mean chg atrial CL (msec)</th>
<th>Max chg atrial CL (msec)</th>
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<td>238</td>
<td>3.1</td>
<td>6</td>
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</table>

Mean = 2 sd—all pts

|            | 194 ± 24.5 | 205 ± 17.5 | 216 ± 19.3 | 192 ± 18.4 | 4.3 ± 2.9 | 19 ± 11.6 | 0 |

Abbreviations: CL = cycle length; Max = maximum; Min = minimum; chg = change.

### Discussion

#### Characteristics of Type I and Type II Atrial Flutter

**Similarities**

Our data demonstrate that atrial flutter is characterized by a remarkably uniform beat-to-beat cycle length, morphology, polarity, and amplitude of recorded atrial electrograms. An exception to these latter observations occurs in the presence of beat-to-beat electrical alternans, which is associated with two constant populations of atrial electrogram morphology and/or polarity and/or amplitude which alternate on a beat-to-beat basis. In addition, when electrical alternans is present, an alternans in the beat-to-beat cycle length of the atrial electrogram also may be present. These observations characterize both type I and type II atrial flutter.

The beat-to-beat regularity of atrial flutter was first emphasized by Lewis, who measured V-V intervals in patients with classic (type I) atrial flutter and 2:1 or 4:1 atrioventricular (AV) block and demonstrated that "variations in the lengths of intra-auricular cycles . . . average less than 0.0009 to 0.0077 of a second." He also found that sometimes the "maximal variation of the cycles may amount to but usually does not exceed 0.02 second." This agrees well with our data, which was compiled with more precise techniques. The uniformity of beat-to-beat cycle length, morphology, polarity, and amplitude that characterizes the atrial electrogram in both type I and type II atrial flutter distinguishes these rhythms from atrial fibrillation, which has a characteristic change in these beat-to-beat
ATRIAL FLUTTER/Wells et al.

FIGURE 3. ECG leads II and III recorded simultaneously with a bipolar atrial electrogram (AEG) in a patient who developed type I atrial flutter after open heart surgery. The AEG demonstrates both electrical alternans (highlighted by the line drawn which connects the negative deflections of every other electrogram), and a beat-to-beat cycle length alternans (the S represents the shorter and the L the longer of the alternating cycle lengths). Paper recording speed is 50 mm/sec. Time lines are at 1-second intervals.

parameters.\textsuperscript{12, 13} This distinction is helpful in separating atrial flutter from the relatively nonchaotic forms of atrial fibrillation.\textsuperscript{12}

**Differences**

In this and previous studies,\textsuperscript{10, 11} type I atrial flutter always could be influenced with rapid atrial pacing from sites high on the right atrial epicardium. However, type II atrial flutter has not been influenced by rapid atrial pacing from these same sites. Also, the range of rates of type II atrial flutter was faster than that of type I atrial flutter. The limits of the range of rates for each type of atrial flutter may vary from that reported in this study; for instance, it is likely that there is some overlap between the upper range of type I and the lower range of type II.

Are the differences enough to separate atrial flutter into two types? Why isn't type II atrial flutter simply the upper end of the spectrum of atrial flutter? The separation of type I atrial flutter from type II atrial flutter was made on the basis of several observations. The first was the response to pacing. We have considered that type II atrial flutter may not be influenced

FIGURE 4. Histogram from the same patient as in figure 3. Note the bimodal grouping of the atrial cycle lengths, corresponding to the short and long cycle lengths in figure 3.
by rapid pacing from the high right atrium because the pacing site may be so far from the focus of the atrial flutter that the factors of atrial conduction time plus atrial refractoriness preclude the interruption of type II atrial flutter in this fashion. Wellens has emphasized this consideration in discussing the inability of cardiac pacing to interrupt or influence various cardiac arrhythmias.\textsuperscript{14} It may be that in the presence of type II atrial flutter, rapid atrial pacing from a site in the inferior right or left atrium might interrupt this rhythm. Thus, we are not implying that type II atrial flutter cannot be interrupted at all, but rather that it cannot be interrupted when pacing from sites high in the right atrium. The latter consideration may mean that what we have labeled type II atrial flutter is merely a part of the spectrum of atrial flutter, but oc-

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{ECG leads II and III recorded simultaneously with a bipolar atrial electrogram (AEG) in a patient who developed type I atrial flutter. This figure is an example of marked beat-to-beat electrical alternans without alternans in beat-to-beat cycle length. Paper recording speed is 50 mm/sec. Time lines are at 1-second intervals.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure6.png}
\caption{ECG lead III recorded simultaneously with a bipolar atrial electrogram (AEG) from a patient, illustrating type II atrial flutter. Using a pair of interval counters and a character generator, the beat-to-beat interval of the atrial electrogram was measured and printed out.\textsuperscript{15} The bottom trace demonstrates the interval which was measured and the two traces above the bottom trace are the printouts of the previous beat-to-beat cycle length. Note the regularity of the cycle length, polarity, morphology, and amplitude of the recorded atrial electrogram. Also, note the clearly recognized atrial complexes in the ECG. Paper recording speed is 50 mm/sec. Time lines are at 1-second intervals.}
\end{figure}
occurring at very fast atrial rates.

The second observation which led us to separate type II atrial flutter from type I atrial flutter was that on two occasions, we have observed type II atrial flutter change to type I atrial flutter in a stepwise fashion. While this does not demonstrate that the two rhythms are separate, it does suggest that they are not really the same. Also, the change in atrial electrogram morphology and polarity which accompanied the development of type I atrial flutter from type II atrial flutter probably reflects a change in the wavefront of atrial activation which may be due to either a change in the focus generating the rhythm or a rate-dependent change in the sequence of atrial activation independent of a change in focus.

Finally, the observation in four cases that type II atrial flutter was present upon cessation of rapid atrial pacing initiated to treat type I atrial flutter may be more evidence that what we have labeled type I and type II atrial flutter are in fact different rhythms.

While there are many similarities between what we have labeled type I and type II atrial flutter, the differences suggest that they are separate entities.

**Relationship to Common and Uncommon Atrial Flutter**

The terms "common" and "uncommon" atrial flutter have been used to separate types of atrial flutter on the basis of the morphology of atrial complexes in the ECG, common flutter having predominantly negative complexes in leads II, III, and aVf, and uncommon flutter having positive complexes in these same leads.\(^5\) \(^6\) Common atrial flutter seems to correspond to type I atrial flutter. However, uncommon atrial flutter usually has rates less than 300 beats/min and usually less than 250 beats/min, and has been called atrial tachysystole.\(^5\) \(^6\) In any event, it appears to be distinctly different from type II atrial flutter. However, Boineau et al.\(^5\) described a dog with the two

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**Table 3. Clinical Data—Patients with Type II Atrial Flutter**

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<thead>
<tr>
<th>Pt</th>
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<th>Sex</th>
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<th>Disease state</th>
<th>Operation</th>
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<td>M</td>
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<td>CAD</td>
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<td>CAD</td>
<td>2 SVBG</td>
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<tr>
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<td>NSR</td>
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Abbreviations: A fib = atrial fibrillation; AI = aortic incompetence; AS = aortic stenosis; AVR = aortic valve replacement; CAD = coronary artery disease; IHSS = idiopathic hypertrophic subaortic stenosis; MI = mitral incompetence; MS = mitral stenosis; MV = mitral valve; MVR = mitral valve replacement; NSR = normal sinus rhythm; RHD = rheumatic heart disease; SVBG = saphenous vein bypass graft; TS = tricuspid incompetence; TV = tricuspid valve.

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**Table 4. Data—Patients with Type II Atrial Flutter**

<table>
<thead>
<tr>
<th>Pt</th>
<th>Mean atrial rate (beats/min)</th>
<th>Mean atrial CL (msec)</th>
<th>Max atrial CL (msec)</th>
<th>Min atrial CL (msec)</th>
<th>Mean chg atrial CL (msec)</th>
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Mean ± 2 sd—all pts

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</table>

Abbreviations: CL = cycle length; Max = maximum; Min = minimum; chg = change.
types of spontaneous atrial flutter — a slower one with negative atrial complexes in II, III, and aV, and a faster one with positive atrial complexes in these same leads. It is unclear whether this represents an experimental counterpart of the clinical rhythms we have described.

Nature of Type II Atrial Flutter

Perhaps type II atrial flutter represents a rhythm intermediate between atrial fibrillation and type I atrial flutter. This hypothesis has some basis in fact and would help to tie together several notions about the cause of atrial flutter and atrial fibrillation. Whatever the mechanism of classic atrial flutter (reentry, some form of automaticity, or a mechanism not yet known), there is considerable evidence, recently summarized by Scherf and Schott, that this rhythm is generated at a focus producing a rapid, regular rhythm. If this or another focus could generate a still faster, regular rhythm, the atrial response would only be limited by atrial conduction velocity and refractoriness. Thus, type II atrial flutter might be the result of a very rapid, regular rhythm generated at a rate just at or within the limits of the electrophysiologic properties of atrial tissue which will permit an organized 1:1 atrial response. When this same or another focus generates a regular rhythm which is so fast that the entire atria cannot respond in a 1:1 fashion, atrial fibrillation results. That atrial fibrillation can be precipitated and maintained by a single focus firing rapidly has been demonstrated in the experimental animal and man. Thus, it is possible that a focus generating a rapid, regular rhythm may be responsible for atrial flutter (types I and II) and atrial fibrillation, with the rhythm determined by the rate generated by the focus.

Our use of the term “focus” does not imply that a focus is necessarily a discrete point. While it may be so, it may also encompass a circumscribed area. For example, the model of atrial reentry described by Allessie et al. is a discrete focus encompassing an area of less than 1.5 x 1.5 cm of their left atrial tissue bath preparation. Also, a focus may be located in a structure contiguous with the atria, such as one of the AV valves, or may include circus movement around a structure such as a pulmonary vein, the coronary sinus, or one of the venae cavae.

In summary, while we do not know the mechanism of either type I or type II atrial flutter, be it reentry, some form of automaticity, triggered activity or something else, it is possible that a relatively small focus generating different rates could produce either rhythm, and if the rate were fast enough, could produce atrial fibrillation.

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Straddling and Displaced Atrioventricular Orifices and Valves

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SUMMARY This is an anatomic study of 96 hearts with straddling or displaced atrioventricular (AV) orifices and valves. In the complete form, both the annulus and the peripheral connections of either AV valve straddle a ventricular septal defect (VSD) and connect to both ventricles. In the annular form, only the annulus, and in the peripheral type only the peripheral connections of the valve are found in both ventricles. In displaced AV, the entire annulus and periphery of one AV valve are displaced into the opposite chamber. These anomalies are commonly seen in complete transposition with or without ventricular inversion, and in double outlet right or left ventricle. Straddling mitral valve is frequently seen in the Taussig-Bing heart. Any type of VSD may be associated with straddling tricuspid valve; however, they usually are of the AV canal type. Straddling and displaced AV valves should be differentiated from criss-cross hearts in which both AV valves are completely connected to oppositely placed ventricles.

STRADDLING AND DISPLACED atrioventricular (AV) orifices and valves are uncommon congenital malformations that have been dealt with infrequently in the literature. We previously studied the anatomy of a small number of these hearts. We have now studied a large series with the purpose of presenting data useful to clinicians and surgeons.

From the Congenital Heart Disease Research and Training Center, Hektoen Institute for Medical Research; the departments of Pathology: Northwestern University Medical School; Pritzker School of Medicine, University of Chicago; the Chicago Medical School, University of Health Sciences; Loyola University, Stritch School of Medicine; and the Abraham Lincoln School of Medicine, University of Illinois; the Departments of Pediatrics, Medicine and Pathology, Rush Medical College, Chicago, Illinois; and the Armed Forces Institute of Pathology, Washington, D.C.

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Materials and Methods

Ninety-six hearts with straddling or displaced AV orifices and valves were studied. Eighty-one came from the Congenital Heart Disease Research and Training Center and 15 from the Armed Forces Institute of Pathology. These hearts were selected from 4700 congenitally abnormal hearts seen at the former, and 3300 congenitally abnormal hearts seen at the latter (table 1). In addition to the annulus and the connections of the valves, particular attention was focused on: 1) the position of the atrial septum, 2) the size of the tricuspid and mitral orifices, 3) the type and size of the ventricular septal defect (VSD), 4) the size of the right and left ventricles, 5) the type of complex in which the entity was found, and 6) the common associated cardiac abnormalities.

Definitions

Straddling AV orifice and valve. Either one or (rarely) both orifices and valves straddle the ventricular septum over a defect in the ventricular septum so that some part of the orifice and valve lies in both ventricles.

Complete straddling AV orifice and valve. Both the annulus and the peripheral connections lie in both chambers.
J L Wells, Jr, W A MacLean, T N James and A L Waldo

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