Atrial Standstill Secondary to Atrial Inexcitability (Atrial Quiescence)

Recognition and Treatment following Open-Heart Surgery

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SUMMARY

Atrial standstill secondary to atrial inexcitability or atrial quiescence was diagnosed in 11 patients and atrial standstill, in which atrial excitability was still present though depressed, was diagnosed in two patients during the immediate period following open-heart surgery. Atrial quiescence was successfully treated in six patients and atrial standstill with depressed excitability in both patients by the infusion of small doses of isoproterenol. Atrial quiescence was not treated in the other five patients and reverted spontaneously within 24 hours after surgery. It is suggested that atrial quiescence results from relative depolarization of the atrial membrane and that the success of therapy with isoproterenol results from hyperpolarization of the atrial membrane by this drug.

Additional Indexing Words:
Atrial quiescence Atrial standstill Isoproterenol Atrial membrane potential
Depolarization Hyperpolarization Atrial pacing Open-heart surgery
Atrial electrograms Atrial inexcitability

A TRIAL STANDSTILL secondary to atrial inexcitability or atrial quiescence is a rhythm in which there are no P waves in the ECG, an atrial electrogram (EG) cannot be recorded from electrodes either in contact with the atria or within the atrial chambers, and the atria cannot be paced by electrical stimuli delivered through electrodes in contact with the atria. During this rhythm, the ventricles are usually depolarized from an A-V junctional pacemaker.

Although, as summarized by Rosenbaum and Levine,1 there are several descriptions of absence of spontaneous atrial activity in the experimental animal, Sir Thomas Lewis2 was the first to describe such a rhythm in patients. Since then, there have been many other reports, recently summarized by Rosen, Rahimtoo, Gunnar, and Lev.3 Jouve, Delaage, Torresani, Nicolai, Heuillet, and Pinas4 were the first to report the association of the absence of spontaneous atrial activity with the inability to pace the heart with electrical stimuli delivered through electrodes in contact with the atria. Since then there have been four additional reports.5, 6, 7

Studies on isolated perfused cardiac tissue8, 9 have demonstrated that inexcitability is associated with a low (<55 mv) membrane resting potential. In many instances, infusion
of very small amounts of catecholamine into the tissue bath perfusate acts to hyperpolarize the resting membrane, and thereby restores electrical excitability.\textsuperscript{9–11} Therefore, it was hypothesized that atrial quiescence could be reversed by administration of small amounts of catecholamine. Experiments designed to study atrial quiescence produced in a donor perfused canine heart tested this hypothesis and demonstrated that atrial quiescence could be successfully treated in the whole heart by the administration of small doses of catecholamines (Waldo AL, Vitikainen KJ, Hoffman BF: Unpublished observations). These data were then applied to the treatment of atrial quiescence in patients.

\textbf{Methods}

Using a technic previously described,\textsuperscript{12, 13} bipolar stainless-steel wire electrodes were implanted in the atria of 13 patients during open-heart surgery and were brought out through the anterior chest wall. This technic is used routinely as an aid in diagnosis and treatment of cardiac arrhythmias during the postoperative period.\textsuperscript{12, 13} The electrodes were isolated from ground and from the recording instruments by an isolation transformer. In the recovery room, bipolar atrial EGs and simultaneous ECG leads were monitored on a DR-12 Electronics for Medicine switched-beam oscilloscope and recorded on phtographic paper moving at speeds of 10–200 mm/sec. ECG recordings were calibrated at 2 cm/mv.

Pertinent information about each patient is included in table 1. The preoperative rhythm was atrial fibrillation in six patients and sinus rhythm in seven patients. All patients were receiving maintenance doses of digoxin until the day before surgery, and six patients were receiving diuretics prior to surgery. All patients received halothane anesthesia. In the postoperative period, the serum K\textsuperscript{+} was normal, and there were no significant acid-base problems for each patient.

For each patient in whom no atrial activity was demonstrated in either the atrial EG or ECG recordings, an attempt was made to pace the atria through the implanted bipolar wire electrodes. Stimuli of 2-msec duration with amplitudes up to 10 mA were provided by a Medtronic 1187 Special Digital Threshold Stimulator and delivered through a stimulus isolator. Following this procedure, for eight patients an intravenous infusion of isoproterenol, concentration 1 \(\mu g/ml\), was begun at an infusion rate of 1 ml/min. Blood pressure, and heart rate and rhythm were monitored constantly. If the blood pressure fell, or if the spontaneous heart rate became too rapid (> 100 beats/min), or if any clinically serious arrhythmias appeared, we planned to stop the infusion. The infusion was continued until the atrial quiescence disappeared, i.e. until there was evidence of spontaneous atrial activity and until the atria could be paced.

The atrial quiescent rhythms of five patients were not treated with isoproterenol, but rather

\begin{table}[h]
\centering
\caption{Clinical Information for Patients Studied}
\begin{tabular}{|c|c|c|c|c|}
\hline
Pt & Age & Sex & Preoperative diagnosis & Surgical procedure \\
\hline
1 & 75 & M & AI & MV replacement \\
2 & 47 & M & AI, MS & AoV and MV replacement \\
3 & 60 & F & MS, MI, AI & MV replacement \\
4 & 47 & M & AI, MS & AoV and MV replacement \\
5 & 51 & M & MS, LVA & Aneurysmectomy, mitral commissurotomy \\
6 & 37 & F & TI & TV replacement \\
7 & 59 & F & Thrombus on aortic SE valve & AoV replacement \\
8 & 57 & F & AI & AoV replacement \\
9 & 59 & F & MS, MI & MV replacement \\
10 & 67 & F & MS & MV replacement \\
11 & 47 & M & AI, MI & AoV and MV replacement \\
12 & 48 & M & MS & MV replacement \\
13 & 38 & F & Akinetic area of LV, MI & Excision of akinetic tissue and MV replacement \\
\hline
\end{tabular}
\end{table}

Abbreviations: AI = aortic insufficiency; MS = mitral stenosis; MI = mitral insufficiency; LVA = left ventricular aneurysm; TI = tricuspid insufficiency; SE = Starr-Edwards; MV = mitral valve; AoV = aortic valve; TV = tricuspid valve; LV = left ventricle.

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were observed for spontaneous remission of the atrial quiescence. These patients thereby served as controls.

**Results**

Figure 1 illustrates the postoperative rhythm in patient 6. The ventricles were being paced through a ventricular electrode (placed during surgery) because the spontaneous rhythm, an A-V junctional rhythm, was too slow. Note the absence of P waves in the ECG and the absence of any atrial activity in the atrial EG. Stimuli delivered through the atrial wire electrodes failed to capture the atria (fig. 2). An infusion of isoproterenol was then started. In about 10 min evidence of spontaneous atrial activity appeared (fig. 3). Note that while the atria were captured by the spontaneous atrial beat, there was no ventricular capture. Figure 4A shows the rhythm about 5 min later than figure 3 and illustrates that now the spontaneous atrial rate has increased to about 30 beats/min, and that antegrade A-V conduction has returned (beat 3 is a fusion beat). When the external ventricular pacemaker was shut off (fig. 4B), a spontaneous A-V junctional rhythm with
atrial capture beats appeared. Note the long P-R intervals of the atrial capture beats in figure 4A and B, as well as the absence of retrograde A-V conduction. For all cases studied, when atrial activity reappeared, antegrade A-V conduction was considerably prolonged and retrograde A-V conduction was absent. Also, in figure 4B, note that the morphology of the ventricular complexes was identical during the junctional beats (beats 1, 2, 4, and 6) when compared with the atrial capture beats (beats 3 and 5). For all cases studied, there was no difference in the morphology of the ventricular complexes recorded during atrial quiescence as compared with those recorded when an atrial rhythm returned. With the reappearance of atrial activity, the atria of this patient could be paced. Figure 4C shows the patient’s spontaneous rhythm several hours later.

Figure 5 illustrates a similar sequence for patient 1. The initial postoperative rhythm was atrial quiescence (fig. 5A); about 15 min following the onset of infusion of isoproterenol, slow spontaneous atrial activity appeared along with evidence of antegrade conduction (fig. 5B); the atria could then be paced (fig. 5C); and several hours later, when atrial pacing was no longer clinically indicated, the patient had a spontaneous atrial rhythm (fig. 5D).

Atrial quiescence reappeared in two patients about 1 hour after the initial successful treatment with isoproterenol. Reinfusion of isoproterenol again reversed the atrial quiescence.

In two patients, the postoperative rhythm was A-V junctional, but there was no evidence of atrial activity in either the ECG or atrial EG. However, in each case, the atria could be paced, although only with very strong stimuli, 8.8 and 9.8 ma, respectively. Also, the resulting P-R intervals were very long, 0.60 and 0.50 sec, respectively. Infusion of small amounts of isoproterenol, 10 μg in each case, restored spontaneous atrial activity, reduced the pacing threshold to normal, and reduced the P-R intervals to 0.28 and 0.34 sec, respectively. Figure 6 illustrates this sequence in patient 4. These patients, therefore, while manifesting atrial standstill did not manifest the complete syndrome of atrial quiescence. Although initially there was no evidence of spontaneous atrial activity in either the ECG or atrial EG, the atria could be paced.

For all patients treated, the total dose of isoproterenol required to reverse atrial quiescence ranged from 15 to 25 μg. In no patient did we observe the occurrence of any clinically significant arrhythmias associated with isoproterenol administration, nor did we observe any clinically significant effect of its administration on the patients’ blood pressures. In all patients treated with isoproterenol, the spontaneous A-V junctional rhythm did increase in rate, but never more than 25 beats/min. Since the spontaneous rhythm was usually relatively slow (i.e., average 60 beats/min; range 50–65 beats/min), the increase in heart rate, usually about 15 beats/min
(range 10–25 beats/min) was clinically quite acceptable.

For the five patients who exhibited atrial quiescence, but who did not receive isoproterenol, in each instance, spontaneous atrial activity returned within 12–20 hours of surgery. Also, in every instance the initial appearance of atrial activity, though usually transient, was associated with endotracheal suctioning and/or coughing associated with pain, i.e. circumstances associated with endogenous catecholamine release.

Discussion

As previously summarized, the absence of spontaneous atrial activity has been called atrial standstill, atrial paralysis, atrial asystole, and inhibition of the auricles. While all these terms reflect the absence of a mechanical event, atrial contraction, they do not suggest with which, if any, electrophysiologic abnormality it is associated. We have introduced the term atrial quiescence in an effort to separate a specific cardiac electrophysiologic entity, atrial standstill secondary to atrial inexcitability, from a host of entities in which there is atrial standstill, but in which atrial excitability remains intact. For instance, the several reports of the absence of atrial contraction despite the presence of a normal sinus rhythm, so-called electrical-mechanical uncoupling, represent an example of atrial standstill but not of atrial quiescence. Further, the usual explanation of atrial standstill is that it results from S-A nodal arrest or S-A-nodal exit block with concurrent retrograde A-V-nodal block. This describes one form of atrial standstill but does not adequately describe atrial quiescence. Thus, the term atrial quiescence serves to identify a form of atrial standstill in which there is no spontaneous atrial activity and in which the atria are inexcitable.

To date, absence of spontaneous atrial activity has only been described in adults (it is usually transient) and has been associated with digitalis or quinidine administration; myocardial infarction, atrial tissue degeneration, and, now, open-heart surgery. Also, some cases

\[\text{Figure 5}\]

(A) Rhythm recorded from patient 1 in the open-heart recovery room following open-heart surgery. V = a ventricular electrogram recorded through the atrial electrodes. (B) Rhythm recorded from patient 1 about 15 min after the initiation of isoproterenol administration. V = the ventricular electrogram; A = the atrial electrogram recorded through the atrial electrodes. The third and perhaps ninth ventricular beats are atrial capture beats. (C) Rhythm recorded from patient 1 after that recorded in B demonstrating that the heart can be paced from the atria. S = the stimulus artifact. (D) Spontaneous atrial rhythm recorded from patient 1 several hours after open-heart surgery. EG = the atrial electrogram. Time lines are at intervals of 1 sec; paper speed is 50 mm/sec. See text for discussion.
ATRIAL STANDSTILL

Figure 6

Rhythms recorded from patient 4 while the atria were paced at the same rate before (A) and after (B) isoproterenol administration. Before isoproterenol the spontaneous rhythm was A-V junctional with absence of spontaneous atrial activity. The atria could be paced only with a very strong stimulus (S), and the ventricles were captured by the atria with a P-R interval of 0.50 sec. After administration of 10 μg of isoproterenol, the atria could be paced with a much smaller stimulus (note the great diminution in the size of the stimulus artifact from A to B) and the P-R interval decreased to 0.34 sec. Time lines are at intervals of 1 sec; paper speed is 25 mm/sec. See text for further discussion.

have been ostensibly idiosyncratic. While the causes may be many, we suggest that the common denominator is probably relative depolarization of the atrial membrane (i.e., low membrane resting potential). It is clearly established that cardiac tissue will be inexcitable if the membrane potential is too low (usually < -55 mv). Further, it has been established in studies on isolated perfused cardiac tissue that catecholamines in low concentration will hyperpolarize the resting membrane, restoring excitability and conduction toward normal. Therefore, the fact that small doses of isoproterenol restored atrial excitability in the patients in our series lends strong support to our hypothesis that atrial quiescence results from relative depolarization of the atrial membrane. We recognize that atrial quiescence following open-heart surgery may be a unique form of this arrhythmia and therefore conclusions based on our data may not be applicable to cases of atrial quiescence associated with other precipitating factors. However, these other factors such as digitalis toxicity, quinidine toxicity, and myocardial infarction are known to cause relative depolarization of the resting membrane of cardiac tissue. It is of interest in this regard that Lippestad and Marton and Jouve et al. each treated one patient manifesting A-V-junctional bradycardia and absence of spontaneous atrial activity with catecholamine (isoproterenol and Aleudrin, respectively) and reported that spontaneous atrial activity reappeared.

It is of some interest to know if the S-A node is involved in atrial quiescence. Is the SA node also quiescent or is there S-A exit block? These and other questions concerning the involvement of the S-A node are not answered by this study. However, it is of interest that the A-V node seemed to be involved in all our cases, for, when atrial excitability was restored, initially there was prolonged antegrade A-V conduction and absent retrograde A-V conduction.

The ability to diagnose and treat atrial quiescence in the immediate period following open-heart surgery provides an additional advance in patient care. By restoring atrial excitability, the atria may be paced to suppress arrhythmias, to treat bradyarrhythmias, and to increase cardiac output. The careful administration of isoproterenol (1 μg/min) until atrial excitability and spontaneous atrial activity have been restored has proven safe and effective. It should be anticipated that small additional doses of isoproterenol may have to be administered if the atrial pacing threshold and/or P-R interval increase. It is important to emphasize that the administration of isoproterenol to patients manifesting atrial quiescence must be slow.

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and in low concentration. Too rapid administration and/or too large a concentration of isoproterenol is likely to produce clinically significant arrhythmias and changes in systemic blood pressure. The applicability of this mode of therapy to patients with atrial quiescence unrelated to open-heart surgery remains to be documented. However, as discussed earlier, the return of spontaneous atrial activity in two patients who received a catecholamine to treat an A-V junctional bradycardia 4.25 does provide some indication that this mode of therapy may indeed be successful in these cases too.

Finally, the successful treatment of atrial quiescence with a catecholamine should provide a great impetus for an examination of the use of this class of drugs in the treatment of other arrhythmias in which relative depolarization of the cardiac membrane plays a major role in the production of the arrhythmia, e.g., arrhythmias which result from depression of cardiac conduction with reentry.8

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References
2. Lewis T: Exceptional types of slow heart action. Quart J Med 6: 221, 1913

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