Sinoatrial-Node Entrance Block

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SUMMARY
Sinus-node function was characterized in 13 patients during cardiac catheterization by the introduction of progressively premature atrial depolarizations. Curves relating the extent of sinus-node depression following these premature depolarizations and their degree of prematurity were constructed. The maximum extent of sinus-node depression following premature depolarizations and A-V-nodal and atrial refractoriness were determined. Maximum sinus-node depression could be demonstrated to be independent of sinus rate. In six patients "early" atrial premature depolarizations demonstrated entrance block into the sinus-node pacemaker. Sinoatrial (SA) node entrance block could be clearly distinguished from atrial echoes and repetitive atrial firing subsequent to stimulation during the atrial relative refractory period. Prolonged refractoriness of tissues conducting impulses between atrium and sinus node was unrelated to parameters of sinus-node automaticity (sinus rate or maximum depression following premature atrial depolarizations) or to the refractoriness of the atrium itself.

Additional Indexing Words:
Atrial premature depolarizations  Atrial refractoriness  Automaticity
A-V-nodal refractoriness  Sick sinus syndrome  Sinoatrial exit block

This study was intended to develop a method to evaluate sinus-node function in normal patients which could subsequently be applied to patients with SA-node dysfunction. The sinus node acts as an electric generator discharging at a specific rate. To function as a cardiac pacemaker, however, the action potentials generated within the sinus node must exit and initiate atrial depolarization. Accordingly, clinical bradyarrhythmias involving the sinus node have been divided into those which represent failure of the electric generator (sinus arrest, marked sinus bradycardia), and those due to failure of the generated impulse to result in a propagated atrial depolarization (sinoatrial exit block).

The inability to record sinus-node depolarization in the intact human heart has allowed abnormalities of conduction from the sinus node to the atrium to be evaluated only indirectly.

The present study was initiated in order to establish certain interventions which may uncover SA-node dysfunction at a time when bradycardia or exit block is not present. Programmed premature atrial depolarizations were introduced during sinus rhythm in 13 patients, none of whom presumably had sinus-node dysfunction, so that normal sinus-node function could be assessed. The well-known phenomenon of postextrasystolic depression of cardiac pacemakers was utilized to characterize a facet of sinus-node automaticity. The method also provided a means by which the refractoriness of tissues conducting impulses between atrium and sinus node could be measured.

Methods
Thirteen patients referred to our laboratory for cardiac catheterization procedures designed to evaluate chest pain not diagnostic of angina...
pectorsis were included in this study. All were men between the ages of 42 and 67 years, and had: (1) no clinical evidence of cardiomegaly or heart failure; (2) normal standard 12-lead ECG; (3) normal cardiac silhouette on chest X-ray; and (4) no cardioactive medications. The design and objectives of our investigation were explained to each patient, and each was requested to permit the insertion of a second catheter not required to perform the anginal testing. Signed informed consent was obtained.

Patients were brought to the catheterization laboratory in the nonsedated, postabsorptive state. Using standard techniques, a quadripolar catheter was advanced via the right basilic vein and positioned in the right atrium so that the distal two poles lay against the lateral wall of the mid right atrium. Electrodes on this catheter were spaced so that the two proximal poles were then adjacent to the junction of the right high atrium and superior vena cava—the region of the sinus node. In the 10 consenting patients, a second catheter was advanced via the femoral vein, and His-bundle electrograms were obtained by techniques previously described.4

Electrograms from these two catheters were displayed on a switched-beam oscilloscope and were used to record, respectively, depolarization of the high right atrium and low interatrial septum. These electrograms, ECG leads 1, 2, and 3, and accurately generated time marks at 10- and 100-msec intervals were recorded on magnetic tape. Analog tracings were subsequently transferred to photographic paper for analysis. Electrograms were displayed at frequency settings of 40–500 Hz.

**Stimulation Sequence**

The electrogram recorded from the high right atrium was used to trigger a second oscilloscope whose time base was adjusted so that one sweep encompassed 10–15 sinus cycles. The delayed trigger output of this oscilloscope triggered a single waveform and pulse generator adjusted to equal the patient’s sinus-cycle length. As a result, stimuli from this pulse generator could be placed anywhere throughout one sinus cycle with an accuracy of ± 1 msec. Stimuli 1.5 msec in duration and twice diastolic threshold were delivered to the mid right atrium via a stimulus isolation unit and were used to evoke atrial premature depolarizations (APD) during every tenth to fifteenth sinus cycle—the test cycle. The entire sinus cycle was scanned during successive test cycles by progressively decreasing the coupling interval between the sinus beat and the atrial stimulus. Between 50 and 100 test cycles were studied in each patient.

In figure 1, six typical test cycles are shown in which premature stimuli were used to evoke increasingly premature atrial depolarizations (A2). In every patient, intervals between successive atrial depolarizations were measured from the atrial electrogram. Tape and photographic paper speeds were coordinated so that these measurements could be made with an accuracy of ± 5 msec. During each test cycle (fig. 1), three intervals were measured: (1) A1-A1 = the interval between the two atrial depolarizations of sinus origin immediately preceding the atrial premature depolarization (APD); (2) A1-A2 = the interval between the atrial depolarization of sinus origin and the stimulated APD; (3) A2-A3 = the interval between the stimulated APD and the succeeding atrial depolarization of sinus origin. A1-A2 and A2-A3 intervals were then expressed as a percentage of the immediately preceding A1-A1 interval.

Other intervals were measured as follows: A-H interval = the interval from atrial depolarization in the high right atrium to the initial deflection of the His-bundle depolarization conducted from it. H-V interval = the interval between the initiation of His-bundle depolarization and the initiation of ventricular depolarization as reflected in any of the surface or intracavitary electrograms. Latency = the interval between the stimulus artifact and the atrial depolarization resulting from it. After the entire interval of atrial excitability had been explored with premature depolarizations in each patient, rapid atrial pacing to evoke angina was performed according to methods previously described.5 The patient was considered to have angina pectoris when during rapid atrial pacing (130–160 beats/min) characteristic S-T-segment depression occurred accompanied by chest pain identical to that for which the testing was being performed. Using this test, six of our patients were diagnosed as having angina pectoris. Coronary arteriography was not performed.

**Results**

**Sinus Depression following a Single APD**

The effects of single stimulated atrial premature depolarizations (APD) introduced during sinus rhythm were analyzed in all patients (fig. 1). The atrial cycle following the APD (A2-A3) and the atrial cycle terminated by the premature depolarization (A1-A2) were both expressed as a percentage of the immediately preceding sinus cycle (A1-A1). This transformation allowed intervals to be compared in the same individual independent of sinus rate and allowed comparison between
The method by which sinus-node function following single stimulated APD's was determined is shown in six representative test cycles (panels A–F). In each panel are recorded: atrial electrogram (AE), His-bundle electrogram (HBE), and ECG leads 1, 2, and 3. Below are time marks at 100-msec intervals. The heavy vertical bar aligns the last atrial depolarization of sinus origin (A₁) before the premature stimulus (arrow) evokes the atrial premature response (A₂). A₃ is the sinus beat following A₂. The numbers below each atrial electrogram reflect the duration of the intervals A₁–A₂ and A₂–A₃ when expressed as a percentage of the immediately preceding A₁–A₁ interval.

Panels A–D: As A₂ is evoked with increasing prematurity (90, 68, 54, 46%) the A₂–A₃ interval becomes prolonged (approximately 130%).

Panel E: The premature stimulus falls within the atrial relative refractory period. Latency between stimulus and response (A₂) is markedly increased. Note also that A₂ falls within the effective refractory period of the A-V node—the impulse fails to propagate to the His bundle.

Panel F: The premature stimulus is introduced more prematurely than in panel E; it fails to evoke any atrial response. This premature stimulus falls within the atrial refractory period.

patients. In every patient, A₂–A₃ intervals were plotted as a function of A₁–A₂ intervals. A typical curve is shown in figure 2. In all patients, as the A₁–A₂ interval was shortened from 100 to 70% of the A₁–A₁ interval, the A₂–A₃ interval became progressively longer. This lengthening corresponds to a linear depression of the sinus pacemaker following these
A typical graph relating $A_2A_3$ to $A_1A_2$ intervals is constructed for a patient in whom SA-node entrance block was not demonstrated (group I). $A_1A_2$ and $A_2A_3$ are expressed as a percentage of the immediately preceding $A_1A_2$ interval. The diagonal line indicates where points would have been expected to fall if the pause following the introduction of $A_2$ were fully compensatory. There is a linear depression of the sinus pacemaker following “late” $A_1$'s (prematurity equal to 100 to 70% of the preceding sinus-cycle length). Shortening the $A_1A_2$ interval beyond 70% results in no further depression of the sinus pacemaker (i.e., $A_2A_3$ does not continue to increase progressively). This is the “plateau” section of the curve (see Results). Values for the effective refractory period of the A-V node (AV ERP) and the refractory period of the atrium (At RP) are indicated by vertical lines.

relatively late APD's. This initial linear depression was noted in all patients.

In every patient, maximum depression of the sinus node was observed following APD’s introduced at approximately 75% of the sinus-cycle length. Increased prematurity of the stimulated premature beat resulted in no further increase in the $A_2A_3$ interval. In all patients, when APD’s were introduced with prematurity greater than 70% of the sinus-cycle length, the $A_2A_3$ intervals remained relatively constant, and a “plateau” of variable length was inscribed on the curves relating $A_2A_3$ to $A_1A_2$ intervals. The length of this “plateau” varied from patient to patient. The “plateau” was interrupted when the atrial refractory period, or the refractory period of the tissues conducting impulses from the atrium into the sinus node, was encountered.

A numerical value for maximum sinus-node depression was calculated as the weighted average of all $A_2-A_3$ intervals when $A_1-A_2$ intervals were equal to 70–80% of the $A_1-A_3$ interval, and the results for our patients are found in table 1. Although maximum sinus-node depression varied from individual to individual (117–132%), it was reproducible for any given patient when repeated during the same catheterization procedure. The extent of maximum sinus-node depression for the group was not a linear function of sinus-cycle length, and depression following a single APD was not greatest in patients with the slowest sinus rates.

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In six of these 13 patients, when APD’s were introduced with prematurity equal to 30–40% of the previous sinus cycle, the subsequent $A_2-A_3$ intervals abruptly became shorter than 100%. Typical recordings are shown which demonstrate this phenomenon (fig. 3). In the upper panels, APD’s ($A_2$) are introduced with progressive prematurity. All enter the sinus node and depress it. Following these APD’s, the next atrial depolarization of sinus origin is delayed to the same extent ($A_2-A_3 = 115\%$). When $A_2$ is introduced with more prematurity (panel D), the $A_2-A_3$ interval suddenly shortens. Instead of being delayed, the atrial depolarization subsequent to $A_2$ occurs when the sinus node would have been expected to result in atrial depolarization if $A_2$ had not been introduced. This occurs because of entrance block into the sinus node, whose automaticity thus remains undisturbed.

A representative curve relating $A_2-A_3$ to $A_1-A_2$ intervals in a patient in whom SA-node entrance block was demonstrated is shown in figure 4. The sudden interruption of the “plateau” segment of the curve shows the point at which SA-node entrance block first occurred: the sinoatrial-node effective refractory period (SAERP). The lower diagonal line on this graph shows where the next sinus beat ($A_3$) would have been expected to occur if $A_1-A_2 + A_2-A_3$ were equal to $A_1-A_3$; i.e., $A_3$ occurs “on time” as though $A_2$ were not introduced. The close relationship between this line and the observed $A_2-A_3$ intervals illustrates the first criterion by which SA-node
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Table 1

Electrophysiologic Data

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<th>Patient</th>
<th>Sinus-cycle length (msec)</th>
<th>A-H interval (msec)</th>
<th>H-V interval (msec)</th>
<th>Maximum sinus-node depression (%)</th>
<th>SA ERP (msec)</th>
<th>Atrial RP (msec)</th>
<th>A-V ERP (msec)</th>
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Group I

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<th>Patient</th>
<th>Sinus-cycle length (msec)</th>
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<th>H-V interval (msec)</th>
<th>Maximum sinus-node depression (%)</th>
<th>SA ERP (msec)</th>
<th>Atrial RP (msec)</th>
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Group II

Abbreviations: SA ERP = sinoatrial effective refractory period; atrial RP = atrial refractory period; A-V ERP = the effective period of the A-V node.

*His-bundle electrograms were not obtained.
†Percent of immediately preceding A1-A1 interval.
‡Less than the atrial RP.

entrance block was judged to have occurred.

Four criteria were used to determine if SA-node entrance block was the mechanism responsible for the sudden shortening of A2-A3 intervals following early APDs: (1) the A1-A3 interval corresponded closely to the preceding A1-A1 interval, i.e., A3 occurred when the sinus node would have been expected to depolarize the atrium if A2 had not been introduced (figs. 3-6); (2) the P-wave configuration and the sequence of atrial depolarization during A3 was identical to the previously observed sinus beats (figs. 3, 5, and 6); (3) A2 demonstrated no increase in latency, nor was conduction from the high right atrium to the low interatrial septum prolonged, i.e., the A1-A2 intervals over which A2-A3 suddenly shortened was clearly distinct from the atrial relative refractory period (figs. 1, 3, and 5-7); and (4) the sinus-cycle length immediately following the short A2-A3 interval was similar to the A1-A1 cycle length immediately preceding the stimulated APD (figs. 3 and 6).

These criteria allowed SA-node entrance block to be clearly distinguished from prematurely occurring atrial depolarizations which might have resulted from atrial reentry via the A-V node, or repetitive atrial firing secondary to stimulation during the atrial relative refractory period. Figure 6 contrasts an atrial echo beat with SA-node entrance block in the same patient. In the case of the atrial echo beat, the prematurely occurring atrial depolarization following the APD occurs (a) later than would be expected of the next sinus beat; (b) has a reversed sequence of atrial depolarization and inverted P waves in the inferiorly directed ECG leads; and (c) obviously enters the sinus node and depresses it since the subsequent sinus cycle is much longer than the sinus cycle preceding the APD.

Repetitive firing resulting from stimulation during the atrial relative refractory period is shown in figure 7. This phenomenon is clearly different from SA-node entrance block in that (a) there is increasingly long latency between stimulus and the atrial response, A2; (b) the next atrial depolarization occurs considerably earlier (400 msec) than would have been

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These four panels show four test cycles taken from the records of a patient in whom SA entrance block was demonstrated (group II). The format is identical to figure 1.
A typical graph relating $A_2A_3$ intervals to $A_1A_2$ intervals is shown for one of the patients in whom SA-node entrance block was demonstrated (group II). The upper diagonal line again shows where points would have been expected to fall if the pause following $A_2$ were completely compensatory. As $A_2$ is evoked with increasing prematurity ($A_1A_2$ shortened from 100 to 70%) the sinus pacemaker is progressively depressed ($A_2A_3$ becomes increasingly prolonged). Increasing the prematurity of $A_2$ still further results in no further sinus-node depression ($A_2A_3$ becomes no longer).

At $A_1A_2$ intervals between 42 and 33%, $A_2A_3$ suddenly shortens. The lower diagonal line indicates where $A_2A_3$ values would be expected to fall if $A_2$ failed to enter the sinus node; i.e., if $A_2$ demonstrated SA-node entrance block, $A_2$ would occur at a time which would make the $A_1A_2$ interval identical to the preceding $A_2A_3$ interval. The close relationship between expected and observed values for $A_2A_3$ intervals resulting from SA-node entrance block is demonstrated.

The refractory period of tissues conducting impulses between atrium and sinus node is indicated by the vertical line labeled SA RP. The effective refractory period of the A-V node (AV ERP) and the refractory period of the atrium (At RP) are also indicated by vertical lines.

Panels A–C: The $A_1A_3$ interval is progressively shortened (85, 63, 50%), and the maximum depression of sinus-node pacemaker having been achieved in panel A, the $A_2A_3$ interval remains constant.

Panel D: When the $A_1A_3$ interval is equal to 44% of the immediately preceding $A_1A_2$ interval, the $A_2A_3$ interval suddenly shortens from 115 to 49%. The interval encompassing $A_2$ ($A_1A_3$) becomes approximately equal to the preceding $A_1A_1$ interval. $A_2A_3$ is unexpectedly short because $A_2$ has failed to penetrate the sinus node; i.e., $A_3$ demonstrates SA-node entrance block. Note: (1) there is no increased latency between $A_3$ and the stimulus which evokes it; (2) the sequence of atrial depolarization during $A_3$ is identical to preceding sinus beats, i.e., the impulse proceeds from high right atrium to low interatrial septum; (3) the P wave on the surface ECG which reflects $A_3$ is upright; and (4) the next sinus-cycle length ($A_3A_1$) is approximately equal to the preceding sinus-cycle length $A_1A_1$. Repetitive SA-node entrance block is clearly demonstrated in figure 8. In this patient after an $A_1A_2$ interval was found which would always result in SA-node entrance block, atrial premature depolarizations were evoked during each of several consecutive sinus cycles. That these stimulated APD's do not enter the sinus node is apparent, since the nonstimulated atrial depolarizations continue to occur at the same sinus-cycle length, completely unaltered by the introduction of these APD's.

In each patient, the $A_1A_2$ interval at which SA-node entrance block first occurred was defined as the SA-node effective refractory period, that is, the effective refractory period of tissues conducting impulses from the atrium to the region of the primary pacemaker within the sinus node. In the six patients in whom SA-node entrance block occurred, SA effective refractory periods ranged between 34 and 50% of the sinus-cycle length (table 1). In these patients the refractoriness of tissues responsible for conducting impulses between atrium and sinus node was distinct from, and clearly longer than, the refractory period of the atrium itself (table 1).
Figure 5

P-wave morphology and the intraatrial conduction of sinus beats subsequent to the introduction of single stimulated APD's are shown. In each panel is shown: ECG leads 1, 2, and 3, atrial electrogram (AE) recorded from the high right atrium, and His-bundle electrogram (HBE) reflecting depolarization of the low interatrial septum. Time marks at 100 msec appear below each panel. Stimuli are shown by arrows and the intervals in milliseconds between successive atrial depolarizations are given above each atrial electrogram.

Panel A: An APD, evoked 390 msec following a sinus beat, enters the sinus node. Due to pacemaker depression the next atrial depolarization of sinus origin occurs 1180 msec later. Note that the P-wave morphology and interatrial conduction of this beat are identical to the preceding sinus beats.

Panel B: An APD evoked 390 msec following a slightly longer sinus cycle (1080 msec) is, as a percentage of sinus-cycle length, slightly more premature than the APD shown in panel A. Atrial depolarization following this APD occurs after only 640 msec. The APD has failed to enter the sinus node. Note: (1) the sum of the intervals surrounding the APD (390+640 msec) is approximately equal to the preceding sinus-cycle length (1030 compared with 1080 msec); (2) the beat following the APD demonstrates P-wave morphology identical to all other sinus beats in this patient; (3) during A3, the sequence of atrial depolarization is from high right atrium to low interatrial septum; and (4) interatrial conduction time during A3 is identical to all the other sinus beats.
**Atrial and A-V-Nodal Refractoriness**

For the present investigation we have defined the atrial refractory period as the longest $A_1$-$A_2$ interval at which atrial premature stimuli 1.5 msec in duration and twice diastolic threshold consistently fail to evoke an atrial response. Although this measurement is obviously related to catheter position, stimulus strength, and duration, as well as to intrinsic properties of the atrial myocardium, the atrial refractory period was surprisingly constant in each patient. Within the group of 13 patients, however, atrial refractoriness varied considerably (280–370 msec or 27–46% of the sinus-cycle length). Atrial refractoriness was not a linear function of sinus rate in our group of patients.

In the 10 patients in whom His-bundle recordings were obtained, A-H and H-V intervals were normal in all. Since our method closely parallels the “extrastimulus method” by which A-V refractoriness has classically been

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**Figure 6**

A single atrial echo beat is contrasted with SA-node entrance block following a stimulated APD in the same patient. Conventions are the same as for figure 5; the intervals in milliseconds between successive atrial depolarizations are indicated above each atrial electrogram.

**Panel A:** A single stimulated APD 490 msec following a sinus beat results in an atrial echo beat 550 msec later. Note that during this echo beat atrial depolarization proceeds from low interatrial septum to high right atrium (the thin vertical arrow) and that P waves in the inferiorly directed leads (2 and 3) are inverted. The sinus-cycle length following this atrial echo is prolonged (1000 msec), presumably because the echo beat also enters the sinus node and depresses it.

**Panel B:** Following an APD more premature than that shown in panel A (430 msec), SA-node entrance block is demonstrated. Atrial depolarization following the APD occurs when the sinus node would have been expected to depolarize the atrium, had the APD not been introduced (i.e., 430 + 440 msec is equal to the preceding sinus-cycle length of 870 msec). Atrial depolarization during this beat proceeds from high right atrium to low interatrial septum (thin vertical arrow). P waves are upright in the surface ECG. Following SA-node entrance block in this instance, the next sinus cycle is somewhat shorter than expected (750 msec). See text for discussion.
The effects of atrial stimuli introduced during the relative atrial refractory period are demonstrated in these two panels. In each panel are shown: ECG leads 1, 2, and 3, atrial electrogram (AE), two His-bundle electrograms (HBE), and time marks at 10 and 100 msec. The intervals in milliseconds between successive atrial depolarizations are given above each atrial electrogram.

Upper panel: An APD (A1) is evoked 290 msec following a sinus beat. There is considerable latency between stimulus and response (30 msec), yet A1 still enters the sinus node and depresses it so that the next sinus beat occurs after an interval of 1070 msec.

Lower panel: An APD is evoked 300 msec after a sinus beat. As a percentage of sinus-cycle length this A2 is more premature than that depicted above. Again, increased latency between stimulus and response is observed and the premature stimulus results in repetitive atrial firing 230 msec after the stimulated APD. Repetitive atrial firing cannot be confused with SA-node entrance block since the sum of the intervals surrounding the APD (300+230, or 530 msec) is 400 msec shorter than the preceding sinus-cycle length. Note, in addition, that the sinus beat following this APD evoked during the atrial "vulnerable" period is also delayed, since one (or both) of the evoked atrial depolarizations enters the sinus node and depresses it.

measured, A-V-nodal effective refractory periods were determined. A-V-nodal refractoriness ranged between 290 and 500 msec and was obviously prolonged in only one of our...
SA-node entrance block is demonstrated when atrial premature depolarizations (APD) are evoked by premature stimuli within the SA-node effective refractory period during successive sinus cycles. Left: Sinus rhythm with a cycle length of 800 msec. Right: Arrows indicate stimuli which evoke a single APD during each of three successive sinus cycles. Note that the sinus-cycle length (800 msec) is completely unaffected by these APD's, all of which fail to enter the sinus node. Each stimulated APD propagates to the His bundle but not to the ventricles. Right bundle-branch block shown in the surface ECG resulted from positioning of the His-bundle catheter, and disappeared shortly after these recordings were made.

Group I vs Group II Patients

From our studies, these 13 patients could be divided into two distinct groups: group I—seven patients in whom SA-node entrance block could not be produced; group II—six patients in whom SA-node entrance block was demonstrated.

Although the sinus-cycle length tended to be longer in group II patients there was no statistical difference between the two groups (t = 1.62; P > 0.05). Similarly, maximum depression of the sinus node following single APD's (t = 1.89; P > 0.05) and atrial refractoriness (t = 0.008; P > 0.05) was not different between the two groups. In patients where SA-node entrance block was produced, conduction pathways between atrium and sinus node may demonstrate prolonged refractoriness even when the refractoriness of the atrial myocardium in general is not prolonged. In all of the patients who demonstrated SA-node entrance block (group II), replication of their presenting complaint and characteristic S-T-segment depression could be produced by rapid atrial pacing; none of the group I patients had either pain or S-T-segment changes.

Discussion

A variety of clinical and electrocardiographic findings have been recognized to result from abnormalities of sinus-node function. They have been grouped and called the “sick sinus syndrome.” Basically, two pathologic electrophysiologic mechanisms can be postulated to account for all the sinus dysrhythmias observed in this condition: (1) abnormalities of the sinus node as an electric generator; and (2) abnormalities of conduction from the sinus node to the atrium.

None of the patients in this study had clinical evidence of sinus-node dysfunction. Yet, the methods developed allow an approach by which these two characteristics may be independently assessed during cardiac catheterization in patients with sinus dysrhythmias.
Sinus-Node Depression following a Single APD

As early as 1896, Engelmann noted in the frog heart that premature stimulation of the atrium or sinus region prolonged the duration of the cycle succeeding the stimulus. Similar studies are well summarized by Eccles and Hoff, and Pick, Langendorf, and Katz described similar findings in the clinical electrocardiograms of patients with spontaneous atrial premature depolarizations. In 1969, Bonke et al. demonstrated in the isolated rabbit right atrial preparation, that premature atrial depolarizations lengthen the succeeding sinus cycle in this same characteristic fashion. Their microelectrode recordings from the sinus node directly demonstrated that, following passive depolarization of a pacemaker cell in the sinus node, its subsequent rate of spontaneous diastolic depolarization was slowed.

We assumed these observations would apply equally well to the human sinus node and elected to evaluate sinus-node depression following single progressively premature stimulated atrial depolarizations (A2). In our patients, the curves relating A2-A3 (the postextrasystolic cycle) to A1-A2 (the length of the cycle shortened by the atrial premature depolarization) were somewhat different from those observed in the isolated rabbit right atrium. In contrast to Bonke et al., we found an initial linear depression of the sinus pacemaker when A1-A2 intervals were shortened from 100 to 70% of the immediately preceding sinus-cycle length, but as atrial depolarizations were made increasingly premature no further depression of the sinus-node pacemaker was observed (figs. 2 and 4).

Clinically, the “automaticity” of the sinus-node pacemaker has been characterized only by its rate. The present study would seem to indicate that the maximum extent of sinus pacemaker depression following premature atrial depolarizations might offer another independent parameter by which the sinus node could be evaluated. In our patients, maximum sinus-node depression was not a linear function of sinus rate.

Sinoatrial-Node Entrance Block

Rare examples of spontaneous interpolated atrial extrasystoles may be found in published clinical electrocardiograms. It was postulated that these atrial premature depolarizations fail to conduct into the region of the sinus pacemaker, which then fires and depolarizes the atrium after an interval equivalent to a normal sinus cycle. With the introduction of progressively premature APD's during sinus rhythm, we were able to demonstrate SA-node entrance block in six of our 13 patients. Utilizing strict criteria (see Results) SA-node entrance block could be clearly distinguished from atrial echoes and repetitive atrial firing due to stimulation during the atrial relative refractory period.

Atrial echoes have been demonstrated in isolated tissue preparations to result from atrial reentry via the A-V node. In patients with atrial echoes and paroxysmal SVT, strong evidence for a similar mechanism has been demonstrated. In the case of atrial echoes, the cycle length following the stimulated APD has been shown to be reciprocally related to the length of the cycle terminated by the APD. In addition, during the reentrant (echo) beat, the sequence of atrial depolarization has been shown to proceed from low interatrial septum to the high right atrium. In the present study, the “early” appearance of A3 following single APD's which resulted in SA-node entrance block could be clearly distinguished from atrial echoes (see Results).

Stimulation during the atrial relative refractory period (“vulnerable period”) has been demonstrated to result occasionally in repetitive atrial firing or atrial fibrillation. Repetitive firing subsequent to these stimuli is characterized by increased latency between stimulus and response, and frequently by prolonged intraatrial conduction. Furthermore, premature stimuli evoked during the “vulnerable period” are of such prematurity that a further decrease in the A1-A2 interval results in a failure of atrial capture. When stimulated APD's resulted in what we have called SA-node entrance block none of these phenomena was observed. In fact, the A1-A2

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intervals over which SA-node entrance block was demonstrated were generally quite prolonged and could be clearly distinguished from the atrial relative refractory period (fig. 4).

The sinus cycle following both atrial echo beats and repetitive atrial firing is generally prolonged when compared to the sinus cycle preceding them. This occurs because one, or both, of the atrial premature depolarizations enter the sinus node and depress the sinus pacemaker. The sinus cycle following an APD demonstrating SA-node entrance block is generally equal to the immediately preceding sinus cycle (fig. 3). Occasionally we noted that the subsequent sinus cycle was shorter than expected (fig. 5). The mechanism responsible for this speeding of sinus rate following SA-node entrance block is currently under investigation in our laboratory. Preliminary results suggest that the increase in sinus rate is neurogenically mediated.18

Bonke et al. demonstrated that during increasingly premature atrial depolarizations conduction in the atrium shows essentially no change, but the conduction time within the sinus node itself increases progressively.10 Strauss and Bigger have reported preliminary studies where tissues surrounding the pacemaking area of the sinus node (perinodal fibers) have shown refractoriness considerably greater than that shown for atrial myocardium in general.19 Various degrees of SA-node entrance block were demonstrated in their studies. In our patients who demonstrated block into the sinus node, the refractoriness of tissues responsible for transmitting impulses between the atrial myocardium and the sinus node is greater than that of the atrium itself.

In many animal species it has been shown that depolarization of the sinus node occurs 20–40 msec before atrial activation.20, 21 In man depolarization of the sinus node cannot be detected and therefore subtle conduction abnormalities between sinus node and atrium cannot be demonstrated. Measurement of the refractoriness of conduction pathways between sinus node and atrium, as in the present study, may provide this type of information.

Our technique measures only the refractoriness of tissues conducting impulses from the atrium into the primary pacemaking area of the sinus node. Sinus exit block and SA-node entrance block are not the same, but both utilize the same conducting tissues, and bidirectional conduction capabilities in other cardiac tissues are related.22, 23 Our study does not obviate the need for some direct measure of conduction time from sinus node to atrium.

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