British Heart Journal, 1977, **39**, 771–777

Indirect measurement of sinoatrial conduction time in patients with sinoatrial disease and in controls

BERESFORD CROOK[1], DAVID KITSON, MICHAEL McCOMISH, AND DAVID JEWITT

From the Department of Cardiology, King's College Hospital, London

Clinical recognition of sinoatrial disease currently depends on the presence of transient sinus bradycardia, sinoatrial block, or supraventricular tachyarrhythmias. The value of clinical electrophysiological assessment in these patients is not clear. Using intracardiac electrophysiological recordings and programmed stimulation we have examined 14 patients with sinoatrial disease and 11 control patients undergoing investigation for chest pain.

Intracardiac conduction times were normal in all patients. There was no significant difference of sinus node recovery times between the sinoatrial disease and control groups. Sinoatrial conduction times were measured by the indirect method and two populations were identified. However, the mean values of 128±27 ms in patients and 112±30 ms in controls were not significantly different and major overlap rendered this measurement clinically valueless.

It is concluded that no current electrophysiological measurement has diagnostic value in patients with sinoatrial disease.

Patients with sinoatrial disease have various arrhythmias which are, most commonly, sinoatrial block or sinus arrest, sinus bradycardia, and supraventricular tachycardias (Greenwood and Finkelstein, 1964; Bouvrain *et al.*, 1967). The diagnosis of this condition has depended on recognition of the characteristic arrhythmias which are frequently transient and may not be apparent on routine electrocardiography (Crook *et al.*, 1973). The need has remained for a reproducible measure of sinus node function or of sinoatrial conduction which might identify patients with this condition.

Among attempts to evaluate sinus node function, overdrive suppression has proved to be of limited value since a majority of patients with sinoatrial disease may show results within the normal range (Gupta *et al.*, 1974). A technique for measuring sinus node depression after single and progressively more premature atrial depolarisations was described by Goldreyer and Damato in 1971. The same technique was used by Strauss and colleagues in 1973 as an indirect measure of sinoatrial conduction time rather than as an index of sinus node depression. Sinoatrial conduction time was measured by the difference between the basic sinus cycle length and the atrial recovery time, when paced atrial premature depolarisations in the earlier part of atrial diastole resulted in a constant recovery interval caused by reset of the sinus node.

In practice, however, conflicting results have been obtained concerning the value of this test for the identification of patients with sinoatrial disease (Hirschfeld *et al.*, 1975; Masini *et al.*, 1975). It has also been suggested that indirect sinoatrial conduction time must be corrected for the basic sinus cycle length (Reiffel *et al.*, 1974). However, the relation of sinoatrial conduction time to the basic sinus cycle length has not been fully examined.

We have attempted to measure sinoatrial conduction time by the indirect method in a group of patients with the characteristic arrhythmias of sinoatrial disease and in a comparable control group with no known arrhythmias. We have also investigated the relation between sinoatrial conduction time and basic sinus cycle length in order to determine whether correction for basic cycle length would be appropriate.

Patients and methods

Sinoatrial conduction time and sinus node recovery time were measured in each of 25 patients, 14 of

[1]Present address: Thoraxcentrum, Academisch Ziekenhuis, Dijkziet, Dr Molewaterplein 40, Rotterdam, Holland.

Table 1 *Electrocardiographic and electrophysiological details of the 14 patients with sinoatrial disease*

Age (y)	Sex	Electrocardiogram			Distribution of normalised return against test cycles	Sinus node recovery time (ms)	Sinoatrial conduction time (ms)
		Sinus bradycardia	Sinoatrial block	Supraventricular tachycardias			
72	M	40/min	+	—	Chaotic	720	—
67	M	—	+	—	Linear	1080	—
45	F	48	—	+	Normal	980	123
27	F	54	+	+	Linear	710	—
40	F	38	+	+	Normal	920	113
73	M	50	+	—	Chaotic	1010	—
25	F	48	+	+	Chaotic	1450	—
51	F	50	+	—	Normal	740	122
60	F	—	+	—	Normal	870	134
71	M	44	—	+	Normal	1150	101
41	M	48	+	+	Normal	1080	135
38	M	50	+	+	Chaotic	1540	—
35	F	—	+	+	Normal	985	172
46	F	—	+	+	Normal	850	125
Means and standard deviation						1006 + 249	128 + 27

whom suffered from typical sinoatrial disease (Table 1). The patients with sinoatrial disease were all symptomatic and had at least 2 of the 3 characteristic arrhythmias, sinus bradycardia, sinoatrial block, or supraventricular tachyarrhythmias. The other 11 patients (Table 2) were 'controls' suffering from chest pain but no known arrhythmias, and these were investigated with electrophysiological studies at the time of coronary arteriography. All patients had given informed written consent and none had received previous sedation or antiarrhythmic drugs within 2 weeks of the investigation.

Quadripolar and bipolar electrodes were inserted percutaneously into the right femoral vein. The quadripolar electrode was positioned at the upper right atrium using the distal pair of electrodes for programmed stimulation and the proximal pair of electrodes for sensing and recording spontaneous right atrial activity. Simultaneous records of the His bundle were obtained from the bipolar electrode together with surface electrocardiographic leads I, III, and V1. The atrioventricular (AH) and His-Purkinje (HV) conduction intervals were measured from these records.

Table 2 *Clinical and electrophysiological details of 11 control patients with chest pain*

Age (y)	Sex	Coronary obstructions	Distribution of normalised return against test cycles	Sinus node recovery time (ms)	Sinoatrial conduction time (ms)
62	M	+	Normal	880	85
32	M	+	Normal	640	81
44	M	—	Normal	1140	97
35	M	+	Normal	1110	154
42	M	+	Chaotic	820	—
44	F	—	Normal	920	100
56	M	+	Normal	740	116
59	M	+	Normal	830	138
47	M	+	Normal	830	126
57	M	+	Chaotic	1125	—
47	M	+	Normal	1100	121
Means and standard deviations				921 ±172	112 ±30

Sinus node recovery time was measured by pacing the atrium at a rate just below that producing Wenckebach periodicity, with pacing rates ranging from 60 to 170 beats a minute. After pacing for 30 seconds and switching off, the interval from the last paced atrial complex to the atrial recovery complex was measured.

Sinoatrial conduction time was measured by the method described by Strauss and colleagues (1973). The upper atrial signals were sensed and paced impulses introduced at predetermined intervals from the spontaneous beat with a programmable stimulator (Devices Ltd.). A pulse width of 2 ms was used and a voltage of 2 or 3 times the diastolic threshold. A single premature paced depolarisation was programmed to follow each eighth sensed sinus beat with a predetermined delay. This delay was increased for each paced beat with a 5 or 10 ms increment so that paced impulses were programmed to occur during the whole non-refractory part of the atrial cycle.

The following intervals were measured from the permanent records made with an 8-channel ink jet recorder (Mingograph).

Previous sinus cycle length (PC) was the interval between the last two spontaneous atrial beats before the paced impulse was introduced.

Test cycle length (TC) was the interval between the last spontaneous sinus beat and the paced impulse.

Return cycle length (RC) was the interval between the paced premature impulse and the subsequent returning spontaneous atrial beat.

The relation between the lengths of the test and return cycles was shown graphically for each patient. For the construction of these distributions the results were expressed in two ways. The return cycles were either first normalised as fractions of their corresponding basic (previous) sinus cycle lengths (i.e. $\frac{RC}{PC}$), or were plotted directly (without normalisation) against the test cycle lengths. The curve most commonly obtained (Fig. 1) shows a plateau zone where the earlier paced impulses have entered and reset the sinus node and a tail zone where the later paced impulses have fallen after the spontaneous sinus node depolarisation. In the tail zone, sinus node reset has not occurred so that the return cycles now become shorter and exactly compensatory. Calculation of sinoatrial conduction time was made from those values falling in the plateau zone of the curve. The atrial return cycles in this zone represent the time taken for the paced impulse to enter the sinus node from the atrium, the duration of the return sinus node cycle, and the time taken for the return sinus node impulse to enter and trigger the atrium. The sinus node return cycle after the paced impulse is assumed to be similar to the basic sinus cycle length (previous sinus cycle length). Hence by subtracting this value (PC) from the return cycle (RC), conduction time into and out of the sinus node can be calculated. This value is then halved to give an approximation to the sinoatrial conduction time (SACT). Expressed as a formula, $SACT = \frac{RC-PC}{2}$. A mean sinoatrial conduction time is calculated from all the return and previous cycles in the plateau zone of the graph.

A computer graph plot and sinoatrial conduction time calculations were made in this way for each patient studied.

The discriminative value of the sinoatrial conduction time results for the sinoatrial disease and control patients was then assessed (Student's t test).

To investigate the relation of sinoatrial conduction time to basic cycle length, the different sinoatrial conduction time values corresponding to all the points in the plateau zone were plotted against corresponding previous sinus cycle lengths so that a curve expressing the sinoatrial conduction time to previous sinus length relation was initially sought for each patient individually. In addition, a single composite curve was constructed for all the values from 17 of the patients in whom a clear plateau zone was obtained.

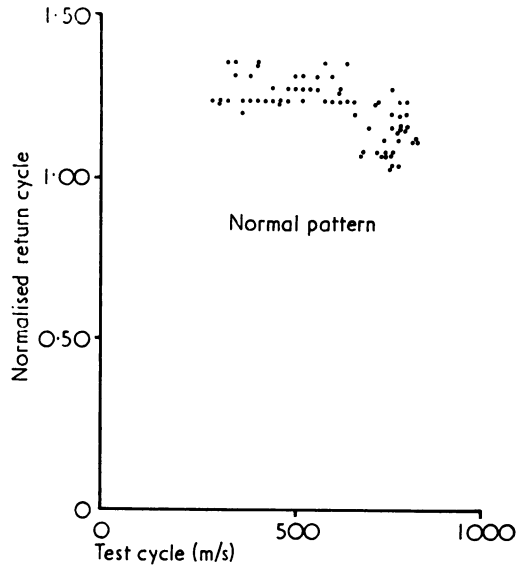

Fig. 1 *Distribution of normalised return* $\frac{RC}{PC}$ *against test cycle lengths. There is a plateau zone to the left and a tail zone to the right.*

Results

The atrioventricular (AH) and His-Purkinje (HV) conduction intervals were within normal limits in all

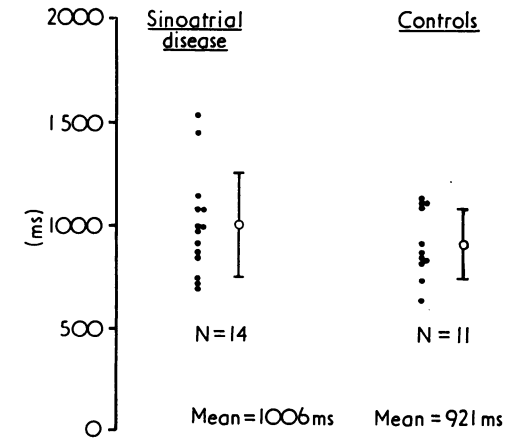

Fig. 2 *Sinus node recovery times in the patients with sinoatrial disease and the controls. The vertical bars represent the means and standard deviations.*

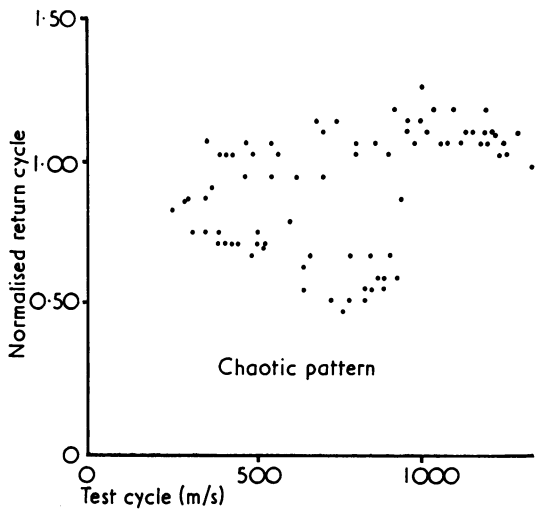

Fig. 3 *Distribution of normalised return against test cycle lengths to show a typical 'chaotic' pattern.*

from the patients included in this study.

Sinus node recovery time showed no significant difference between the sinoatrial disease and control patients though a small difference between the mean values for each group was observed (Fig. 2 and Tables 1 and 2).

Sinoatrial conduction time could be measured satisfactorily in 17 of the 25 patients where clear

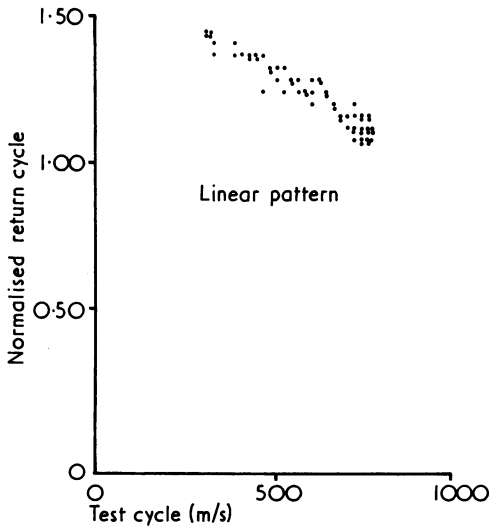

Fig. 4 *Distribution of normalised return against test cycle lengths to show a linear pattern.*

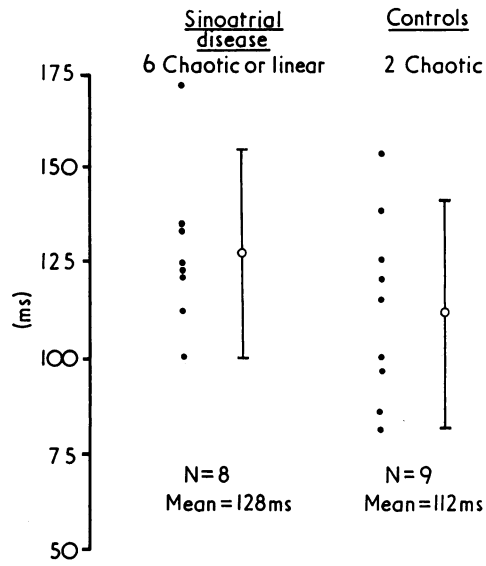

Fig. 5 *Sinoatrial conduction times in the patients with sinoatrial disease and the controls. The vertical bars represent the means and standard deviations.*

plateau zones could be identified (Fig. 1) in the plots of the normalised return and test cycle lengths. In the remaining 8 patients a distinct plateau zone was not seen either because the plotted values showed a chaotic pattern (Fig. 3, 6 patients) or a linear prolongation of return cycles in response to decreasing test cycles (Fig. 4, 2 patients). Similar graphs of test against return cycles without normalisation were obtained and the same pattern of chaotic, linear, or plateau curves was found. Sinoatrial conduction time was calculated from the values in the plateau zone from both methods of plotting the original graphs, and similar values were obtained despite the differences in normalisation. The sinoatrial conduction time results for each patient are shown in Tables 1 and 2 and Fig. 5.

The sinoatrial conduction time mean values for the patients with sinoatrial disease did not differ significantly from the mean values obtained in the control patients.

The overall mean of the mean sinoatrial conduction time results for the 8 patients with sinoatrial disease was 128 ± 27 ms and for the 9 patients with chest pain was 112 ± 30 ms.

For the 17 patients with a clear plateau zone, no relation was found between sinoatrial conduction time and previous cycle length values when these were plotted for each patient individually. When all the values for these patients were put together for a composite plot a poor correlation was observed:

Sinoatrial conduction time $= -(0{\cdot}083 \pm 0{\cdot}1)$ previous sinus cycle length $+ 189 \pm 8{\cdot}6$ with correlation coefficient of $-0{\cdot}33$.

Discussion

Sinus node recovery time may be increased to some extent by an increased rate of pacing (Narula *et al.*, 1972). We chose to pace at a high rate before switch-off and accepted that pacing for 30 seconds might be adequate and avoid discomfort (Mandel *et al.*, 1971). Our results were similar to those of other workers in failing to discriminate between patients with sinoatrial disease and controls (Gupta *et al.*, 1974; Lee *et al.*, 1975).

The indirect measurement of sinoatrial conduction time, described by Strauss *et al.* (1973), necessitates construction of a graph to show the relation between test and return atrial cycles. Calculation of sinoatrial conduction time is made from values falling in the plateau zone of the curve which correspond to sinus node reset. For this graph, test and return cycle lengths have been plotted, either with both normalised as fractions of the basic sinus cycle length (Strauss *et al.*, 1973) or plotted directly against each other without normalisation (Reiffel *et al.*, 1974). Both basic sinus cycle length and return cycle length will be influenced in a similar way by autonomic and other factors, and if basic sinus cycle lengths (previous cycle length) are plotted against corresponding return cycle lengths the regression is approximately linear (Reiffel *et al.*, 1974). Hence in order to obtain a graphic demonstration of the relation of return to test cycle length and allow for the variation of return cycle length resulting from other physiological variables, we chose initially to normalise only the return cycles which were then plotted against direct values for test cycle lengths. However, plots were also made without normalisation.

The appearances of the graphs were similar in each of the 17 patients with or without normalisation of the return cycles, and similar values for sinoatrial conduction time resulted. However, less scatter of points occurred with normalisation of the return cycles.

In 8 of our 25 patients the plots of return against test cycles showed a linear or chaotic pattern and were unsuitable for the method of analysis described by Strauss and colleagues (1973). This problem was not observed by Goldreyer and Damato (1971) or Reiffel *et al.* (1974) though in some cases a linear prolongation of return cycle rather than a plateau zone was noted by Hirschfeld *et al.* (1975). The chaotic pattern was more common among our patients with sinoatrial disease than in the controls. Two separate populations of basic sinus cycle lengths have been observed in some patients with sinoatrial disease (Crook and Cashman, 1976) with frequent rate switching suggesting two primary pacemaker sites in the sinus node. This effect may be the same as that causing the variation of sinus and return cycle lengths in the patients with the chaotic response pattern. A linear pattern could be explained if conduction from sinus node to atrium were so prolonged that the sinus node was never reset by the premature atrial depolarisations. Increasing prolongation of the atrial recovery cycle in the rabbit with progressively more premature atrial depolarisations has been attributed to a progressive increase of conduction time of the stimulus into the sinus node and a consequent shift of pacemaker within the sinus node (Bonke *et al.*, 1971).

The range of sinoatrial conduction time values in the 17 patients in our study was similar to that observed in other studies (Engel *et al.*, 1973; Reiffel *et al.*, 1974; Hirschfeld *et al.*, 1975; Masini *et al.*, 1975). Our conclusion that sinoatrial conduction time does not afford any distinction between patients with sinoatrial disease and those without, is in agreement with that of Hirschfeld *et al.* (1975) and differs from that of Reiffel *et al.* (1974), Masini *et al.* (1975) and Breithardt *et al.* (1976). In a more recent paper from Strauss *et al.* (1976) the indirectly measured sinoatrial conduction time was prolonged in 6 of 16 patients with sinoatrial disease.

The dependency of sinoatrial conduction time on basic sinus cycle length was first suggested by Reiffel *et al.* (1974). However, as pointed out by these authors, their method of showing the relation by calculating mean sinoatrial conduction times for groups of longer, shorter, and intermediate sinus cycles, introduces a statistical effect which will exaggerate any apparent inverse relation of sinoatrial conduction time to previous sinus cycle length. We chose to indicate the relation of sinoatrial conduction time to basic sinus cycle length by plotting all the sinoatrial conduction time values $\left(\frac{RC-PC}{2}\right)$ against previous sinus cycle length values in the plateau zone from each patient individually. The wide scatter of the calculated values of sinoatrial conduction times compared with the limited range of previous sinus cycle lengths in most patients meant that acceptable regression lines could not be fitted.

When, however, a composite SACT/PC plot was made of all the values from each of the 17 patients the inverse correlation between sinoatrial conduction time and previous sinus cycle length was poor

(slope gradient RC = 0·83 PC). Correction of individual sinoatrial conduction time values for basic sinus cycle length appeared, therefore, inappropriate as it could only be based on this poor regression obtained from the composite results.

The failure to obtain a satisfactory plateau zone in a third of our patients, the uncertainty of correction for basic sinus cycle length, and the wide range of the results in our control group (Table 2) were major objections to the application of this technique to the identification of patients with sinoatrial disease.

In addition to the methodological limitations of this technique, it remains questionable whether sinoatrial conduction time measured in this way is representative of the true conduction time between the sinus node and the adjacent atrium. With direct recording from the sinus node and the surrounding atrium, conduction times of 10 to 60 ms have been recorded in the rabbit (Paes de Carvalho *et al.*, 1959; Klein *et al.*, 1973; Yamaguchi and Mandel, 1975). The properties of the sinoatrial fibres are in keeping with a conduction delay at this site (Strauss and Bigger, 1972). However, direct records have not been made in man. Any direct measurement of sinoatrial conduction time would depend on the exact sites of the recording electrodes and such measurements may not relate to the physiological value obtained by the indirect method of measuring sinoatrial conduction time. An essential premise for the calculation of sinoatrial conduction time by the indirect method is that the return atrial cycle length is comparable to the previous sinus cycle length, plus conduction time from the atrium into the sinus node and from the sinus node back to the atrium. However, microelectrode studies in rabbits have shown that the returning sinus node cycle after a premature atrial depolarisation may be prolonged or shortened compared with the basic sinus node cycle length and that variation of retrograde and anterograde conduction between sinus node and atrium occurs in different rabbits (Klein *et al.*, 1973). The duration of the return sinus node cycle after a premature atrial depolarisation may be longer or shorter than the normal spontaneous sinus cycle length and may vary with the prematurity of the test stimulus (Bonke *et al.*, 1969, 1971). Such considerations from animal work throw doubt on the validity of the calculation of sinoatrial conduction time by the indirect method and may also explain some of the practical difficulties with the use of this technique that we have observed in man. Indirect measurements may be an overestimate if, as a result of the premature atrial depolarisations, the sinus node return cycle or conduction interval between the sinus node and the atrium has been prolonged.

At present, sinus node recovery time and the indirect measurement of sinoatrial conduction time have been the most widely used electrophysiological techniques for the assessment of sinoatrial disease. This present study has failed to confirm that these measurements are of any clinical value.

References

Bonke, F. I. M., Bouman, L. N., and Schopman, F. J. G. (1971). Effect of an early atrial premature beat on activity of the sinoatrial node and atrial rhythm in the rabbit. *Circulation Research,* **29,** 704–715.

Bonke, F. I. M., Bouman, L. N., and van Rijn, H. E. (1969). Change of cardiac rhythm in the rabbit after an atrial premature beat. *Circulation Research,* **24,** 533–544.

Bouvrain, Y., Slama, R., and Temkine, J. (1967). Le bloc sinoauriculaire et les "maladies du sinus". *Archives des Maladies du Coeur et des Vaisseaux,* **60,** 753–773.

Breithardt, G., Siepel, L., Both, A., and Loogen, F. (1976). Calculated sino-atrial conduction time (SACT) in patients with normal and abnormal sinus node function. Abstracts of Free Communications, VII European Congress of Cardiology, Amsterdam.

Crook, B. R. M., and Cashman, P. M. M. (1976). The R-R interval histogram. *Postgraduate Medical Journal,* **52,** Suppl. 7, 46–53.

Crook, B. R. M., Cashman, P. M. M., Stott, F. D., and Raftery, E. B. (1973). Tape monitoring of the electrocardiogram in ambulant patients with sino-atrial disease. *British Heart Journal,* **35,** 1009–1013.

Engel, T. R., Bond, R. C., and Schaal, S. F. (1973). First degree sinoatrial heart block. *Circulation* **47–48,** Suppl. IV, 161.

Goldreyer, B. N., and Damato, A. N. (1971). Sinoatrial-node entrance block. *Circulation,* **44,** 789–802.

Greenwood, R. J., and Finkelstein, D. (1964). *Sinoatrial Heart Block.* (American Lecture Series). Thomas, Springfield, Illinois.

Gupta, P. K., Lichstein, E., Chadda, K. D., and Badui, E. (1974). Appraisal of sinus nodal recovery time in patients with sick sinus syndrome. *American Journal of Cardiology,* **34,** 265–270.

Hirschfeld, D. S., Peters, R., Kunkel, F., and Scheinman, M. M. (1975). Sinoatrial conduction time (SACT) and abnormal perinodal refractoriness in patients with sinus node disease (SND). *Circulation,* **51–52,** Suppl. 11, 112.

Klein, H. O., Singer, D. H., and Hoffman, B. F. (1973). Effects of atrial premature systoles on sinus rhythm in the rabbit. *Circulation Research,* **32,** 480–491.

Lee, C. H., Cohen, L. S., and Cannom, D. S. (1975). Limitations of sinoatrial recovery time in assessing sinus node dysfunction. *Circulation,* **52,** Suppl. II, 12.

Mandel, W., Hayakawa H, Danzig, R., and Marcus, H. S. (1971). Evaluation of sinoatrial node function in man by overdrive suppression. *Circulation,* **44,** 59–66.

Masini, G., Dianda, R., and Grazina, A. (1975). Analysis of sino-atrial conduction in man using premature atrial stimulation. *Cardiovascular Research,* **9,** 498–508.

Narula, O. S., Samet, P., and Javier, R. P. (1972). Significance of the sinus-node recovery time. *Circulation,* **45,** 140–158.

Paes de Carvalho, A., de Mello, W. C., and Hoffman, B. F. (1959). Electrophysiological evidence for specialised fiber types in rabbit atrium. *American Journal of Physiology,* **196,** 483–488.

Reiffel, J. A., Bigger, J. T., and Konstam, M. A. (1974). The relationship between sinoatrial conduction time and sinus cycle length during spontaneous sinus arrhythmia in adults. *Circulation,* **50,** 924–934.

Strauss, H. C., and Bigger, J. T. (1972). Electrophysiological properties of the rabbit sinoatrial perinodal fibres. *Circulation Research,* **31,** 490–506.

Strauss, H. C., Bigger, J. T., Saroff, A. L., and Giardina, E. G. V. (1976). Electrophysiologic evaluation of sinus node function in patients with sinus node dysfunction. *Circulation,* **53,** 763–776.

Strauss, H. C., Saroff, A. L., Bigger, J. T., and Giardina, E. G. V. (1973). Premature atrial stimulation as a key to the understanding of sinoatrial conduction in man. *Circulation,* **47,** 86–93.

Yamaguchi, I., and Mandel, W. (1975). Effects of antiarrhythmic drugs on sinus node to atrial conduction time in isolated atrial tissue. *Circulation,* **51–52,** Suppl. II, 259.

Requests for reprints to Dr. David Jewitt, Cardiac Department, King's College Hospital, Denmark Hill, London SE5 9RS.