Detection of Patients With Sick Sinus Syndrome by Use of Low Amplitude Potentials Early in Filtered P Wave

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Objectives. This study sought to determine whether patients with sick sinus syndrome could be detected by analyzing the initial portion of the signal-averaged P wave corresponding to the electrical activity of the perinodal atrial myocardial cells.

Background. In sick sinus syndrome, pathophysiologic abnormalities have been shown not only in the sinus node, but also in the atrial muscle, especially the perinodal portion.

Methods. The study included 41 patients with sick sinus syndrome and 140 age-matched control subjects. Eighteen of 41 patients with sick sinus syndrome had paroxysmal atrial fibrillation. Signal-averaged P wave electrocardiograms (ECGs) were recorded through a bandpass filter of 40 to 300 Hz with a P wave–triggering technique. Signals of the orthogonal bipolar leads were combined into a spatial magnitude. The root mean square voltage for the initial 30 ms (EP30) and the duration of initial low amplitude signals <4 μV (ED4) of the filtered P wave were measured. The root mean square voltage for the last 20 ms (LP20) and the duration of the filtered P wave were also measured.

Results. EP30 was significantly lower and ED4 was significantly

longer in patients with sick sinus syndrome than in the control subjects (EP30 [mean ± SD]: 2.18 ± 0.90 vs. 3.94 ± 1.45 μV, p < 0.0001; ED4: 31.7 ± 14.5 vs. 14.0 ± 7.4 ms, p < 0.0001), although there was no significant difference in LP20 between patients with sick sinus syndrome without paroxysmal atrial fibrillation and the control subjects. The duration of the filtered P wave was significantly but minimally longer in patients with sick sinus syndrome than in the control subjects (139.8 ± 18.8 vs. 127.3 ± 13.6 ms, p < 0.0001). The criteria of EP30 <3.0 μV and ED4 >22 ms as atrial early potential gave a sensitivity of 76%, a specificity of 91%, a positive predictive value of 74% and a negative predictive value of 93% for identification of patients with sick sinus syndrome.

Conclusions. These results suggest that the long, low amplitude signals early in the filtered P wave on the signal-averaged ECGs are characteristic of sick sinus syndrome. Thus, the atrial early potential could be a useful marker to identify patients with sick sinus syndrome.

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In the pathologic studies of sick sinus syndrome, abnormalities such as degeneration and fibrosis have been shown not only in the sinus node, but also in the atrial muscle, especially the perinodal portion (1–4). It was also reported that fractionated atrial endocardial electrograms were recorded in patients with sick sinus syndrome during sinus rhythm using intraatrial catheter mapping (5), and that the fragmented atrial activity zone in the atrial extrastimulation method became widened (6,7). These findings show that some pathologic and electrophysiologic abnormalities in the atrial muscle, other than the sinus node, might be involved in sick sinus syndrome (8).

We recently reported (9,10) that electrophysiologic abnormalities of the atrial muscle in patients with paroxysmal atrial

fibrillation could be detected noninvasively as atrial late potentials by signal-averaged P wave electrocardiograms (ECGs). However, it remains unclear how such pathophysiologic abnormalities of the atrial muscle in sick sinus syndrome would be reflected on the atrial signal-averaged ECGs. Therefore, the purpose of this study was to determine whether patients with sick sinus syndrome could be detected by clarifying the characteristics of the atrial signal-averaged ECGs.

Methods

Patients. The study group included 41 consecutive patients with and 140 age-matched control subjects without sick sinus syndrome. The clinical characteristics of the study group are shown in Table 1. There were no significant differences in age and gender between the two groups. Heart rate was significantly slower in patients with sick sinus syndrome than in the control subjects. Sick sinus syndrome was diagnosed using the recordings of the conventional ECG, ambulatory 24-h Holter monitoring or bedside monitoring, according to the classification of Rubenstein et al. (11). Thirty-seven patients with sick sinus syndrome had documented episodes of sinus arrest or

Table 1. Clinical Characteristics of Study Patients

	SSS Group (n = 41)	Control Group (n = 140)
Male/female	19/22	79/61
Age (yr)	63 ± 11	62 ± 12
Range	24-81	22-82
Heart rate (beats/min)	59 ± 13	67 ± 11*
Range	30-86	45-93
Coexistent arrhythmias		
PAF	18	36
AVNRT	—	27
VT	—	14
Organic heart disease		
CAD	9	10
HHD	4	1
MVR	2	4
ASD	2	3
HCM	1	4
Myocarditis	1	0

*$p < 0.01$ versus sick sinus syndrome (SSS). ASD = atrial septal defect; AVNRT = atrioventricular node reentrant tachycardia; CAD = coronary artery disease; HCM = hypertrophic cardiomyopathy; HHD = hypertensive heart disease; MVR = mitral valve regurgitation; PAF = paroxysmal atrial fibrillation; VT = ventricular tachycardia.

sinoatrial block (with a pause >2 s) with atrioventricular (AV) junctional or ventricular escape beats, and the other four patients had persistent and unexplained sinus bradycardia at a heart rate of <40 beats/min on the rest ECG. The sinus pause documented by Holter monitoring was 4.0 ± 1.6 s (range 2.3 to 10.2). Eighteen of 41 patients with sick sinus syndrome had paroxysmal atrial fibrillation documented on the ECG. Thirty-five of 41 patients with sick sinus syndrome experienced symptoms related to the arrhythmias. Stokes-Adams attacks (syncope) occurred in six patients. Seven patients experienced presyncope, 12 light-headedness, 6 palpitation and the other 4 easy fatigability. Seventeen of 41 patients with sick sinus syndrome required a permanent pacemaker.

In contrast, the control subjects included 36 patients with and 104 patients without a history of paroxysmal atrial fibrillation documented on the ECG. In these control subjects, neither sinus arrest nor sinoatrial block was recorded during the conventional ECG, bedside monitoring or 24-h Holter monitoring. Sixty-nine of 104 patients without paroxysmal atrial fibrillation had no evidence of cardiac disease. Each patient gave written informed consent to participate in the study, which was approved by the Osaka Prefectural Hospital Review Committee.

Signal-averaged ECG recording. None of the patients in this study had received antiarrhythmic drugs for at least 1 week before undergoing signal-averaged ECG. Two patients with and five patients without sick sinus syndrome took digitalis at the recording of the signal-averaged ECG. In an electrically shielded room, signal-averaged ECGs were recorded from a modified X, Y and Z lead system by use of the VCM-3000 (Fukuda Denshi, Ltd.), which was recently developed for P wave-triggered signal averaging. The X lead was between the

right and left shoulders (standard lead I). The aVF lead was used as the Y lead. The precordial V_1 lead was used as the Z lead. The signal from each lead was amplified up to 5 μV/cm, passed through a unidirectional Butterworth filter of 40 Hz (slope 18 dB/octave) to 300 Hz (slope 12 dB/octave) and then converted from analog to digital data to a 12-bit accuracy at a sampling rate of 1 kHz.

Signal averaging. All of the digital data were stored on a floppy disk. Ventricular ectopic beats and gross noise were eliminated by a conventional QRS template-matching program before proceeding to the P wave recognition program, according to the algorithm for the P wave-triggering system (9). A specially filtered (10 to 30 Hz) P wave derived from the selected dominant sinus P wave of the standard lead II served as a reference signal for all processing. After passing through a P wave recognition program to eliminate ectopic atrial beats, signals >200 beats were averaged on a trigger point within a specially filtered P wave. Noise levels were measured every 1 ms in the last 20 ms of the TP segment on the filtered lead of a vector magnitude, the square root of $X^2 + Y^2 + Z^2$. Signal averaging was continued until the noise amplitude at all points in this interval was reduced to <1 μV (peak noise level). The root mean square noise value was 0.44 ± 0.18 μV.

Data analysis. The signals for the X, Y and Z leads were combined into the vector magnitude. The filtered P wave in the vector magnitude was defined as signals within the interval showing a persistent level >1 μV. The onset and offset of filtered P wave were manually determined (9) without knowledge of the patients' clinical data. (The interobserver's variation to measure the duration of filtered P wave was 1.4 ± 2.7% [n = 34].) We measured the root mean square voltages for the initial 10, 20 and 30 ms of filtered P wave (EP10, EP20, EP30) and the shortest durations from the onset up to 3, 4 and 5 μV of filtered P wave (ED3, ED4, ED5). Furthermore, the root mean square voltages for the terminal 10, 20 and 30 ms of filtered P wave (LP10, LP20, LP30) and the duration and root mean square voltage of the total filtered P wave were also measured. In this study, the reproducibility of the P wave-triggered signal-averaged ECGs was examined on the basis of two recordings made <1 week apart in 46 randomly selected patients (15 patients with sick sinus syndrome and 31 control subjects). The percent variation of intraindividual recordings to measure EP30, ED4 and the duration of filtered P wave was 3.7 ± 4.5%, 6.6 ± 6.4% and 2.2 ± 2.9%, respectively.

Measurement of sinoatrial conduction time. For comparison with the initial portion of filtered P wave, sinoatrial conduction time was measured by the method of Narula et al. (12) during the electrophysiologic study, which was performed within a day of recording the signal-averaged ECGs in 32 patients with sick sinus syndrome and 41 control subjects (AV node reentrant tachycardia in 27 patients and ventricular tachycardia in 14 patients). Two bipolar catheters (6F USCI, with two ring electrodes 10 mm apart) were inserted percutaneously into the right femoral vein and were advanced into the high right atrium under fluoroscopic guidance. High right atrial electrograms were recorded through a bandpass filter of
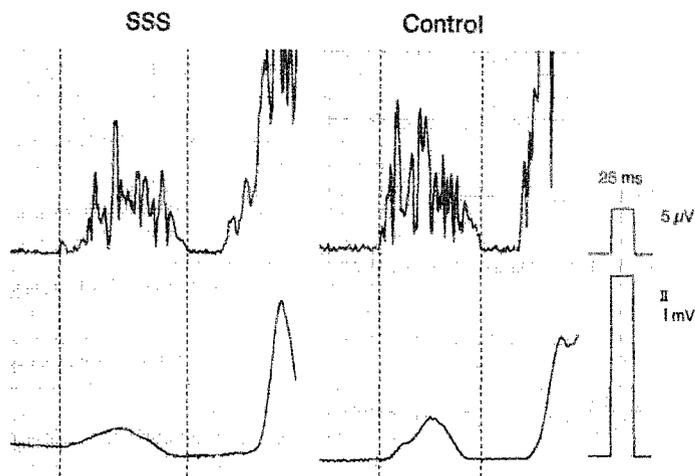
Figure 1. Representative signal-averaged P wave electrocardiograms in patients with (left) and without (right) sick sinus syndrome (SSS). Dashed lines indicate the beginning or end of filtered P wave. Note that the initial portion of filtered P wave is lower in amplitude and longer in duration in a patient with sick sinus syndrome than in a control subject.

30 to 500 Hz. Atrial stimulation was performed by use of a programmable stimulator (Nihon Koden, Ltd.) at twice the diastolic threshold and 2-ms duration. The high right atrium was paced for eight beats at a rate slightly faster (10 beats/min) than the control sinus rhythm. Pacing was abruptly stopped to allow spontaneous sinus rhythm to return, and recordings were continued for eight subsequent spontaneous cycles. This procedure was repeated three or four times. Sinoatrial conduction time was obtained as half of the interval, which was calculated by subtracting the mean sinus cycle from the interval between the last paced atrial electrogram and the atrial electrogram of the first sinus beat.

Statistical analysis. Data are presented as mean value ± SD. Statistical analysis was performed using a nonparametric test. The Mann-Whitney U test was used to compare the patients with sick sinus syndrome with the control subjects. The Kruskal-Wallis test was used for comparison among the following four groups: patients with sick sinus syndrome with and without paroxysmal atrial fibrillation and control subjects with and without paroxysmal atrial fibrillation. The Pearson correlation formula was used to compare sinoatrial conduction time with the initial portion of filtered P wave. The statistical significance was detected at $p < 0.01$.

Results

Figure 1 depicts two original tracings of the signal-averaged ECGs in representative patients with and without sick sinus syndrome. Of note, the initial portion of filtered P wave is lower in amplitude and longer in duration in patients with sick sinus syndrome than in control subjects, although there seems to be no difference in the terminal portion between the two groups. Table 2 summarizes data on the variables of filtered P wave in signal-averaged ECGs.

Initial portion of filtered P wave in patients with and without sick sinus syndrome. Figure 2 shows a comparison of EP10, EP20 and EP30 between the patients with sick sinus

syndrome and the control subjects. EP10, EP20 and EP30 were significantly lower in the patients with sick sinus syndrome than in the control subjects. Figure 3 shows the comparison of ED3, ED4 and ED5 between the two groups. ED3, ED4 and ED5 were also significantly longer in the patients with sick sinus syndrome than in the control subjects. The differences between the two groups remained significant after accounting for the presence or absence of a history of paroxysmal atrial fibrillation (Table 2). EP30 was significantly lower and ED3 and ED4 longer in patients with sick sinus syndrome with than in patients without Stokes-Adams attack (EP30: 1.30 ± 0.58 vs. 2.26 ± 0.75 µV, p < 0.01; ED3: 36.3 ± 21.4 vs. 20.9 ± 11.0 ms, p < 0.01; ED4: 48.3 ± 20.7 vs. 29.0 ± 10.5 ms, p < 0.005). ED3 was also significantly longer in patients with sick sinus syndrome with than in those who did not require a permanent pacemaker, whereas ED4 tended to be longer and EP30 lower (ED3: 30.6 ± 12.3 vs. 19.1 ± 11.3 ms, p < 0.005; ED4: 38.8 ± 16.8 vs. 29.3 ± 11.8 ms, p = 0.03; EP30: 1.70 ± 0.58 vs. 2.31 ± 0.70 µV, p = 0.02).

Terminal portion of filtered P wave in patients with and without sick sinus syndrome. LP10 and LP20 were significantly lower in the patients with sick sinus syndrome than in the control subjects (Table 2). Although LP10 and LP20 were also significantly lower in the patients with both sick sinus syndrome and paroxysmal atrial fibrillation than in the control subjects without paroxysmal atrial fibrillation, there were no significant differences in these variables between patients with sick sinus syndrome without paroxysmal atrial fibrillation and the control subjects. LP20 was significantly lower in patients with sick sinus syndrome with than in those without paroxysmal atrial fibrillation. Irrespective of the presence of sick sinus syndrome, LP20 was useful for identifying patients with paroxysmal atrial fibrillation, as previously reported (9,10).

Duration and root mean square voltage of total filtered P wave in patients with and without sick sinus syndrome (Table 2). The patients with sick sinus syndrome had a significantly longer duration of filtered P wave than did the

Table 2. Variables in Atrial Signal-Averaged Electrocardiograms in Patients With Sick Sinus Syndrome and in Control Subjects

	SSS Group			Control Group		
	Total (n = 41)	With PAF (n = 18)	Without PAF (n = 23)	Total (n = 140)	With PAF (n = 36)	Without PAF (n = 104)
EP10 (μV)	1.25 ± 0.58*	1.17 ± 0.53*	1.30 ± 0.48*	2.08 ± 0.91	1.98 ± 0.92	2.08 ± 0.91
EP20 (μV)	1.72 ± 0.91*	1.63 ± 1.08*	1.80 ± 0.71*	3.14 ± 1.44	3.08 ± 1.77	3.15 ± 1.31
EP30 (μV)	2.18 ± 0.90*	2.15 ± 0.96*	2.20 ± 0.88*	3.94 ± 1.45	3.85 ± 1.80	3.96 ± 1.31
ED3 (ms)	23.7 ± 12.1*	25.4 ± 11.8*	22.3 ± 12.4*	10.9 ± 6.5	12.1 ± 7.7	10.5 ± 5.8
ED4 (ms)	31.7 ± 16.5*	30.6 ± 14.0*	32.6 ± 15.0*	14.0 ± 7.4	15.1 ± 8.5	13.5 ± 7.1
ED5 (ms)	37.5 ± 17.6*	34.2 ± 16.0*	40.1 ± 18.9*	19.3 ± 10.4	20.2 ± 10.2	19.0 ± 10.4
LP10 (μV)	1.83 ± 0.72†	1.60 ± 0.45‡	2.03 ± 0.86	2.15 ± 1.0	1.95 ± 1.34	2.28 ± 0.84
LP20 (μV)	2.46 ± 0.96†	2.02 ± 0.56‡§	2.79 ± 1.03	3.07 ± 1.35	2.25 ± 0.66‡	3.34 ± 1.63
LP30 (μV)	3.69 ± 1.66	3.48 ± 1.77	3.87 ± 1.58	4.22 ± 1.73	4.02 ± 1.95	4.29 ± 1.64
Ad (ms)	139.8 ± 18.8*	149.1 ± 20.1‖§	132.5 ± 14.2¶	127.3 ± 13.6	138.1 ± 13.7‡	122.4 ± 16.3
P-RMS (μV)	6.04 ± 2.03	6.20 ± 1.31	5.82 ± 2.05	6.36 ± 2.55	6.80 ± 2.78	6.28 ± 1.54

*$p < 0.0001$; †$p < 0.01$ versus control; ‡$p < 0.001$, ‖$p < 0.0001$, ¶$p < 0.01$ versus control without paroxysmal atrial fibrillation; §$p < 0.01$ versus sick sinus syndrome without paroxysmal atrial fibrillation. Ad = duration of total filtered P wave; ED3, ED4, ED5 = durations of low amplitude signals <3, 4 and 5 μV in the initial portion of filtered P wave; EP10, EP20, EP30 = root mean square voltages for the initial 10, 20 and 30 ms of filtered P wave; LP10, LP20, LP30 = root mean square voltages for the last 10, 20 and 30 ms of filtered P wave; PAF = paroxysmal atrial fibrillation; P-RMS = root mean square voltage of total filtered P wave; SSS = sick sinus syndrome.

control subjects, irrespective of the presence of a history of paroxysmal atrial fibrillation. Furthermore, the duration of filtered P wave was significantly longer in patients with sick sinus syndrome with than in those without paroxysmal atrial fibrillation. In contrast, there was no difference in the root mean square voltage of filtered P wave between patients with and without sick sinus syndrome.

Identification of patients with sick sinus syndrome by use of signal-averaged ECG. The receiver operating characteristic curves, as functions of variables in the initial portion of filtered P wave, are plotted in Figure 4. EP30 and ED4 were chosen to discriminate patients with sick sinus syndrome from the control subjects, because these variables shifted the most upper right sided in each graph. When the criterion EP30 <3.0 μV was used, the sensitivity, specificity and positive and negative predictive values were 85%, 74%, 54% and 95%, respectively.

In contrast, when the criterion ED4 >22 ms was used, the sensitivity, specificity and positive and negative predictive values were 76%, 87%, 65% and 92%, respectively. When both criteria EP30 <3.0 μV and ED4 >22 ms were combined, which we defined as atrial early potentials, the sensitivity, specificity and positive and negative predictive value were 76%, 91%, 74% and 93%, respectively.

Correlation of sinoatrial conduction time with low amplitude and its duration during early filtered P wave (Fig. 5). EP10, EP20 and EP30 were significantly inversely correlated with sinoatrial conduction time (EP10: r = -0.44, p < 0.001; EP20: r = -0.62, p < 0.0001; EP30: r = -0.67, p < 0.0001). ED3, ED4 and ED5 were also significantly correlated with sinoatrial conduction time (ED3: r = 0.60, p < 0.0001; ED4: r = 0.64, p < 0.0001; ED5: r = 0.58, p < 0.0005). The filtered P-wave duration was also correlated with sinoatrial conduction

Figure 2. Plot of root mean square (RMS) voltages in the initial portion of filtered P wave in patients with and without sick sinus syndrome (SSS). EP10, EP20 and EP30 indicate root mean square voltages for the initial 10, 20 and 30 ms of filtered P wave. **Open circles** indicate patients with paroxysmal atrial fibrillation. Plots with **asterisk** indicate patients with sick sinus syndrome with Stokes-Adams attack. EP10, EP20 and EP30 are significantly lower in patients with than without sick sinus syndrome. Furthermore, EP30 is significantly lower in patients with sick sinus syndrome with than without attacks.
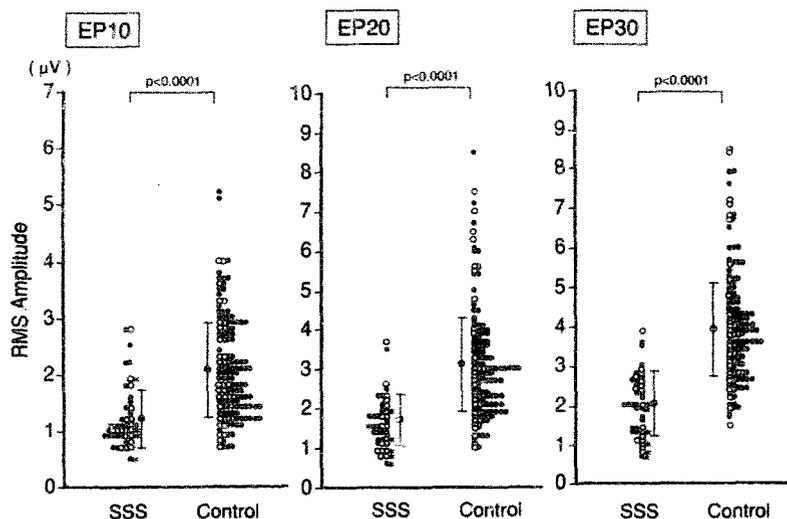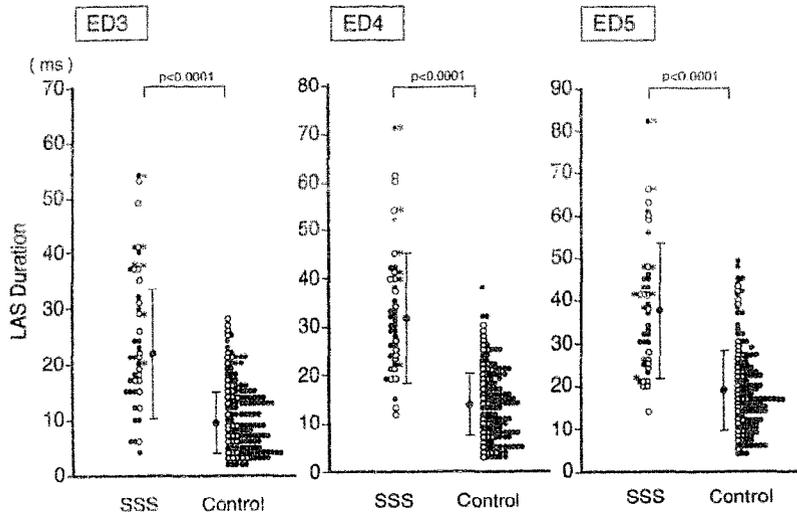
Figure 3. Plot of durations of low amplitude signal (LAS) in the initial portion of filtered P wave in patients with and without sick sinus syndrome (SSS). ED3, ED4 and ED5 indicate durations of low amplitude signal <3, 4 and 5 μV in the initial portion of filtered P wave. Open circles indicate patients with paroxysmal atrial fibrillation. Plots with asterisk indicate patients with sick sinus syndrome with Stokes-Adams attack. ED3, ED4 and ED5 are significantly longer in patients with than without sick sinus syndrome. Furthermore, ED3 and ED4 are significantly longer in patients with sick sinus syndrome with than without attacks.

time, although the statistical significance was weak (r = 0.34, p < 0.01). In contrast, LP10, LP20 and LP30 were not significantly correlated with sinoatrial conduction time.

Effect of atropine on the atrial early potentials. When heart rate was accelerated by the administration of atropine (68 ± 6 to 91 ± 5 beats/min) in six patients without sick sinus syndrome, EP30 significantly increased (3.62 ± 0.83 to 4.46 ± 0.72 μV, p < 0.01) and ED4 significantly decreased (16.6 ± 1.8 to 10.2 ± 2.3 ms, p < 0.01). In contrast, in five patients with sick sinus syndrome, there were slight changes in these variables (EP30: 2.34 ± 0.51 to 2.52 ± 0.76 μV; ED4: 25.8 ± 11.3 to 22.8 ± 13.9 ms; heart rate: 45 ± 12 to 54 ± 15 beats/min), although the change was not statistically significant.

Discussion

Signal-averaged ECGs have recently been developed to detect ventricular and atrial late potentials from the body surface and have provided a useful approach to identify

patients at risk for ventricular tachycardia (13-16) and paroxysmal atrial fibrillation (9,10,17,18). The present study demonstrated that the long, low amplitude signals in the initial portion of filtered P wave in the signal-averaged ECGs are characteristic of sick sinus syndrome, and that patients with both sick sinus syndrome and Stokes-Adams attacks had longer and lower atrial early potential. These results suggest that the atrial early potential is a useful marker to identify patients with sick sinus syndrome, especially those at risk of Stokes-Adams attacks.

Pathophysiologic speculation about low amplitude potentials early in filtered P wave in patients with sick sinus syndrome. Pathologic studies showed that patients with sick sinus syndrome had a lesion such as degeneration and fibrosis not only in the sinus node itself but also in the perinodal atrial muscle (1-4). The low amplitude potentials early in the filtered P wave may mainly reflect the conduction abnormalities in the perinodal atrial muscles or perinodal sinoatrial conducting cells. This speculation may be supported by the finding that the
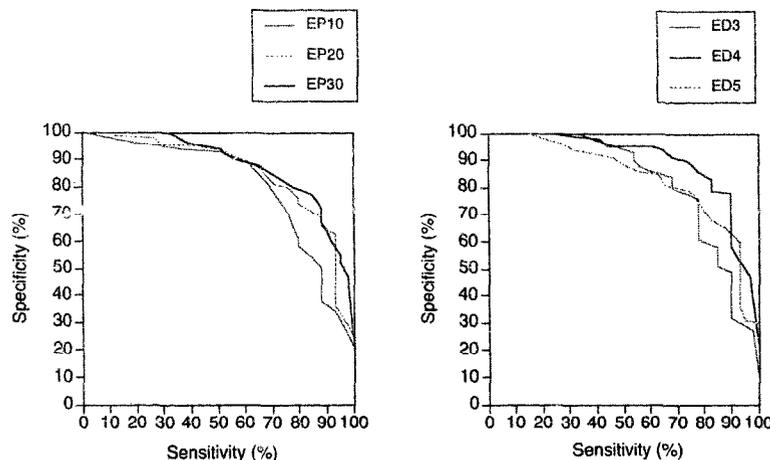

Figure 4. Receiver operating characteristic curves for the variables in the initial portion of filtered P wave for identification of patients with sick sinus syndrome. EP10, EP20 and EP30 indicate root mean square voltages for the initial 10, 20 and 30 ms of filtered P wave. ED3, ED4 and ED5 indicate durations of low amplitude signal <3, 4 and 5 μV in the initial portion of filtered P wave. EP30 and ED4 shifted the most upper right side in each figure.

Figure 5. Correlation of sinoatrial conduction time with the variables in atrial early potentials. EP30 significantly correlates and ED4 significantly inversely correlates with sinoatrial conduction time. EP30 = root mean square voltage for the initial 30 ms of filtered P wave; ED4 = duration of low amplitude signal <4 μV in the initial portion of filtered P wave; SACT = sinoatrial conduction time measured by the method of Narula et al. (12).
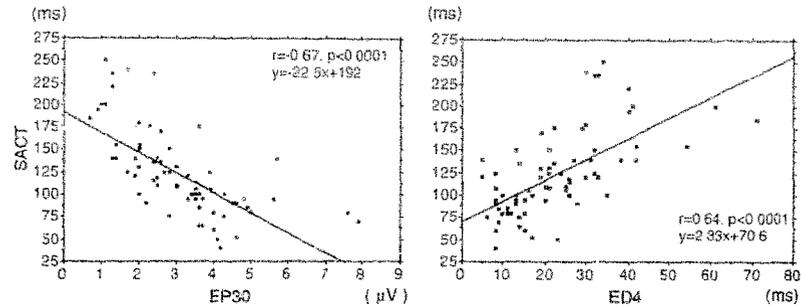
beginning of filtered P wave is almost identical in time to that of the P wave on the standard ECG in Figure 1. Basically, atrial early potential seems to be electrophysiologically different from sinoatrial conduction time, which is the time required for a sinus impulse to exit from the node and reach the atrial myocardium. However, in this study, the low amplitude potentials early in the filtered P wave significantly inversely correlated, and the duration of atrial early potentials also significantly correlated with sinoatrial conduction time. This result may imply that the pathologic process in sick sinus syndrome occurs in the perinodal atrial muscle as well as the sinus node.

We can speculate about the pathogenesis of the low amplitude in the initial portion of filtered P wave in patients with sick sinus syndrome through the following example. In sick sinus syndrome, the conduction of excitation from the sinus node through perinodal tissue becomes slower because perinodal atrial muscles are widely separated by fibrous tissue (1–4). Thus, we think that the abnormality of conduction in the perinodal portion may reflect the low amplitude of the initial portion of filtered P wave. This speculation is supported by evidence that fractionated atrial electrograms were mainly recorded in the high right atrium in the vicinity of the sinus node during sinus rhythm using intraatrial catheter mapping in patients with sick sinus syndrome (5), and that fractionated electrograms were also recorded from the atrial muscle, where there was wide separation of individual myocardial fibers by fibrous tissue (19).

In the present study, although heart rate correlated with EP30 (r = 0.165, p = 0.03) and inversely correlated with ED4 (r = −0.206, p < 0.01), the correlation was very weak. Furthermore, when heart rate was accelerated by the administration of atropine in patients without sick sinus syndrome, EP30 significantly increased and ED4 significantly decreased. In contrast, in patients with sick sinus syndrome, there were slight changes in these variables, although the changes were not statistically significant. These results suggest that the effect of autonomic tone on the low amplitude potentials early in filtered P wave was subtle in patients with sick sinus syndrome, although the initial portion of filtered P wave may be affected by changes in autonomic tone. Thus, low amplitude potentials early in the filtered P wave in patients with sick sinus syndrome may be related to pathologic changes, such as degeneration and fibrosis in perinodal tissue, rather than changes in autonomic tone.

Paroxysmal atrial fibrillation in patients with sick sinus syndrome. In the present study, no differences in the variables in the initial portion of filtered P wave were found between the patients with sick sinus syndrome with and without paroxysmal atrial fibrillation. Furthermore, there were no significant differences in the variables in the initial portion of filtered P wave between the control subjects with and without paroxysmal atrial fibrillation. Therefore, it is clear that the low amplitude signals in the initial portion of filtered P wave are not characteristic of patients with paroxysmal atrial fibrillation, but rather of those with sick sinus syndrome (20). Steinberg et al. (17), Guidera and Steinberg (18) and Fukunami et al. (9) reported that the duration of signal-averaged P wave was longer in patients with paroxysmal atrial fibrillation. These results suggest that the P wave would be longer in patients with paroxysmal atrial fibrillation because of late rather than early low amplitude signals.

Electrophysiologic studies with intraatrial catheter mapping showed that prolonged and fractionated atrial electrograms were more widely distributed in the right atrium in patients with sick sinus syndrome with rather than without paroxysmal atrial fibrillation (5). In the present study, patients with both sick sinus syndrome and paroxysmal atrial fibrillation had a significantly longer duration and lower voltage for the terminal 20 ms of filtered P wave than those with sick sinus syndrome without paroxysmal atrial fibrillation. These findings suggest that the greater the extent of intraatrial conduction defect, the higher the probability that paroxysmal atrial fibrillation would coexist in patients with sick sinus syndrome.

Study limitations. In the present study, the low amplitude of the initial portion of filtered P wave was not always found in all patients with sick sinus syndrome. The initial low amplitude signals may be lacking in patients whose disease is purely limited to depressed automaticity of the sinus node without sinoatrial conduction disease or atrial disease.

As far as the initial portion was concerned, it was fortunate that we did not need to take the ringing effect into consideration, because the signals in our study were filtered in the forward direction. However, the total duration of filtered P wave might be somewhat influenced by the ringing effect, although the effect was thought to be subtle because of relatively low amplitude signal. Incidentally, the percent variation of intraindividual recordings (day to day) was sufficiently small (2.2 ± 2.9%).

The criteria used to differentiate patients with from those without sick sinus syndrome were based on a retrospective best-fit analysis of the data. The sensitivity, specificity, positive predictive value and negative predictive value look promising. However, the criteria developed retrospectively are not always good when applied prospectively. Further prospective study will be needed to verify our results.

Conclusions. This study revealed that the low amplitude signals early in the filtered P wave are characteristic of sick sinus syndrome. Thus, the atrial early potential in the signal-averaged P wave ECGs is a useful marker to identify patients with sick sinus syndrome.

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