Effects of heart rate and atropine on 'dual AV conduction'

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In patients with evidence of dual AV conduction, a premature atrial depolarization is normally conducted via a fast conducting pathway with a long refractory period. At a critically timed coupling interval, the effective refractory period is reached and now the impulse is conducted over a pathway with a slow conduction velocity and a short effective refractory period. At this moment in the His bundle electrocardiogram, a sudden increase in the AH interval occurs which is called the 'break' phenomenon.

This phenomenon was studied in 14 patients, with a history of supraventricular paroxysmal tachycardia, at the patient's own heart rate, at different paced heart rates, and after the administration of atropine. In 11 patients the 'break' phenomenon could be elicited during sinus rhythm; in 3 when the heart rate was accelerated. The effective refractory period of the fast conducting pathway was prolonged in 9 patients, remained unchanged in 3, and was shortened in 2 when the heart rate was increased. The effective refractory period of the slow conducting pathway was reached when block occurred proximal to the His bundle. This parameter was increased in 8 patients, remained unchanged in 3, and was decreased in 1 patient with augmentation of the heart rate. This effective refractory period was not measured in 2 patients. Atropine led to a shortening of the refractory period of both pathways in 8 patients studied. Atrial echo phenomena indicating the beginning of a re-entry circuit occurred at an AH prolongation that was not always identical to that measured at the point of 'break'. Widening, as well as narrowing, of the echo zone was found, indicating that the re-entry circuit was in a state of labile equilibrium. In cases where shortening of the pathways involved in the re-entry circuit was found, structures other than nodal may exist; therefore paranodal bypass must be considered.

Animal experiments (Janse *et al.*, 1971; Van Capelle *et al.*, 1972; Moe, Cohen, and Vick, 1963) as well as electrophysiological studies in the intact human heart (Goldreyer and Bigger, 1971; Goldreyer, Weiss, and Damato, 1971) suggest that the existence of two parallel conducting pathways between atria and ventricles is responsible for the occurrence of atrial and ventricular echoes and for certain types of supraventricular tachycardias. Their presence is thought to be caused by longitudinal dissociation of the AV junction rather than to different morphological structures. 'Whether or not 2 anatomically distinct pathways exist, they cannot serve as the substrate for reciprocal responses unless they also differ functionally. They may differ with respect to refractory period duration, margin of safety, response to adrenergic or cholinergic neural influences, response to drugs

or ionic environment, or any combination of these; but differ they must' (Moe and Mendez, 1966).

To evaluate the functional differences in the two pathways between atria and the bundle of His in the intact human heart it is necessary that both pathways differ not only in respect to their refractory behaviour but in regard to their conduction velocity as well. Functional behaviour of both pathways can be studied, provided the effective refractory period of the faster conducting pathway is longer than the effective refractory period of the slower conducting pathway. Under these circumstances a sudden prolongation of the AH interval induced by premature atrial depolarizations occurs when a critical shortening of the coupling interval is reached (Denes *et al.*, 1973; Denes, Wu, and Rosen, 1974b; Rosen, Mehta, and Miller, 1974). The sudden 'break' in AV nodal conduction time allows the measurement of refractory periods of

Received 5 June 1975.

both pathways between atria and the bundle of His, as suggested by Denes *et al.* (1974b).

This break phenomenon will occur when the faster conducting pathways become refractory and thus the precondition for triggering paroxysmal supraventricular tachycardia (PSVT) is established. It is, however, not always possible to elicit a break phenomenon at the patient's own basic heart rate. We therefore studied the influence of a variable heart rate and atropine administration on the break phenomenon and the trigger mechanism for atrial echoes and supraventricular tachycardia in 14 patients with a history of paroxysmal supraventricular tachycardia.

Patients and methods

Fourteen patients (6 male and 8 female; ages ranging from 17 to 56 years) with paroxysmal supraventricular tachycardia who exhibited a break of AH interval during premature atrial stimulation were studied. None of the patients showed electrocardiographic patterns of WPW syndrome. In 5 patients PR intervals were 130 ms or less (see Table 1).

All patients consented to the electrophysiological study and were in a non-sedated state and without anti-arrhythmic medication at the time of examination. A 5-electrode catheter was placed via the right femoral vein at the right side of the ventricular septum adjacent to the bundle of His according to Scherlag *et al.* (1969). Two appropriate electrodes were selected to record filtered (40–200 Hz) low right atrial potentials and bundle of His depolarizations (HBE). A second catheter with four electrodes was positioned via the same femoral vein in the proximity of the sinus node. Two electrodes were used to record high right atrial potentials (AE), while the remaining two electrodes served for atrial stimulation. Simultaneously, several surface electrocardiographic leads were registered. Surface electrocardiographic and intracardiac electrograms were recorded on magnetic tape and displayed by means of an ink writing system with a paper speed of 100 mm/s. The atrial stimuli consisted of rectangular impulses of 2.0 ms duration and twice diastolic threshold.

As a first step the driving cycle length was gradually decreased by steps of 10 ms to a minimal SS interval of 300 ms, and the frequency-dependent prolongation of the intranodal conduction time (AH interval) as well as the appearance of second degree AV block was observed. Secondly, during sinus rhythm and at different paced heart rates refractory periods of the AV conduction system were determined by the extrastimulus method according to Wit *et al.* (1970). The extrastimulus (S_2) was introduced after every 8th driven (S_1) or spontaneous beat. Coupling intervals were decreased by 10 ms decrements in successive test cycles. PQ, AH, and HQ intervals were measured as previously described (Neuss and Schlepper, 1974). A_1 and H_1 represent the atrial and His bundle potentials of the last beat, whether

spontaneous or driven; A_2 and H_2 represent the atrial and His bundle deflection in response to the extra stimulus.

The effective refractory period of the atrium (ERP A) was derived from the longest S_1 - S_2 interval at which atrial capture failed to occur. In some patients appearance of multiple atrial responses to S_2 prevented the determination of the atrial effective refractory period, as we tried to avoid producing atrial fibrillation by further decreasing S_1 - S_2 intervals. The effective refractory period of the fast conducting pathway (ERP FP) was defined as the A_1 - A_2 interval at which a sudden prolongation of the A_2 - H_2 interval suggested block of the fast conducting pathway. The effective refractory period of the slow conducting pathway (ERP SP) was defined as the longest A_1 - A_2 interval at which additional impulse propagation via the slow pathway was blocked. The functional refractory period of the atrium (FRP A) was defined as the shortest possible A_1 - A_2 interval which could be elicited by shortening the coupling interval. In 8 patients 0.5 mg atropine sulphate was administered intravenously and the studies were repeated 5 to 10 minutes after the injection.

Results

Analysis of AV conduction showed PA, AH, and HQ intervals during sinus rhythm within the normal range in all patients (see Table 1).

(1) Atrial pacing with increasing heart rate led to second degree AV block (type I) proximal to the bundle of His in 10 patients, while 1 : 1 AV conduction persisted down to a driving cycle length of 300 ms in 4 patients.

In one patient (Case 1) second degree AV block occurred early, at a driving cycle length of 700 ms. In this patient an atypical AV nodal Wenckebach phenomenon was observed. The sudden prolongation of the AH interval (increment 230 ms, from AH 120 to 350 ms) at a driving cycle length of 700 ms resulted in an atrial echo, the AV conduction of which was blocked proximal to the bundle of His. The findings were identical to those presented by Denes *et al.* (1973). In five other patients (Cases 3, 5, 6, 9, and 11) a sudden increase of the AH interval (increment: 100 to 230 ms) was observed at a critical driving cycle length. In four patients this 'break' in the AH interval initiated a paroxysmal supraventricular tachycardia as demonstrated in Fig. 1 (Case 11). When in this patient the atrial pacing cycle length was decreased from 330 to 320 ms a sudden prolongation of the AH interval (140 to 230 ms) occurred. Supraventricular tachycardia became evident when pacing was discontinued.

(2) Refractory periods: The refractory periods of the atrium and the AV node (AVN) observed at different heart rates are summarized in Table 2.

TABLE 1

Case No.	Age and sex	D	Basic cycle length (ms)	PA (ms)	AH (ms)	HQ (ms)	Second degree AV block SS interval (ms)	Break of critical cycle length (ms)	AH at increasing AH to AH (ms)	AP rate echo phen. (ms)
1	39 M	NM	1000	40	70	35	700	700	120-350	A'
2	51 M	φ	720	30	120	50	340	—	—	—
3	17 F	φ	690	25	90	40	350	410	180-280	SVT
4	54 F	φ	780	40	100	40	400	—	—	—
5	52 F	φ	810	30	50	50	—*	320	160-280	SVT
6	61 M	CHD	1030	20	100	50	390	570	160-240	—
7	30 F	φ	740	30	80	55	330	—	—	—
8	42 M	φ	780	45	50	40	—*	—	—	—
9	24 M	φ	970	35	95	50	470	500	150-360	SVT
10	32 F	φ	590	20	60	45	—*	—	—	—
11	23 F	φ	620	30	60	40	—*	320	140-230	SVT
12	56 F	φ	850	20	60	40	380	—	—	—
13	47 M	φ	780	30	90	50	330	—	—	—
14	20 F	φ	670	25	55	50	370	—	—	—

Abbreviations: D=diagnosis; φ=no detectable heart disease; NM=non-acute myocarditis; CHD=coronary heart disease; M=male; F=female; AP=atrial pacing; A'=atrial echo; SVT=supraventricular tachycardia.

*1 : 1 AV conduction down to a cycle length of 300 ms.

TABLE 2

Case No.	Cycle length (ms)	ERP FP (ms)	FRP SP (ms)	ERP A (ms)	AH basic cycle length (ms)	AH break (ms)	AH max. (ms)	Echo. (ms)	Crit. AH (ms)	RR SVT (ms)	HA' (ms)
1	C 1000	400	380	320	70	160-450	460	A'	450	—	190
	C 800	560	≥560**	300	100	—	150	—	—	—	—
	A 800	<320*	— **	300	75	—	120	—	—	—	—
	A 700	<320*	— **	300	80	—	150	—	—	—	—
	A 600	330	≥330**	— **	90	—	130	—	—	—	—
2	C 720	<290*	— **	280	120	—	210	—	—	—	—
	C 600	310	<250*	240	120	270-330	370	—	—	—	—
	C 500	310	<250*	240	180	260-310	410	—	—	—	—
	C 400	310	280	— **	230	280-340	470	SVT	430	400	100
	A 700	280	≥290**	— **	120	—	210	—	—	—	—
	A 600	250	≥250**	— **	120	—	210	—	—	—	—
	A 500	260	≥260**	— **	140	—	280	—	—	—	—
	A 400	290	250	— **	190	270-340	400	SVT	400	370	100
3	C 690	350	280	— **	90	160-270	330	SVT	270	380	65
	C 500	390	280	— **	90	160-260	340	SVT	320	380	65
4	C 780	330	<320**	— **	100	260-480	480	SVT	480	510	120
	C 600	330	280	— **	170	230-450	490	SVT	470	510	120
	C 500	350	300	— **	200	240-410	480	SVT	410	510	120
5	C 810	<290*	— **	270	50	—	90	—	—	—	—
	C 700	290	<260*	230	70	180-240	270	A'	240	—	90
	C 600	320	<230*	210	70	120-260	320	SVT	270	330	90
	C 500	310	250	200	90	130-250	290	SVT	270	330	90
	C 400	310	<310**	— **	110	150-250	250	A'	250	—	90
	A 500	<230*	— **	200	70	—	160	—	—	—	—
	A 400	<220*	— **	200	80	—	160	—	—	—	—

TABLE 2 Continued

Case No.	Cycle length (ms)	ERP FP (ms)	ERP SP (ms)	ERP A (ms)	AH basic cycle length (ms)	AH break (ms)	AH max. (ms)	Echo.	Crit. AH (ms)	RR SVT (ms)	HA' (ms)
6	C 1030	460	< 330*	310	100	130-220	320	A'	300	—	90
	C 600	— **	330	280	150	— —	330	A'	290	—	90
	C 500	— **	320	270	280	— —	350	A'	320	—	90
	A 900	340	290	— **	80	160-210	240	—	—	—	—
	A 500	390	290	250	130	160-240	340	A'	290	—	90
7	C 740	< 280*	— **	240	80	— —	250	—	—	—	—
	C 600	270	< 260*	220	85	280-450	470	—	—	—	—
	C 400	290	< 270**	— **	220	300-370	370	—	—	—	—
	A 520	< 230**	— **	— **	80	— —	180	—	—	—	—
	A 400	< 220**	— **	210	90	— —	220	—	—	—	—
8	C 780	310	< 270*	260	50	100-190	200	A'	190	—	110
	C 600	300	230	200	60	100-170	220	SVT	170	320	110
	C 500	260	230	— **	80	140-210	220	SVT	210	260	110
	C 400	250	230	190	75	120-190	210	SVT	190	270	110
	C 300	210	200	— **	90	120-220	220	A'	220	—	110
9	C 970	410	380	290	95	290-360	370	A'	360	—	20
	C 600	440	340	260	160	240-320	430	SVT	320	450	20
10	C 500	300	< 270**	— **	60	160-200	220	SVT	220	280	90
	C 400	300	< 260**	— **	110	120-180	220	SVT	200	290	90
11	C 620	320	< 300**	— **	60	100-220	220	SVT	220	300	90
	C 400	260	< 260**	— **	80	140-240	240	SVT	240	300	90
12	C 850	340	300	250	60	120-210	280	A'	280	—	80
	C 700	330	290	230	70	150-300	510	SVT	300	480	80
	C 600	330	290	230	80	130-420	480	A'	420	—	80
	C 500	350	290	— **	90	120-250	570	SVT	460	480	80
	A 700	< 290	— **	230	50	— —	100	—	—	—	—
	A 600	< 260*	— **	190	70	— —	150	—	—	—	—
	A 500	290	< 230*	180	70	130-200	220	—	—	—	—
	A 400	300	260	170	90	120-190	230	—	—	—	—
13	C 780	320	280	230	90	180-300	470	A'	300	—	130
	C 600	350	330	200	110	200-310	380	A'	310	—	120
	C 500	350	— **	190	120	— —	190	—	—	—	—
	A 600	< 250*	— **	220	50	— —	170	—	—	—	—
	A 500	< 240*	— **	200	80	— —	180	—	—	—	—
	A 400	< 230*	— **	190	100	— —	200	—	—	—	—
14	C 670	320	< 290*	250	60	120-300	330	A'	300	—	35
	C 500	320	260	180	70	200-340	450	A'	340	—	35
	C 400	360	300	— **	100	120-310	380	A'	310	—	35
	A 500	< 270*	— **	240	40	— —	80	—	—	—	—
	A 400	240	220	— **	65	140-310	440	SVT	310	330	25

Abbreviations: ERP FP=effective refractory period of the fast conducting pathway; ERP SP=effective refractory period of the slow conducting pathway; ERP A=effective refractory period of the atria; AH break=sudden prolongation of A_2 - H_2 interval from . . . to . . .; AH max.=maximal observed prolongation of A_2 - H_2 interval; echo.=echo phenomena; crit. AH=critical A_2 - H_2 interval at which echo phenomena appear; RR SVT=cycle length of tachycardia (PSVT); HA'=retrograde conduction time for atrial echoes (H potential to retrograde atrial deflection in HBE); C=control; A=after atropine; *=ERP FP or SP is shorter than the shortest possible A_1 - A_2 interval; **=not measured.

In 11 patients a sudden prolongation of the A_2 - H_2 interval could be provoked during sinus rhythm, so the effective refractory period of the fast pathway

(ERP FP) could be measured. These sudden prolongations of A_2 - H_2 ranged from 70 to 270 ms. In the remaining three patients (Cases 2, 5, and 7)

FIG. 1 Electrocardiogram (leads II, III, and V_1), high right atrial electrogram (AE), and His bundle electrogram (HB) in Case 11. In this and all subsequent figures: S=stimulus artefact, A=atrial potential, A'=retrograde atrial depolarization, H=His bundle potential, V=ventricular potentials. Conventional ladder diagram: A=atrial level, N=level of AV junction, HPS=His-Purkinje system, V=ventricular myocardium.

During atrial pacing with a cycle length of 320 ms a sudden prolongation of the AH interval from 140 to 230 ms was observed. When pacing was discontinued a paroxysm of supraventricular tachycardia with a cycle length of 320 ms became evident. Time marks=200 ms.

no break phenomenon became apparent. At intervals shorter than the ERP FP atrial echoes occurred in all 11 patients, 4 of whom developed a paroxysm of supraventricular tachycardia.

In 5 of the 11 patients showing the break phenomenon the effective refractory period of the slow pathway (ERP SP) could be measured only when further shortening of A_1 - A_2 resulted in AV block above the bundle of His. In 3 patients AV conduction via the slow conducting pathway was limited by the effective refractory period of the atria; in the remaining 3 patients the ERP SP could not be measured for technical reasons (multiple response to A_2).

(3) Rate-dependency of refractory periods of the atrioventricular node: In the 3 patients in whom no break phenomenon was apparent at sinus

rhythm it could be provoked when basic cycle length was decreased. This was because of a prolongation of the effective refractory period of the fast pathway and/or a shortening of the effective refractory period of the atria.

A rate-dependent prolongation of the effective refractory period of the fast pathway was found in 9 patients. An example is given in Fig. 2 (Case 4): at a basic cycle length of 600 ms a premature atrial depolarization with a S_1 - S_2 interval (identical with an A_1 - A_2 interval) of 340 ms was conducted with an A_2 - H_2 interval of 220 ms (Fig. 2a). Shortening of S_1 - S_2 to 330 ms resulted in prolongation of A_2 - H_2 to 450 ms. The first atrial echo, which then initiated a paroxysm of supraventricular tachycardia, was elicited at an A_1 - A_2 interval of 300 ms (Fig. 2b), the corresponding A_2 - H_2 interval being 490 ms. At

FIG. 2 Electrocardiogram (lead II), atrial electrogram (AE), and His bundle recording (HBE) in Case 4. (a) Basic cycle length 600 ms: a premature atrial depolarization with an S_1 - S_2 interval of 340 ms was conducted with an A_2 - H_2 interval of 220 ms. (b) Basic cycle length 600 ms: at an S_1 - S_2 interval of 300 ms an A_2 - H_2 interval of 490 ms resulted, and atrial echo initiating a paroxysm of supraventricular tachycardia occurred. (c) Basic cycle length 500 ms: a premature atrial depolarization with an S_1 - S_2 interval of 360 ms was conducted with an A_2 - H_2 interval of 240 ms. (d) Basic cycle length 500 ms: shortening of S_1 - S_2 to 350 ms resulted in a break phenomenon and the occurrence of supraventricular tachycardia.

a basic cycle length of 500 ms the break phenomenon occurred at an A_1 - A_2 interval of 350 ms (Fig. 2c, 2d). The essential A_2 - H_2 interval for the initiation of supraventricular tachycardia was found to be 410 ms (Fig. 2d).

In 3 patients no significant change in the effective refractory period of the fast pathway was seen (Cases 6, 10, and 12), while in two patients (Cases 8 and 11) this decreased when basic heart rate was accelerated. This is demonstrated in Fig. 3 (Case 8): at a basic cycle length of 600 ms the effective refractory period of the fast pathway was reached at an S_1 - S_2 interval (identical to A_1 - A_2) of 300 ms. The sudden prolongation of A_2 - H_2 was accompanied by the appearance of an atrial echo and the initiation of supraventricular tachycardia (Fig. 3a and b). At a basic cycle length of 500 ms the effective refractory period of the fast pathway was decreased to 260 ms (Fig. 3c and d).

Shortening of the basic cycle length resulted in a shortening of the effective refractory period of the slow pathway in only 1 patient (Case 9), while it was prolonged in 8 patients. In 3 patients no significant effects of heart rate on it were found.

In two patients the rate dependency of this refractory period was not measured.

In all patients in whom the effective refractory period of the atria was measured at different heart rates a shortening was observed when the heart rate was increased.

(4) The effects of atropine on the refractory periods: All 8 patients investigated showed a decrease of the effective refractory period of the fast pathway after atropine administration. As far as it could be investigated, the slow conducting pathway behaved similarly.

In 4 patients (Cases 1, 5, 7, and 13) the break phenomenon observed under control conditions disappeared after atropine administration and could not be elicited by shortening the basic cycle length. This effect is shown in Fig. 4 (Case 5): under control conditions at a driving cycle length of 500 ms and a coupling interval of 310 ms a sudden increase of the H_1 - H_2 and A_2 - H_2 interval was observed (Fig. 4a and b). After atropine with the same driving cycle length the break phenomenon disappeared (Fig. 4c) and the A_2 - H_2 interval increased continuously (Fig. 4d).

FIG. 3 Electrocardiogram (lead I), atrial electrogram (AE), and His bundle recording (HBE) in Case 8. Time marks=100 ms. (a) Basic cycle length 600 ms: at an S_1 - S_2 interval of 310 ms A_2 - H_2 measured 100 ms. (b) Basic cycle length 600 ms: shortening of S_1 - S_2 to 300 ms resulted in a sudden prolongation of A_2 - H_2 to 170 ms and the occurrence of an atrial echo which initiated a supraventricular tachycardia. (c) Basic cycle length 500 ms: at an S_1 - S_2 interval of 270 ms A_2 - H_2 measured 140 ms. (d) Basic cycle length 500 ms: shortening of S_1 - S_2 to 260 ms resulted in a prolongation of A_2 - H_2 to 210 ms and the occurrence of an atrial echo.

In 3 patients at low heart rates after atropine no break phenomenon was observed. However, it could be provoked by shortening the basic cycle length (Cases 8, 12, and 14).

In only one patient could a break phenomenon be detected while in sinus rhythm after atropine. In this case (Case 6: Fig. 5) at a basic cycle length of 500 ms AV conduction occurred only via the slow conducting pathway under control conditions, as shown by the A_2 - H_2 intervals varying between 250 and 280 ms (Fig. 5a and b). Atrial echoes were seen at a critical A_2 - H_2 interval of 320 ms (Fig. 5b). A sudden prolongation of the A_2 - H_2 interval (from

160 to 240 ms) was elicited at an A_1 - A_2 interval of 390 ms after atropine administration. If A_2 - H_2 was further prolonged to 290 ms atrial echoes occurred (Fig. 5d). This is graphically demonstrated in Fig. 6. It is evident that atropine (Fig. 6c and d), at basic rate of 120/min, facilitated AV conduction via the fast conducting pathway, so that a break phenomenon could be demonstrated.

(5) The echo phenomena and supraventricular tachycardia: Echo phenomena can be provoked when the AV conduction of a premature atrial depolarization occurs via the slow conducting pathway, while AV conduction down the fast

FIG. 4 The effects of atropine on the break phenomenon in Case 5 are graphically demonstrated. H_1-H_2 intervals (top panel) and A_2-H_2 intervals (bottom panel) are depicted as a function of A_1-A_2 intervals. Basic cycle length is 500 ms. In control conditions a sudden prolongation of H_1-H_2 (panel a) and A_2-H_2 (panel b) occurred at an A_1-A_2 interval of 310 ms. After atropine administration no break phenomenon occurred up to the shortest possible A_1-A_2 interval of 230 ms (panel c and d).

FIG. 5 Electrocardiogram (lead I and II), atrial electrogram (AE) and His bundle recording (HBE) in Case 6. Time marks=100 ms. Basic cycle length 500 ms. Under control conditions A_1-H_1 intervals varied between 250 and 280 ms (panel a and b). Shortening of A_1-A_2 intervals was accompanied by a smooth increase of A_2-H_2 intervals. At a critical A_2-H_2 interval of 320 ms (panel b) an atrial echo appeared. After atropine administration (panel c and d) A_1-H_1 intervals shortened to 130 ms. While a typical break phenomenon occurred at an A_1-A_2 interval of 390 ms (not shown), the critical A_2-H_2 interval at which atrial echoes appeared was shortened to 290 ms (panel d). After oriprenaline administration (panel e and f) A_1-H_1 intervals shortened to 80 ms. A typical break phenomenon occurred at an A_1-A_2 interval of 270 ms (not shown). The critical A_2-H_2 interval was further shortened to 210 ms (panel f).

FIG. 6 Graph showing the A_2 - H_2 intervals (upper panel) and the H_1 - H_2 intervals (lower panel) as a function of the A_1 - A_2 intervals. Same case as in Fig. 5. Basic cycle length 500 ms. Under control conditions no break phenomenon was evident (panel a and b). The graph suggests that the appearance of the break phenomenon after atropine administration (panel c and d) and after orciprenaline (panel e and f) is because of improvement of conductivity in a fast-conducting pathway.

conducting pathway is blocked owing to its refractory state. With the exception of Case 6, this behaviour was demonstrated by the break phenomenon.

Furthermore, the occurrence of an echo phenomenon depends on a critical A_2 - H_2 interval. In none of the patients could an atrial echo or supraventricular tachycardia be elicited unless A_2 - H_2 reached a critical value (given in Table 2). The A_2 - H_2 prolongation caused by a break phenomenon did not always reach this critical value.

In all cases of junctional tachycardia the HA' intervals (from H to the start of the retrograde atrial depolarization) were shorter than the $A'H$ intervals. During supraventricular tachycardia this HA' interval remained constant and did not depend on the basic cycle length or the preceding A_2 - H_2 interval.

In all patients who showed disappearance of the break phenomenon after atropine medication supraventricular tachycardia could not be provoked by a premature atrial depolarization (Cases 1, 5, 7, and 13). In the remaining patients, with the exception of Case 12, atrial echoes could be elicited after atropine by a premature atrial depolarization at a basic cycle length at which break phenomena could be demonstrated. However, in Case 12 after atropine the increment of the A_2 - H_2 interval (AH_{max} in Table 2) was less, so that the critical A_2 - H_2 interval could not be reached.

In two patients (Cases 1 and 6) junctional tachycardias could be elicited only after orciprena-

line medication. In Case 1 study at high rates after atropine could not be achieved for technical reasons. Therefore it cannot be excluded that the break phenomenon that occurred after orciprenaline medication might also be provoked at similar frequencies after atropine. The behaviour of Case 6 after administration of orciprenaline is presented in Fig. 5e and f and in Figs. 6e and f. At a basic cycle length of 500 ms orciprenaline shortened the A_1 - H_1 interval to 80 ms (Fig. 5e). A sudden prolongation of the A_2 - H_2 interval from 110 to 190 ms could be provoked at a coupling interval of 270 ms. The A_2 - H_2 prolongation to 210 ms at a coupling interval of 240 ms (Fig. 5f) caused a stable supraventricular tachycardia, while under control conditions and after atropine medication the re-entry mechanism was spontaneously terminated after the two atrial echoes depicted. The critical A_2 - H_2 interval was shortened from 320 ms (control) and 290 ms (after atropine) to 210 ms.

Discussion

As suggested by Moe and Mendez (1966), longitudinal dissociation of the AV junction 'can be adequately explained on the basis of differences in effective refractory period without invoking basic differences in conduction velocity'. While the break phenomenon may represent substitution of a fast conducting pathway by a slow conducting pathway (Rosen *et al.*, 1974), it could also be caused by a

sudden increase in local conduction delay within a relatively refractory channel (Hoffman *et al.*, 1963). However, the coincidence of the break phenomenon in human beings with the occurrence of echo phenomena and supraventricular tachycardia strongly points to the first hypothesis, which we will follow for the interpretation of our findings.

Rate dependency of refractory periods and the echo zone

Shortening of the cycle length led to a uniform decrease of the atrial effective refractory period in our patients, which agrees with the findings of Cagin *et al.* (1973), and Denes *et al.* (1974a). According to these authors prolongation of the effective refractory period of the AV node should be expected with cardiac acceleration. While this was the case in most of our patients, the refractory period of the slow pathway shortened in 1 patient and of the fast pathway in 2 patients.

The echo zone is defined by that critical time interval in which spontaneous or induced premature depolarizations can elicit echo phenomena. It is limited by the effective refractory period of the slow pathways or that of the atria on one side and on the other by the refractory period of the fast pathway or the A_1 - A_2 interval at which the critical A_2 - H_2 prolongation is reached. Rate-dependent changes of the refractory periods should therefore affect the echo zone. Taking into account these factors under control conditions and their different rate dependency, uniform behaviour of the echo zone should not be expected with cardiac acceleration. In accord with this, widening as well as narrowing of the echo zone was found when heart rate was increased.

Influence of the autonomic nervous system on the refractory periods

Owing to its anticholinergic action atropine invariably shortens the effective refractory period of the slow and fast conducting pathways. Improvement in antegrade as well as retrograde AV nodal conduction encourages the occurrence of atrial echoes (Case 7) and the induction of stable junctional tachycardias (Case 14). After atropine medication the break phenomenon can be elicited with greater or less ease depending on the basic conditions. With a relatively short effective refractory period of the fast pathway further shortening by atropine can cause disappearance of the break phenomenon (Fig. 4). If the fast-conducting pathway is antegradely blocked under control conditions, shortening of its effective refractory period by atropine may cause the appearance of the break phenomenon at

the identical basic cycle length (Case 6, Fig. 6). Furthermore, the echo zone can be influenced by shortening of the critical A_2 - H_2 interval (Case 12). This may be explained by the decrease of the effective refractory period of an upper common pathway in the re-entry circuit (Mendez *et al.*, 1965).

As expected, the effect of orciprenaline is similar to that of atropine. These findings clearly demonstrate the importance of changes in sympathetic and/or parasympathetic nervous tone in relation to the trigger mechanism of junctional tachycardias. It emphasizes the role of the autonomic imbalance often found in patients prone to paroxysmal supraventricular tachycardia.

Anatomical substrate of dual AV conduction

It has previously been suggested that dual AV conduction is anatomically correlated with a paranodal bypass or with longitudinal dissociation of the AV node (Kistin, 1965). The specific pharmacological influence of atropine on the AV node (Akhtar *et al.*, 1974) suggests that the AV node is included in the fast-conducting pathway. This points to a longitudinal dissociation of the AV node. However, if a paranodal bypass inserts into the distal part of the AV node, the shortening of the effective refractory period of the fast-conducting pathway could be caused by the behaviour of the refractory period of the nodal part of this pathway.

Usually the effective refractory period of the AV node increases whereas the refractory periods of the atria and bundle of His decreases when the basic cycle length is shortened (Denes *et al.*, 1974a; Cagin *et al.*, 1973). The prolongation of the effective refractory period of the fast pathway with cardiac acceleration in some patients suggests—in the light of the considerations mentioned above—a longitudinal dissociation. On the other hand, the shortening of the refractory period of the fast pathway with decreasing basic cycle length in other patients could be explained by a paranodal bypass system.

Further pharmacological investigations may well be helpful to determine the anatomical substrate in these patients (Spurrell, Krikler, and Sowton, 1974).

Occurrence of break phenomenon and provocation of junctional tachycardias

As previously shown, a critical combination of the effective refractory periods of the atria, or the upper common pathway, and the fast- and the slow-conducting pathways is needed for the manifestation of both these phenomena. From a consideration of the individual properties of these refractory periods under control conditions, one would expect that

FIG. 7 Electrocardiogram (lead II), atrial electrogram, and His bundle recording in Case 7. Panel a and b=control conditions. (a) Basic cycle length 600 ms: at an S₁-S₂ interval of 300 ms A₂-H₂ measured 240 ms. (b) Basic cycle length 600 ms: shortening of S₁-S₂ to 270 ms resulted in a prolongation of A₂-H₂ to 450 ms. (c) After atropine medication: at sinus rhythm with a cycle length of 520 ms a premature atrial depolarization with a coupling interval of 230 ms was conducted with an A₂-H₂ interval of 180 ms. A short-coupled atrial extrasystole (A⁺), after this induced premature atrial depolarization produced a similar AH prolongation as in panel b and was followed by a junctional tachycardia.

these phenomena might be provoked by changing basic cycle length (Cases 2, 5, and 7) or by pharmacological intervention (Case 6). The break phenomenon may be considered as a diagnostic clue for the presence of dual AV conduction; patients with paroxysmal supraventricular tachycardia should be studied by the provocative methods described to elicit it.

The association of the break phenomenon with the occurrence of atrial echoes can be explained by the development of a unidirectional block of the fast-conducting pathway. However, it is possible

that such a unidirectional block could already exist in sinus rhythm when the fast pathway would be concealed. Thereby atrial echoes could occur without a previous break phenomenon at a critical A₂-H₂ prolongation. This interpretation is favoured by the provocation of a break phenomenon by the positive dromotropic effect of the pharmacological agents used at the same basic cycle length (Fig. 5 and 6).

On the other hand, it is necessary to have sufficient delay in the re-entry cycle to be able to provoke junctional tachycardias, otherwise the structures

previously depolarized (upper common pathway) cannot be activated again. So, in spite of a break phenomenon and a significant A_2 - H_2 prolongation, refractoriness of the upper common pathway may prevent atrial echoes. Shortening of this refractory period by pharmacological agents or by changing the basic cycle length may therefore permit atrial echoes.

In Case 7 at a basic stimulated cycle length of 600 ms and a coupling interval of 270 ms a break phenomenon (increment 240 to 450 ms) occurred. Atrial echoes failed to appear (Fig. 7a and b). After atropine the spontaneous basic cycle length was 520 ms. Premature atrial depolarizations were not able to provoke a break phenomenon. An additional short-coupled atrial extrasystole after an induced premature atrial depolarization produced a similar AH prolongation, as in Fig. 7b, and was followed by a junctional tachycardia (Fig. 7c). A possible explanation is offered: Atropine shortened the effective refractory period of the fast pathway in such a way that a unidirectional block could be provoked only by a dual premature atrial depolarization; shortening of the refractory period of the upper common pathway now allowed the occurrence of atrial echoes at AH intervals which did not permit this before atropine administration.

The phenomena described depend on a critical combination of conduction times and refractory periods of the structures between atria and the bundle of His which were shown to be very sensitive to changes in rate and to the administration of pharmacological agents affecting the autonomic nervous control of the heart. Because of these complex multifactorial interrelations a wide inter-individual variability can be observed in the various factors involved.

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