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Electrophysiology

Catheter-Induced Mechanical Trauma to Accessory Pathways during Radiofrequency Ablation: Incidence, Predictors and Clinical Implications

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OBJECTIVES To evaluate the incidence, predictors and clinical implications of nonintentionally catheter-induced mechanical trauma to accessory pathways during radiofrequency ablation procedures.

BACKGROUND Data on the incidence and significance of catheter-induced trauma to accessory pathways are scarce.

METHODS Consecutive patients (n = 381) undergoing radiofrequency ablation of accessory pathways at two different institutions were closely monitored for appearance of mechanical block of accessory pathways during catheter manipulation.

RESULTS Mechanical trauma to accessory pathways was observed in 37 (9.7%) patients. According to a multivariate analysis, the only independent variable associated with this phenomenon was the anatomical pathway location ($p = 0.0001$). The incidence of trauma of either right anteroseptal (38.5%) or right atriofascicular pathways (33.3%) was significantly greater than that of pathways (≤10%) at all remaining locations ($p < 0.0001$). The duration of conduction block observed ranged from ≤1 min to >30 min in 19% and 35% of patients, respectively. "Immediate" application of radiofrequency pulses at sites of mechanical block (<1 min after occurrence) was associated with a 78% long-term success rate at follow-up. This contrasted with a 25% long-term success rate in patients in whom pulses were delivered 30 min after occurrence of block ("delayed pulses"). Finally, in 24% of patients persistent trauma-induced conduction block led to discontinuation of the ablation procedure.

CONCLUSIONS Trauma to accessory pathways is more common than previously recognized and frequently results in prolongation or discontinuation of the ablation procedure and in lower success rates. The only independent predictor of catheter-trauma to accessory pathways is the pathway location. (J Am Coll Cardiol 1999;33:767–74) © 1999 by the American College of Cardiology

Conduction block over anatomical structures sometimes occurs during manipulation of catheters in the cardiac chambers. This conduction block is ascribed to mechanical trauma and is referred to as "catheter-induced trauma." Catheter-induced trauma has been reported in the atrioventricular (AV) node (1), the His bundle (2), the right bundle branch (3), the atrium (4) and the ventricle (5). Despite the increasing number of electrophysiologic investigations and radiofrequency ablation procedures in patients with accessory pathways during the last decade, the incidence of catheter-induced mechanical trauma to accessory pathways has been evaluated in only one study (4). In the present prospective study, we sought to assess the incidence, predictors and clinical implications of catheter-induced mechanical trauma to accessory pathways in a large cohort of patients undergoing radiofrequency ablation. Our results suggest that catheter-induced trauma to accessory pathways is more frequent than previously recognized. Moreover, our results suggest that catheter-trauma has important deleterious consequences.

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PATIENTS AND METHODS

Patients. All 381 consecutive patients who underwent radiofrequency ablation of accessory pathways in the Tel-Aviv (n = 220) and Sheba (n = 161) medical centers from January 1992 to December 1997 were included in the study providing that one of the investigators (B.B.) was present during the procedure. This investigator was in charge of monitoring the surface and intracardiac signals throughout the whole electrophysiologic study. Two experienced physicians were involved in the manipulation of the catheters in

each laboratory. The teams of physicians were different from one laboratory to another. Data were prospectively collected for 249 males and 132 females, ranging in age from 3 months to 75 years (mean 32.7 ± 14.9 years) including 15 patients (4%) who were ≤13 years old at the time of the procedure. The 381 patients had a total of 395 accessory pathways which were manifest, concealed or intermittent in 54.5%, 36.5% and 9% of patients, respectively. Pathway distribution was as follows: left free wall (58%), posteroseptal (21.5%), right free wall (11.5%) and anteroseptal or midseptal (9%). Most patients (89%) underwent a single ablation procedure while 44 patients underwent two or more procedures (mean number of procedures 1.1 ± 0.4). There were no significant differences in baseline demographic parameters or electrophysiologic characteristics between the patients evaluated in the two institutions participating in this study.

Electrophysiologic study. All electrophysiologic studies were performed after written informed consent was obtained. Most patients were mildly sedated with intravenous midazolam. A few patients (especially the youngest ones) underwent the procedure under general anesthesia. Diagnostic catheters (6-French quadripolar electrode-catheters [Bard, Billerica, Massachusetts]) were inserted percutaneously into the right or left femoral veins and positioned in the His bundle area, the right ventricle and occasionally the high right atrium. A 6-French decapolar electrode catheter (Bard) was inserted into the coronary sinus (usually through a left antecubital vein and less commonly through a femoral, jugular or subclavian vein). In very young patients, the number of catheters introduced into the right chambers was limited to the strict minimum.

The diagnostic electrophysiologic study was usually limited to induction and determination of the mechanism of tachycardia (using infusion of isoproterenol if necessary) in patients without preexcitation in sinus rhythm. In patients with antegrade preexcitation, ablation of the accessory pathway was usually attempted after brief evaluation of the characteristics of the retrograde conduction without additional investigation.

Radiofrequency ablation. After completion of the diagnostic part of the electrophysiologic study, an additional catheter for radiofrequency ablation was inserted. For left free wall accessory pathways, the retrograde arterial approach was primarily used. However, in 8% of the cases, the mitral annulus was approached from a patent foramen ovale or using transeptal catheterization. The last technique was used only in patients who had failed ablation with a retrograde arterial approach. Posteroseptal accessory pathways were approached from the venous route first and, in case of failure, from the retrograde arterial approach. Right free wall, right midseptal and right anteroseptal accessory pathways were approached from a femoral vein or from a right jugular vein. In a few cases of right-sided accessory pathways, the ablation catheter was introduced through a special guiding sheat (Daig, Minnetonka, Minnesota). Radiofrequency energy was delivered at sites where accessory pathways potentials were recorded, or at sites demonstrating the earliest antegrade ventricular activation during sinus rhythm and/or earliest retrograde atrial activation during orthodromic reentrant tachycardia or right ventricular pacing.

Two types of ablation catheters (with various curves) were used: 1) Thermistor-embedded tip 8-French catheters (EP Technologies, Sunnyvale, California) and 2) nontemperature-controlled 7-French catheters (Polaris/Mansfield/Webster/Cordis). Both catheters have a 4 mm distal ablation electrode and a deflectable curve. The EPT 8-French catheters were used in all 161 patients treated at the Sheba Medical Center and in the last 86 patients treated at the Tel-Aviv Medical Center while the nontemperature-controlled 7-French ablation catheters were used in the first 134 patients treated at Tel-Aviv Medical Center. Radiofrequency current was administered via a Radionics-3C generator (Burlington, Massachusetts) when using nontemperature controlled catheters and by an EPT generator when using EPT catheters.

Mechanical trauma to pathways. A baseline 12-lead ECG was recorded at the beginning of the electrophysiologic study before introduction of any catheter. Four surface leads (I, II, III and V1) and multiple intracardiac electrograms were closely monitored during placement of the diagnostic and ablation catheters in the cardiac chambers. The localization of accessory pathways was made according to standard criteria (6).

Catheter–trauma to an accessory pathway was considered to exist when sudden complete block of conduction along the pathway occurred during catheter manipulation, as long as the block was unrelated to administration of radiofrequency pulses or drugs and was not accompanied by pain or neurovegetative changes. For patients with manifest accessory pathways, sudden disappearance of preexcitation was considered to represent trauma to the pathway. In patients with concealed pathways, retrograde block in the accessory pathway during ventricular pacing or at termination of orthodromic reentrant tachycardia (if confirmed with ventricular pacing) was taken as an indication for trauma. Finally, for patients with intermittent preexcitation, a conduction block in both directions (antegrade and retrograde) was required.

The duration of the trauma to the accessory pathway (from abolition to recurrence of conduction) was prospectively recorded. In patients who had repeated episodes of trauma, the longest episode was selected for analysis. The electrode catheter that was felt to be the most likely responsible for the trauma induced to the pathway was specified.

Definitions. Whenever trauma-induced conduction block over an accessory pathway was recognized, all catheter manipulations were immediately stopped. If the trauma

was ascribed to the ablation catheter, a single pulse of radiofrequency energy ("immediate pulse") was delivered, providing that the ablation catheter had not moved from the presumed site of trauma. On the other hand, whenever it was felt that the ablation catheter had moved from the site of trauma, a more expectant attitude was observed. If conduction over the accessory pathway resumed, catheter mapping was continued and radiofrequency ablation was eventually performed. If trauma-induced conduction block persisted after a 30 to 150 min observation period, then the mapping and ablation procedure was discontinued or a single pulse of radiofrequency energy was given at the site of presumed accessory pathway block ("delayed pulse"). At the end of the procedure, the presence or absence of conduction over the accessory pathway was noted. The patients were followed at regular out-patient visits to evaluate recurrence of pathway conduction. Recurrence of conduction was considered to be present when ventricular preexcitation or symptomatic tachycardia recurred.

Statistical analysis. All values are expressed as mean ± standard deviation or percentages (as appropriate). Univariate analysis was performed by chi square test for discrete variables, *t*-test and one-way analysis of variance for continuous variables. Multivariate stepwise logistic regression analysis was performed in order to predict which variables were independently associated with catheter trauma. A p-value <0.05 was considered statistically significant.

RESULTS

Incidence and location of catheter-induced trauma. Catheter trauma to accessory pathways occurred in 37 (9.7%) patients, 26 male and 11 female, aged 15 to 75 years (mean age 34.4 ± 16 years) (Table 1). Only two of these patients had structural heart disease. Most (n = 34) patients with catheter trauma had a single accessory pathway, and two or more accessory pathways were present in three patients.

Location of the accessory pathways that endured catheter-induced trauma is shown in Table 1 and representative examples are shown in Figures 1–3. The accessory pathways involved were manifest in 23 (62%) patients, concealed in 11 (30%) and intermittent in three (8%). In addition to catheter-induced trauma to the accessory pathways, trauma to the AV node was observed in two patients with right anteroseptal accessory pathways (Fig. 3). Catheter-induced trauma to the AV node was short-lasting in one patient, but resulted in complete AV block lasting nearly 24 h in the other (Fig. 3).

Predictors of catheter-induced trauma (Table 2). In patients who underwent more than one ablation procedure, the catheter-induced mechanical trauma to the accessory pathway developed during only one of the procedures. Catheter-trauma to the accessory pathways occurred with a similar incidence in the Tel-Aviv and Sheba medical laboratories (9.1% vs. 10.6%, p = NS). There were no significant differences in age and gender of patients with and without catheter-induced trauma. Also, the pattern of conduction (manifest, concealed or intermittent) did not correlate with the occurrence of trauma. However, three variables correlated with the occurrence of mechanical trauma to accessory pathways: 1) the presence of multiple accessory pathways ($p < 0.05$), 2) the type of ablation catheter used ($p < 0.02$) and 3) the anatomic distribution of the accessory pathways. The incidence of trauma of right anteroseptal (10/26, 38.5%) or right atriofascicular pathways (5/15, 33.3%) was significantly greater than that of right midseptal (1/10, 10%), left free wall (18/229, 7.9%), posteroseptal (3/85, 3.5%) and right atrioventricular free wall pathways (0/30) ($p < 0.0001$). By multivariate logistic regression, however, the only independent variable associated with catheter-trauma to accessory pathways was its anatomic location (p = 0.0001). After entering this variable to the model, both the presence of multiple accessory pathways (p = 0.18) and the type of ablation catheter used (p = 0.064) were no longer predictors of catheter-induced mechanical trauma.

Timing of trauma. Trauma to the pathway occurred at the beginning of the procedure, before any radiofrequency pulse was administered, in 20 (54%) of the patients with catheter-trauma. In the remaining 17 patients, it occurred during catheter manipulation after one or more (mean 4.6 ± 3.3) unsuccessful radiofrequency applications had been given. The majority of traumatized right anteroseptal accessory pathways (9 of 10, 90%) were "bumped" before delivery of radiofrequency application, while most left free wall pathways (12 of 18, 67%) were bumped after ≥1 unsuccessful ablation attempts ($p < 0.02$).

Type of catheter involved. The majority (95%) of episodes of catheter trauma occurred during manipulation of an ablation catheter. Only five patients had accessory pathway trauma induced by a diagnostic catheter (including three patients who also had trauma induced by an ablation catheter). Trauma due to diagnostic catheters included traumatic block of a left free wall pathway that occurred during manipulation of a decapolar electrode catheter within the coronary sinus (two patients) and trauma to an anteroseptal pathway during placement of a quadripolar catheter in the His bundle area (one patient). In four patients, all with right atriofascicular fibers, an accessory pathway potential was recorded at the site of mechanical trauma. Interestingly, in all instances trauma-induced block occurred distally to the pathway potential.

Duration of catheter-induced mechanical trauma (Table 1). Catheter-induced trauma to the accessory pathway was very short lasting (resolving within 1 min) in 7 (19%) patients and lasted 5 to 30 min in three (8%). In 14 (38%) patients, an "immediate" radiofrequency pulse was given

Table 1. Characteristics of Patients who Developed Catheter-Induced Mechanical Trauma of their Accessory Pathways

Pt	S/A	AP Site	AP Block Features	RF Ablation Outcome	n	AP at End of RFA	Long-term Results
Tel-Aviv Medical Center							
1A	F 42	LFW (I)	≥30 s*	Immediate	6	Absent	Cure (53 m)
2A	M 33	LFW (C)	≥30*†	Immediate	0	Absent	Cure (42 m)
3A	F 23	RAS (M)	>50 min*§	Discontinued	0	Absent	Recurrence (1 d)
4A	M 21	RAS (M)	12 h*‡	Discontinued¶	0	Absence	Recurrence (1 m)
5A	F 43	LFW (C)	≥30 s*	Immediate	7	Absent	Cure (33 m)
6A	F 75	LFW (M)	≥1 h‖	Delayed	0	Absent	Recurrence (1 w)
7A	M 29	LFW (M)‡‡	≥30 s*	Immediate	4	Absent	Cure (25 m)
8A	F 22	RAF (M)	s*	Immediate	0	Absent	Cure (25 m)
9A	M 16	RAF (M)‡‡	s*§	Immediate	0	Absent	Cure (25 m)
10A	M 16	RAS (C)	≥2.5 h*	Delayed	0	Absent	Recurrence (m)
11A	M 18	RPS (M)	≥30 s*§	Immediate	0	Absent#	Recurrence (1 w)**
12A	M 15	RAF (M)	≤1 min*§	Immediate	6	Absent	Recurrence (<4 m)
13A	M 42	RAS (M)	>30 min*§	Discontinued¶	0	Absent	Recurrence (1 m)
14A	M 71	LFW (C)	≥30 s*	Immediate	0	Absent	Recurrence (1 m)
15A	F 32	RAF (M)‡‡	s*	Immediate	0	Absent	Cure (8 m)
16A	M 42	LFW (M)	≥30 s*	Immediate	0	Absent	Cure (7 m)
17A	M 23	RAS (M)	>30 min*‖	Discontinued¶	0	Absent	Recurrence (1 d)
18A	F 67	LFW (C)	30 min*	Continued	1	Absent	Cure (3 m)
19A	M 45	RAS (I)	≤1 min*	Continued	0	Absent	Cure (2 m)
20A	M 20	RAS (I)	>30 min§	Delayed	0	Absent	Recurrence (1 d)
Sheba Medical Center							
1B	M 20	RAS (M)	>30 min*	Discontinued¶	0	Absent	Cure (70 m)
2B	F 34	LFW (M)	≥30 s*	Immediate	3	Absent	Cure (52 m)
3B	M 36	LFW (M)	≥30 s*	Immediate	3	Absent	Cure (45 m)
4B	F 50	LFW (C)	>30 min*	Discontinued	0	Present	Recurrence (1 d)
5B	F 30	RAF (M)	>30 min*	Discontinued	12	Absent	Recurrence (1)††
6B	M 18	LFW (M)	≥30 s*	Immediate	1	Absent	Cure (31 m)
7B	M 22	RAS (M)	>1.5 h*‡	Discontinued¶	2	Absent	Recurrence (1 m)
8B	M 34	RAS (C)	>1 h*§	Discontinued¶	0	Absent	Recurrence (1 m)
9B	F 27	LFW (M)	s*‖	Continued	0	Absent	Lost follow-up
10B	M 18	RPS (M)	≥30 s*	Immediate	7	Absent	Cure (20 m)
11B	M 40	LFW (C)	≥1.7 h*	Delayed	4	Absent	Cure (19 m)
12B	M 60	LFW (C)	≥30 s*	Immediate	9	Absent	Cure (19 m)
13B	M 29	LFW (M)	≥30 s*‖	Immediate	3	Absent	Recurrence (1d)††
14B	M 25	RMS (M)	s‖	Continued	0	Absent	Cure (11 m)
15B	M 32	LFW (C)	15 min*†	Continued	1	Absent	Cure (11 m)
16B	M 50	RPS (M)	≥30 s*	Immediate	1	Absent	Cure (4 m)
17B	M 49	LFW (C)	5 min*	Continued	9	Present	Lost follow-up

AP = accessory pathway; (C) = concealed; Cure = no recurrence of AP conduction or SVT during follow-up; (d) = day; F = female; h = hour; (I) = intermittent; LFW = left free wall; M = male; (M) = manifest; (m) = month; min = minute; n = number of radiofrequency pulses administered before occurrence of mechanical trauma to the accessory pathway; Pt = patient; RAS = right anteroseptal; RAF = right atriofascicular; RFA = radiofrequency ablation; RMS = right midseptal; RPS = right posteroseptal; s = seconds; S/A = sex/age; (w) = week; * = with RF ablation catheter; † = during transeptal catheterization; ‡ = associated AV nodal trauma; § = reproducible with the same catheter; ‖ = with standard diagnostic catheter; ¶ = no radiofrequency pulse given; # = AP absent in the antegrade direction only; ** = recurrence in the retrograde direction only; †† = late cure (confirmed at electrophysiologic study); ‡‡ =multiple (≥2) accessory pathways.

within 30 s after the occurrence of mechanical trauma to the pathway so that the duration of the pathway trauma could not be determined. In the remaining 13 (35%) patients, catheter mechanical trauma to the accessory pathway lasted more than 30 min before the procedure was either discontinued or a "delayed" pulse administered. Of note, repeated catheter-induced trauma to an accessory pathway was observed during the same procedure in seven (19%) patients (4 of them with right anteroseptal accessory pathways).

Clinical course after catheter-induced mechanical trauma (Table 1). Of the 37 patients with catheter-induced trauma to the accessory pathway, "immediate" ablation was given to 18 (49%) patients and "delayed" ablation to four (11%). In six (16%) patients, the proce-

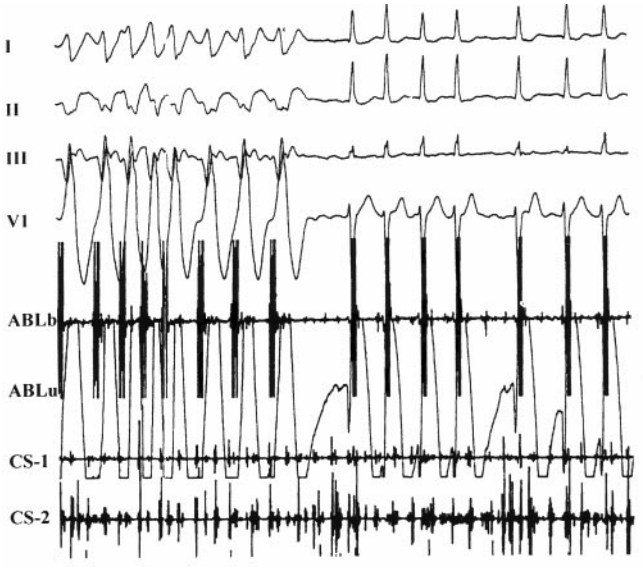

Figure 1. Catheter-induced mechanical trauma to a manifest left posterolateral accessory pathway during atrial fibrillation when manipulating the ablation catheter below the mitral annulus (Patient 7A). Shown are electrocardiographic leads I, II, III and V1 as well as intracardiac electrograms from the ablation (ABL) catheter (bipolar and unipolar) and the distal coronary sinus (CS-1 and CS-2). Note the early ventricular activation at the ablation catheter immediately prior to mechanical trauma.

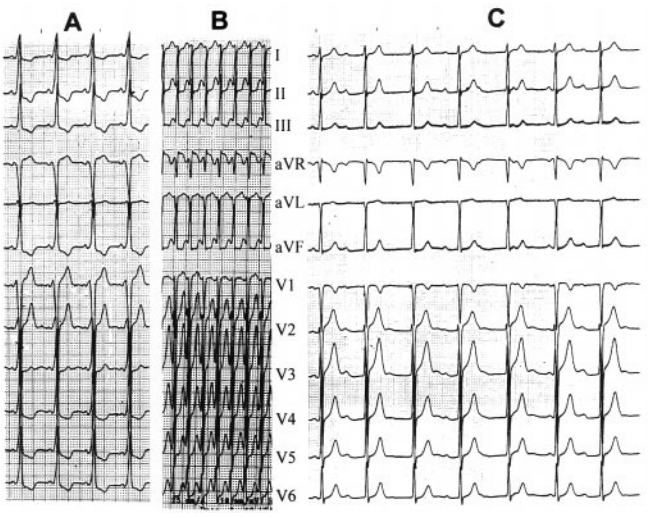

Figure 3. Complete AV block resulting from mechanical catheter-induced trauma to both a manifest right anteroseptal accessory pathway and the AV node (Patient 4A). **(A)** Manifest preexcitation is present in sinus rhythm at baseline. **(B)** Orthodromic AV reentrant tachycardia (260 beats/min) is induced at the beginning of the electrophysiologic study suggesting an excellent retrograde conduction over the right anteroseptal accessory pathway. **(C)** Complete AV block with junctional escape rhythm (75 beats/min) follows simultaneous mechanical trauma to both the accessory pathway and the AV node with the ablation catheter. Note the absence of retrograde conduction during junctional rhythm.

dure was continued after resumption of pathway conduction and in nine (24%) patients, the procedure was discontinued due to persistent trauma-induced block of the accessory pathway.

Of the 18 patients who underwent "immediate" ablation, none had recurrence of conduction over the accessory pathway at the end of the procedure. Fourteen of

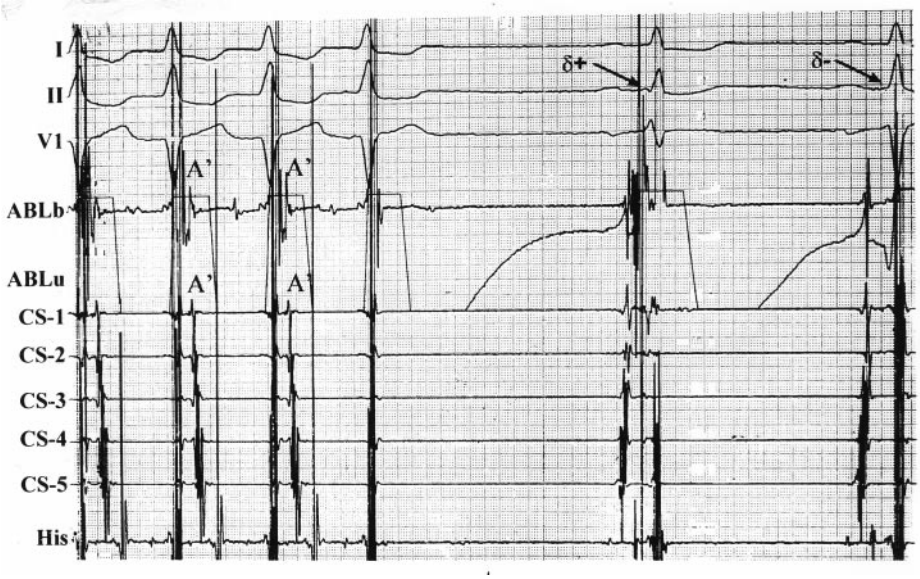

Figure 2. Mechanical trauma in the retrograde direction to a left lateral accessory pathway during orthodromic tachycardia when manipulating the ablation catheter below the mitral annulus (Patient 16A). Note that the retrograde block in the accessory pathway occurs at a site where the ablation catheter shows early atrial activation (VA′ = 70 ms). Also note the abolition of antegrade preexcitation on the second beat following tachycardia termination. Antegrade conduction over the accessory did not return during the following 30 s until an "immediate" pulse of radiofrequency energy was administered. The figure is arranged as in Figure 1.

Table 2. Univariate Comparison of Characteristics in Patients With and Without Catheter-Induced Mechanical Trauma to Accessory Pathways

Patient Characteristic	Trauma (N = 37)	No Trauma (N = 344)	p Value
Tel-Aviv/Sheba	20/17	200/144	NS
Mean age (±SD) in years	34.4 ± 15.9	32.6 ± 14.8	NS
Male sex	26 (70%)	223 (65%)	NS
Single/Multiple AP's	34/3	336/8	0.046
7 Fr/8 Fr catheters*	6/29*	127/217	0.0195
Pathway Characteristic	**Trauma (N = 37)**	**No Trauma (N = 358)**	
Pathway type			
–Manifest	23	192	
–Concealed	11	133	NS
–Intermittent	3	33	
Pathway location			
–LFW	18 (7.9%)	211 (92.1%)	
–RAVFW	0	30 (100%)	
–RAFFW	5 (33.3%)	10 (66.6%)	$p < 0.0001$
–PS	3 (3.5%)	82 (96.5%)	
–RAS	10 (38.5%)	16 (61.5%)	
–RMS	1 (10%)	9 (90%)	

AP = accessory pathway; Fr = French; LFW = left free wall; PS = posteroseptal; RAS = right anteroseptal; RAFFW = right atriofascicular free wall; RAVFW = right atrioventricular free wall; RMS = right midseptal; * = refer only to pathway trauma due to ablation catheters, not to diagnostic catheters.

them (78%) had definite cure of their arrhythmia during a follow-up period of 25 ± 16 months. The remaining four (22%) patients had recurrent conduction over the accessory pathway after a follow-up period ranging from one day to four months. These relatively good long-term results contrast with the outcome observed in the four patients who received a "delayed" ablation. Although evidence of conduction over the accessory pathway was not present at the end of the procedure in any of these four patients, 3 (75%) of them had recurrent symptomatic tachycardias related to recurrence of pathway conduction during follow-up.

Of the six patients in whom the procedure was continued after resumption of pathway conduction following trauma, successful ablation was subsequently achieved in five (83%). Of these five patients, four had definite cure of their arrhythmias during follow-up while the remaining patient was lost for follow-up. Finally, of the nine patients with "persistent trauma" in whom the procedure was discontinued, definite cure was observed in one patient with right anteroseptal pathway while conduction over the pathway recurred during follow-up in 8 (89%) patients. In one of these eight patients (a patient with a right atriofascicular pathway), definite late cure was subsequently observed (and confirmed at repeated electrophysiologic study).

For comparison, the overall acute success rate of radiofrequency ablation procedures in our 344 study patients who did not develop mechanical trauma of their accessory pathways was 86% with a recurrence rate of pathway conduction of 8.4% in these patients with acute success.

Correlation between pathway location and ablation outcome (Table 1). Of the 18 patients with catheter-induced trauma to a left free wall accessory pathway, an "immediate" radiofrequency pulse was given to 11 (61%), achieving a definite arrhythmia cure in nine (82%) of these patients. Of the 10 patients with catheter-induced trauma to a right anteroseptal pathway, the ablation procedure had to be discontinued in seven (70%), and arrhythmia recurrence was observed in six (86%) of these patients. Of the 5 patients with catheter-induced trauma to a right atriofascicular fiber, an "immediate" radiofrequency pulse could be given to four (80%) with a definite arrhythmia cure achieved in three (75%) of these patients.

DISCUSSION

Main findings. In this prospective study of 381 consecutive patients undergoing radiofrequency ablation of accessory pathways, we identified catheter-induced mechanical trauma to an accessory pathway in 37 (9.7%) patients. This series of 37 patients with mechanical trauma to accessory pathways is the largest reported to date, enabling a good assessment of this phenomenon, its predictors and clinical implications. The only independent predictor of catheter-trauma to accessory pathways was the anatomic location of the bypass tract. Catheter trauma was significantly more frequent among patients with right anteroseptal pathways and among those with right atriofascicular pathways. Finally, the occurrence of catheter-induced mechanical trauma to accessory pathways markedly affected the course and the success rate of the ablation procedure.

Comparison with previous studies. Although catheter-induced trauma has been recognized for 20 years, most reports involve selected cases or small series of patients (7–13). The only previous systematic evaluation of the incidence of catheter-induced mechanical trauma to accessory pathways was reported by Chiang et al. (4). That study, which included 367 patients (with 401 accessory pathways), reported catheter-induced trauma of accessory pathways in only nine (2.4%) patients. Possible explanations for the higher (9.7%) incidence of mechanical trauma in our study include the following: first, it is possible that we manipulated the ablation catheters with excessive vigor. However, the similar incidence of mechanical trauma in the two medical centers participating in this study makes this presumption unlikely. This is because different teams of experienced physicians manipulated the catheters in the two institutions. Second, the type of ablation catheter used could have played a role. Only 7-French catheters were used by Chiang et al. (4), whereas both 7-French and 8-French catheters were used in our study. Although the use of an 8-French catheter was not independently associated with the occurrence of mechanical trauma to accessory pathway in our study, the p value found ($p = 0.064$) suggests a trend in favor of its role in the investigated phenomenon. Another plausible explanation for the lower incidence of catheter-trauma reported by Chiang et al. relates to the brief duration of many episodes of trauma-induced conduction-block along the accessory pathways. Indeed, short-lasting mechanical trauma to accessory pathways with resolution within 1 min was observed in seven (19%) patients with catheter trauma in our study. For comparison, Chiang et al. did not mention any case of trauma-induced block of the accessory pathway lasting less than 1 h.

Anatomic location of accessory pathways and catheter-induced trauma. In the present study, right anteroseptal and right atriofascicular pathways exhibited the highest incidence of mechanical trauma (38.5% and 33.3%, respectively). These figures are consistent with observations made by others (10–13). Schluter et al. (10) and Haissaguerre et al. (11) reported transient mechanical block in right anteroseptal or parahissian accessory pathways in five of 12 (42%) patients and two of eight (25%) patients, respectively. Also, McClelland et al. (12) and Cappato et al. (13) reported a 57% (13/23) and a 82% (9/11) incidence of trauma, respectively, in patients with right atriofascicular accessory pathways. It has been suggested that the superficial subendocardial location of right anteroseptal and atriofascicular fibers makes them especially susceptible to mechanical trauma (11,13). Indeed, Cappato et al. (13) took advantage of this susceptibility and intentionally attempted to injure the pathways during catheter manipulation as part of their criteria to identify pathway's location.

Another interesting observation in our study was the relatively high incidence of mechanical trauma to left free wall accessory pathways (7.9%) which was significantly higher than that noted by Chiang et al. (2%) (4). Nearly half of all pathway traumas observed in our study (18 of 37) involved left-sided pathways. Catheter-trauma to left free wall accessory pathways has only rarely been reported (4,8,9). However, it is possible that the incidence of trauma to left free wall accessory pathways is underestimated. This is because a minor degree of preexcitation, which is frequently observed in antegradely conducting left-sided accessory pathways, may render the recognition of their abolition by mechanical trauma more difficult.

Left free wall accessory pathways were usually "bumped" after one or more unsuccessful ablation attempts. This observation suggests that mechanical trauma to left-sided pathways could have been facilitated by injury created by previous radiofrequency applications. In contrast, trauma-induced block of right anteroseptal pathways generally occurred before any application of radiofrequency pulse, suggesting a more sensitive location of these pathways.

The clinical course following catheter trauma also appears to differ among pathways at different locations. The occurrence of catheter-trauma to an atriofascicular pathway (especially when it was immediately preceded by local recording of an accessory pathway potential) or a left free wall accessory pathway prompted the delivery of an "immediate" radiofrequency pulse with subsequent reasonable (75% to 82%) rate of definite cure. In contrast, trauma to a right anteroseptal accessory pathway usually led to discontinuation of the procedure with eventual recurrence of arrhythmias in a high percentage (86%) of patients. It is likely that the risk of damaging the normal conducting system in the latter instance and not in the former played a major role in the different therapeutic attitudes adopted.

Limitations. Mechanical trauma to pathways that exhibit manifest antegrade conduction is generally easy to diagnose during sinus rhythm or atrial fibrillation. In contrast, in patients with concealed accessory pathways, the diagnosis of mechanical trauma requires either orthodromic tachycardia or ventricular pacing. Thus, it is possible that trauma of concealed pathways is actually more frequent than reported in the present study. In addition, one could speculate that the inability to induce tachycardia in some patients with documented spontaneous AV reentry tachycardia is due to trauma to accessory pathways caused during manipulation of diagnostic or ablation catheters.

The natural history of catheter-induced trauma in patients who received an "immediate" ablation could not be defined and one cannot exclude the possibility of definite cure by catheter trauma in these patients. However, the high recurrence of pathway conduction among patients who did not receive radiofrequency ablation immediately upon recognition of trauma makes this possibility very unlikely.

Clinical implications and conclusions. The anatomic distribution of accessory pathways in our study was similar to that reported in large series of patients undergoing ablation procedures (14–18). Accordingly, our results are likely to be

indicative of the risk of catheter-induced trauma during radiofrequency ablation of accessory pathways. Several important practical implications can be drawn from the results of our study. First, close observation of the electrocardiographic recordings—even during long and tedious procedures—is imperative in order to promptly recognize catheter-induced trauma of an accessory pathway. Second, whenever conduction block in the pathway does not resolve within 1 min, and providing that the catheter did not move from the site of presumed trauma, radiofrequency energy should be delivered immediately ("immediate pulse"). In this case, acute successful ablation should be expected in most cases as attested by our results (78% definite cure) and by those reported by Cappato et al. (13). Although this success rate is slightly slower than the success rate achieved in patients with no mechanical trauma of their accessory pathways (86%), adopting such an attitude appears better than waiting for hypothetical resumption of pathway conduction. Such an expectant attitude may prolong the ablation procedure considerably. Moreover, waiting for spontaneous pathway conduction to resume may eventually lead to unintentional movement of the ablation catheter away from the trauma site. Once the ablation catheter moves, attempts to reposition the catheter at the site of trauma for "delayed" radiofrequency application will most likely lead to failure, as attested by the poor late results observed in our study. Therefore, if the pulse is not given "immediately" upon trauma recognition, it seems wise to withdraw the offending catheter, observe the patient and repeat mapping and ablation trial if pathway conduction resumes. Finally, catheter-induced pathway trauma is often persistent, leading to discontinuation of mapping and ablation procedure in 24% of cases of mechanical trauma in our study. Although the long-term risk for recurrence is high, the possibility of definite cure by trauma (observed in two of nine patients) may justify a conservative attitude.

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