Catheter-Induced Mechanical Trauma to Fast and Slow Pathways during Radiofrequency Ablation of Atrioventricular Nodal Reentry Tachycardia: Incidence, Predictors, and Clinical Implications

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Background: Data on the incidence and significance of catheter-induced trauma to fast and slow pathways are scarce.

Objectives: To evaluate the incidence, predictors, and clinical implications of inadvertent catheter-induced mechanical trauma to fast and slow pathways during radiofrequency ablation (RFA) of atrioventricular nodal reentry tachycardia (AVNRT).

Methods: A total of 901 consecutive patients (aged 9–92 years old) with inducible sustained AVNRT underwent RFA of the slow pathway. All procedures were closely monitored for appearance of catheter-induced mechanical block of fast or slow pathways.

Results: Catheter-induced mechanical trauma to fast and/or slow pathways was observed in 121 (13.4%) patients: 86 (71%) patients had trauma of the fast pathway, three (2.4%) had trauma of the slow pathway, and 32 (26.4%) had trauma of both pathways. Mechanical trauma lasted <1 minute in 87 (72%) patients, 1–30 minutes in 23 (19%) and >30 minutes in 11 (9%). A significantly increased procedure discontinuation rate was observed in patients with mechanical trauma as compared to those with no trauma (P < 0.0001). Young patient age (<35) was a strong predictor for the occurrence of mechanical trauma to AV nodal pathways. No significant difference between the trauma and non-trauma groups was found in respect to the number of catheters used during the procedure, the incidence of AV block, and the need for permanent pacemaker implantation.

Conclusions: Mechanical trauma to fast and slow pathways during ablation of AVNRT is more common than previously recognized, occurring especially in patients aged <35 years. (PACE 2007; 30:1233–1241)

atrioventricular node, radiofrequency catheter ablation, heart block

Introduction

Conduction block over anatomical structures sometimes occurs during manipulation of catheters in the cardiac chambers.1–6 This conduction block is ascribed to mechanical trauma and is referred to as “catheter-induced trauma.” Atrioventricular nodal reentry tachycardia (AVNRT) is the most frequent cause of regular, paroxysmal supraventricular tachycardia.7 Two pathways in the region of the AV node are classically assumed to participate in the tachycardia circuit: a “fast pathway” located anteriorly over the apex of Koch’s triangle and a “slow pathway” formed by inferior extension from the compact AV node along the postero-medial tricuspid annulus.7,8 However, there is mounting evidence that the circuit is functionally-based rather than anatomic8 and that nonuniform anisotropy within the triangle of Koch is a substrate that can support reentry involving dual pathways physiology.9 Radiofrequency ablation (RFA) of the slow pathway has become first-line therapy for curing AVNRT.10–14 Many previous studies have shown the high success rate of the procedure associated with a very low incidence of complications (mainly severe AV conduction disturbances requiring pacemaker implantation).10–14 Despite the huge number of reports, we have been able to find only a single study specifically assessing the incidence of mechanical trauma to AV nodal pathways during RFA of AVNRT. Chiang et al.4 found an incidence of 1.6% in a group of 254 treated patients. In the present prospective study, we assessed the incidence, predictors, and clinical implications of catheter-induced mechanical trauma to fast and slow pathways in a large single center cohort of patients undergoing RFA of AVNRT.

Conflict of Interest Statement: No potential conflict of interest.

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Methods

Patient Population (Table I)

The patient population consisted of 901 consecutive patients who underwent RFA of AVNRT during a 14-year period (1/1992–12/2005). All patients had sustained AVNRT induced before or after intravenous administration of isoproterenol at baseline electrophysiologic study. Data were prospectively collected for 554 (61.5%) females and 347 (38.5%) males, ranging in age from nine to 92 (mean 50.8 ± 18.2) years. The patients were divided into quartiles according to the time of the RFA procedure. Among the four patients groups, group 1 was the youngest while group 4 was the oldest (P < 0.0005 for trend). Also, a progressive increase in the frequency of organic heart disease was observed between the study quartiles (P = 0.002). Detailed results of the ablation procedure in the four quartiles of patients have been published elsewhere.14

One of the investigators (B.B.) participated in all ablation procedures but six. This investigator was in charge of monitoring the surface and intracardiac signals throughout the whole electrophysiologic study.

Table I.

Patient Characteristics and Results of the Ablation Procedure

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<th>Patient Group (n = 901)</th>
<th>No Trauma (n = 780)</th>
<th>Trauma (n = 121)</th>
<th>P Value</th>
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| Patients
| characteristics |                        |                     |                  |         |
| Female prevalence | 61.5%                  | 60.5%               | 67.7%            | 0.127   |
| Mean age (years)  | 50.8 ± 18.2            | 52.1 ± 17.7         | 42.7 ± 19.1      | <0.001  |
| Organic heart disease | 8.3%                 | 9.1%               | 3.3%             | 0.032   |
| Induced tachycardia mechanism | Slow/fast | 833 (92.5%) | 720 (92.3%) | 113 (93.4%) | N.S     |
|                          | Fast/slow             | 23 (2.6%)          | 21 (2.7%)        | 2 (1.7%) | N.S     |
|                          | Slow/fast + fast/slow | 7 (0.8%)           | 6 (0.8%)         | 1 (0.8%) | N.S     |
|                          | Various involving slow | 38 (4.2%)       | 33 (4.2%)        | 5 (4.1%) |         |
| Number of catheters used | 2 Catheters       | 584 (64.8%)        | 504 (64.6%)      | 80 (66%) |         |
|                          | >2 Catheters          | 317 (35.2%)        | 276 (35.4%)      | 41 (34%) | 0.748   |
| Acute procedure results | Success             | 877 (97.3%)        | 764 (97.9%)      | 113 (93.4%) | 0.004   |
|                          | Failure               | 10 (1.1%)          | 9 (1.2%)         | 1 (0.8%) | 0.749   |
|                          | Discontinued          | 14 (1.6%)          | 7 (0.9%)         | 7 (5.7%) | <0.001  |
|                          | No of successful RF pulses | 5.0 ± 5.9       | 4.8 ± 5.6        | 6.3 ± 7.4 | 0.035   |
| Procedure-related complications* | > II degree AVB | 31 (3.4%)          | 25 (3.2%)        | 6 (5.0%) | 0.325   |
|                          | - requiring pacemaker | 8 (0.9%)           | 7 (0.9%)         | 1 (0.8%) | 0.938   |

AVB = atrioventricular block; RF = Radiofrequency.

Electrophysiologic Study

All electrophysiologic studies were performed after written informed consent was obtained from the patient or his/her parents. Only three young patients underwent the procedure under general anesthesia; the remaining patients were only mildly sedated with intravenous midazolam. At the beginning of our experience, a multi-catheter approach was used including the placement of three diagnostic electrode-catheters in the coronary sinus (CS), the right ventricular (RV) apex, and the His bundle area, as well as the ablation catheter. Later, a “two-catheter approach” using a single diagnostic electrode-catheter placed in the high right atrium and an ablation catheter was employed, except when ablation of AVNRT was performed after ablation of another arrhythmia (accessory pathway, atrial flutter, or tachycardia) or when the mechanism of the tachycardia was unclear. The ablation catheter was usually a Mansfield/Cordis/Webster catheter (temperature-guided or not) and less commonly a temperature-guided catheter (EP Technologies, Boston Scientific, Natick, MA, USA). Both catheters have a 4-mm distal ablation electrode and a deflectable curve.
The baseline electrophysiologic study included (1) incremental atrial stimulation to evaluate the presence of dual AV nodal physiology as well as the properties of the fast and slow pathways; (2) rapid atrial pacing and/or delivery of one to three extrastimuli as well as ventricular stimulation if AVNRT was not induced with atrial stimulation. If sustained AVNRT (lasting >30 s) was not induced using this protocol, isoproterenol (starting at 1µg/min) was administered at incremental dosage until the basic sinus rhythm increased by ≥20% and the stimulation protocol was repeated.

Radiofrequency Ablation

RFA of the slow pathway was performed according to a standard combined electrophysiological-anatomic approach. Briefly, the catheter tip of the ablation catheter was positioned at the His bundle area and progressively withdrawn along the tricuspid annulus, starting ablation at the most posterior site (near the CS ostium) and progressing to the more anterior locus (closer to the His bundle recording site). RF energy was delivered with a temperature setting of 55–60°C using an initial 26-Watt power that was gradually increased up to 60 Watts if necessary. If an accelerated junctional rhythm was recognized within 30 seconds, the energy delivery was continued for a total of 1 minute. Administration of RF energy was discontinued upon occurrence of AV block, very rapid junctional rhythm, or retrograde VA block during junctional rhythm. Successful ablation or modification of the slow pathway was considered to be achieved when, after RF application, no AV nodal echo or 1–3 AV nodal echo beats, respectively, could be induced with cardiac stimulation during isoproterenol infusion.

Mechanical Trauma to AV Nodal Pathways

A baseline 12-lead electrocardiogram (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. Catheter-induced mechanical trauma to AV nodal pathways was defined as follows: (1) any block in these pathways when it occurred at any time of the ablation procedure during catheter manipulation when the catheter (diagnostic or ablation) was at the culprit area or had been there shortly before occurrence of the block; (2) the block was unrelated to administration of radiofrequency pulses or drugs and was not accompanied by any pain or neuro-vegetative changes.

- Trauma to the fast pathway was defined by any of the following: (1) sudden increase in PR interval (≥50ms) on two consecutive beats; (2) abolition of retrograde fast pathway conduction or significant (arbitrarily defined as ≥150ms) prolongation in ventricular pacing cycle length inducing retrograde fast pathway block.
- Trauma to the slow pathway was defined by the abolition of slow pathway conduction in a patient who manifested obvious slow pathway conduction prior to the trauma.
- Trauma to both the fast and slow pathways was defined by any combination of the above definitions including the occurrence of at least one blocked P-wave. The duration of the trauma to the 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 ablation procedure was discontinued when mechanical trauma to the fast pathway has not fully recovered after 1-hour observation.

Statistical Analysis

All continuous variables were presented as mean ± standard deviation and all categorical variables were presented as number of patients and percentages. For all continuous variables the comparisons between the four study groups were done using one way analysis of variance (ANOVA), and for categorical variables using the Cramer’s V under χ² analysis. For all statistical analyses P-value <0.05 was considered statistically significant. The SPSS statistical package was used to perform all statistical analyses (SPSS Inc., Chicago, IL, USA).

Results (Table I)

Patient Characteristics

Of the 901 patients enrolled in the cohort, mechanical trauma to fast or slow pathway occurred in 121 (13.4%) patients. There were 82 (67.7%) females and 39 (32.3%) males, ranging in age from nine to 92 (mean 42.7 ± 19.1) years. Underlying organic heart disease was present in four (3.3%) patients. As compared to the non-trauma patients, those with mechanical trauma were younger (P < 0.001) and had a lower incidence of organic heart disease (P = 0.032). Analysis of five quintiles of patient age showed that the group of patients aged <35 had the highest incidence of mechanical trauma (26.2%) as compared with the four other groups (P < 0.0005) (Fig. 1). However, there was no significant difference between the mechanical trauma and the non-trauma groups in respect to patient gender. By multivariate logistic regression analysis, the only independent variable associated with
catheter-trauma to AV nodal pathways was patient age (odds ratio 3.14, with 95% confidence interval of 2.09–4.73); however, the presence of organic heart disease was no longer a predictor of catheter-induced mechanical trauma.

Electrophysiological Characteristics

Of the 121 patients with mechanical trauma, the mechanism of tachycardia during electrophysiological study was slow/fast “typical” AVNRT in 113 (93.4%) patients, fast/slow (“atypical” AVNRT) in two (1.7%), both slow/fast and fast/slow AVNRT in one (0.8%), while it involved various slow pathways in five (4.1%) patients. There was no significant difference between the mechanical trauma and the non-trauma patients groups in respect to AVNRT mechanism.

Location and Duration of Catheter-Induced Trauma

Among the 121 patients with catheter trauma, 86 (71%) had fast pathway trauma, three (2.4%) had slow pathway trauma and 32 (26.4%) had both (Figs. 2–4). The effects of mechanical trauma were short-lasting, resolving within 1 minute (and in most cases observed only for a few beats) in 87 (72%) patients. In all instances where mechanical trauma lasted ≥2 beats, the PR interval remained constant before returning to baseline value (Fig. 2). Mechanical trauma lasted 1–30 minutes in 23 (19%) patients. In the remaining 11 (9%) patients, catheter mechanical trauma to slow or fast pathways lasted more than 30 minutes. The longest duration of trauma of the fast pathway was 120 minutes in one patient.

Type of Catheter Involved

In 118 (97.5%) patients, catheter trauma manifestly occurred during manipulation of the ablation catheter. The introduction of a standard diagnostic catheter in the RV apex was responsible for a long-lasting (# 40 min) trauma to both slow and fast pathway in one patient and a short-lasting (seconds) trauma of the fast pathway in another patient. In one patient, long-lasting slow pathway trauma followed the laborious introduction of a decapolar catheter in the CS.

Incidence of Trauma According to Quartiles of Study Periods

Catheter-induced trauma to fast and/or slow pathways was observed in 34 (15.1%), 42 (18.7%),

Figure 1. Percent of patients experiencing mechanical trauma in the five quintiles of patient age.

Figure 2. Transient catheter-mechanical trauma to the fast pathway in a 30-year-old woman. Note that the PR and AH intervals increase by 60 ms on the second complex (*) and return to their initial values 8 seconds later (**).
CATHETER-INDUCED TRAUMA OF AV NODAL PATHWAYS

Figure 3. Catheter-mechanical trauma to both the fast and slow pathway in a 49-year-old woman with antegrade dual AV node physiology. (A) before mechanical trauma, a normal AH interval (100ms) is present; (B) During mechanical trauma, both the fast pathway and the slow pathway were affected (prolongation of AH interval by 60ms followed by second degree AV block). Return to normal AV conduction was observed within 1 minute and ablation procedure subsequently performed.

29 (12.8%), and 16 (7.1%) of the four study quartiles, respectively. A significant decrease in the incidence of catheter-induced trauma was noted between the last three study quartiles (P < 0.0001 for trend).

“Two-Catheter” Versus “Multi-Catheter” Approach

A similar number of patients underwent the ablation procedure using a “two-catheter” approach (64.6% and 66% in the non trauma and trauma groups, respectively). The incidence of catheter trauma was similar in these groups of patients irrespectively of the technique used (13.7% and 12.9% using the “two-catheter” approach and the “multi-catheter” approach, respectively, P = NS).

Ablation Results

In 114 (94.2%) of the 121 patients with catheter-induced mechanical trauma, the procedure was continued after resumption of pathway conduction and successful RFA of the slow pathway was performed during the same procedure in all patients but one (for an overall 93.4% success rate). The procedure was discontinued in seven (5.8%) patients. Of the 780 patients who did not develop mechanical trauma, the overall acute success rate was 97.9% while the procedure had to be discontinued in seven (0.9%). An increased procedure discontinuation rate (P < 0.001) and a decreased success rate (P = 0.004) were observed in the mechanical trauma group as compared to the non-trauma group. The number of radiofrequency pulses required for achieving a successful ablation was higher in the trauma group than in the non-trauma group (6.3 ± 7.4 vs 4.8 ± 5.6, P = 0.035). There were no significant differences in the rate of complications (mainly AV blocks and the need for pacemaker implantation) between the trauma and the non-trauma groups.
Discussion

Main Findings

In this prospective study of 901 consecutive patients undergoing RFA of AVNRT, we observed catheter-induced mechanical trauma to fast and/or slow pathway in 121 (13.4%) patients. This series is the largest reported to date, enabling a good assessment of this phenomenon, its predictors and clinical implications. We found that catheter-induced mechanical trauma to fast and/or slow pathway was short-lasting (<1 min) in most patients (72%), almost always due to the ablation catheter (97.5%), unrelated to the number of catheters used during the procedure and associated with a higher procedure discontinuation rate.

Figure 4. Prolonged damage to both fast and slow pathways with an ablation catheter in a nine-year-old girl. (A) Before mechanical trauma: (a) normal AH (60 ms) is present during sinus rhythm; (b) sustained slow/fast AVNRT (cycle length # 370 ms) is induced with single atrial extrastimulation (A1A2 = 360 ms) at a basic cycle length of 600 ms; (c) during incremental atrial pacing, antegrade dual AV nodal physiology is observed with block in the fast pathway at a cycle length of 370 ms followed by conduction over the slow pathway; (d) excellent retrograde fast pathway conduction is noted with block at a ventricular paced cycle length of 330 ms. (B) After mechanical trauma: (a) prolongation of AH to 150 ms is present during sinus rhythm suggesting damage to the fast pathway; (b) second degree AV block (Wenckebach type) occurs at an atrial pacing cycle length of 570 ms without evidence of slow pathway conduction, suggesting damage to both the antegrade fast and slow pathways. (c) Lack of retrograde conduction during ventricular pacing at a cycle length of 500 ms is noted suggesting impairment of the retrograde fast pathway. Conduction over both pathways recovered after # 50 minutes and enabled subsequent successful RFA of the slow pathway.
but not with a higher risk of AV block requiring pacemaker implantation. According to multivariate analysis, the only independent predictor of mechanical trauma was patient young age (<35).

**Comparison with Previous Studies**

The occurrence of catheter-induced trauma to accessory pathways and atrial and ventricular foci during RFA is well known. However, data on the incidence and significance of catheter-induced trauma to AV nodal pathways during AVNRT ablation are scarce. Chiang et al. reported a 1.6% incidence of mechanical trauma to AV nodal pathways during AVNRT ablation in a group of 254 patients. In our study, we found a much higher incidence of this complication (13.4%) using the standard technique described by Wu et al. There are two possible explanations for the discrepancy between Chiang et al.’s results and ours: (1) Since we found a significant decrease in the incidence of catheter-induced trauma between the last three study quartiles, one may suspect an improved technical expertise in manipulation of the ablation catheter throughout the study period. However, this explanation seems insufficient alone to explain our results due to the following: (a) the same three electrophysiologists in charge of the manipulation of catheters during most ablation procedures were aware of this complication since the inception of our ablation program and did their best to avoid it; (b) the incidence of trauma in the last quartile of patients remained relatively high (7.1%). (2) Another explanation relates to the brief duration (<1 min and frequently less than a few seconds) of catheter-mechanical trauma to AV nodal pathways in most (72%) of our patients. For comparison, Chiang et al. did not mention any case of trauma-induced block to the fast or slow pathway lasting...
less than 1 hour. Thus one may speculate that in their study, short-lasting mechanical trauma was either not diagnosed or not reported. Our data suggest that close ECG monitoring during manipulation of catheters and inclusion of any temporary mechanical trauma played an important role in our observations.

Predictors of Mechanical Trauma

In our previous work dealing with catheter-induced mechanical trauma to accessory pathways, we found no effect of patient age on the incidence of this complication. In contrast, in the present study, a very high incidence (26.2%) of mechanical trauma to AV nodal pathways was observed in the youngest group of patients (aged <35 years). The explanation for this surprising finding is unclear, but could relate to the age dependent morphological changes in the atrioventricular node area. Waki et al. described maturational changes in the AV node area. While the AV node of a <1 year of age is half-oval, dense, and sandwiched between a tightly packed layer of transitional cells and the central fibrous body, with increasing age, the shape of the AV node gradually changes into a more spindle-shaped structure with an increasing amount of fibro-fatty tissue changing the tightly packed nature of the transitional cell zone into a much more loosely arranged morphology. Furthermore, age-related changes include a more upright position of the AV node “plastered” onto the right-sided crest of the septum, and a wider distance between the two inferior extensions of the compact AV node. The effects of age-related changes probably bring about the electrophysiological conditions that result in dual AV node pathways, but may also produce an anatomical environment protective against mechanical trauma in older patients.

Limitations

The great majority of catheter-induced mechanical traumas involved the fast pathway and were easily recognized when sudden prolongation of PR or AH interval occurred. However, it may be more difficult to identify trauma to slow pathway since it requires demonstration of slow pathway conduction prior to the trauma. This could lead to an underestimation of this phenomenon if for example slow pathway trauma occurred during catheter manipulation at slow pathway locations after delivery of radiofrequency pulses unassociated with junctional rhythm and thus not followed by a systematic assessment of slow pathway conduction. Finally, defining the occurrence of at least one blocked P-wave as a trauma to both fast and slow pathway could indicate that antegrade dual AV node physiology was present in all study patients. In fact, antegrade dual AV nodal physiology was proved or highly suspected in only 94% of study patients (all who exhibited a slow/fast AV nodal reentry mechanism). Furthermore, we recognize that the complexity of the AV nodal structure precludes positive distinction of trauma to both fast and slow from trauma to the compact node, the upper common pathway or a pre-Hisian structure.

Clinical Implications

Several implications can be drawn from the results of our study: (1) Close observation of the ECG recordings, even during long and tedious ablation procedures, is imperative in order to promptly recognize catheter-induced mechanical trauma of fast and/or slow pathways. (2) Catheter-induced mechanical trauma to AV nodal pathways results in lower procedure success rate mainly due to higher discontinuation rate. (3) Particular caution is warranted in young patients (aged <35 years) presumably due to the age-dependent AV nodal morphologic changes.

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References


