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Duration of the A(H)–A(Md) interval predicts occurrence of AV-block after radiofrequency ablation of the slow pathway

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Abstract

Purpose Modification of the slow pathway (SP) of the atrio-ventricular node by radiofrequency ablation is the most effective treatment to cure AV nodal reentry tachycardia (AVNRT). However, this therapy may be complicated by AV-block (AVB). We sought to evaluate the predictive value of the A(H)–A(Md) interval—the electrical delay between atrial signals on the His- and the ablation-catheter—upon development of AVB during SP ablation.

Methods The associations between A(H)–A(Md) interval, occurrence of ventriculo-atrial block (VAB) during junctional activity (JA) and transient or permanent AVB were analyzed retrospectively for 1585 RF applications at the SP in 393 patients diagnosed with AVNRT. The value of A(H)–A(Md) was further tested prospectively in 118 AVNRT patients, who were only ablated at targets with intervals >20 ms.

Results Forty-six RF deliveries resulted in transient or permanent AV-conduction disturbances. Shorter A(H)–A (Md) intervals were associated with the occurrence of VAB during JA ($p<0.001$) and AVB ($p<0.001$). A(H)–A(Md) was the strongest predictor for VAB or AVB in multivariate regression analyses, followed by the radiological distance between the catheters. In the prospective study, permanent high-degree AVB was not observed when the A(H)–A(Md) at the ablation site was >20 ms.

Conclusion The A(H)–A(Md) interval is a better predictor for occurrence of conduction block during ablation for AVNRT than the radiological distance between the His- and the ablation-catheter. The risk of permanent AVB can be minimized, if only sites with an A(H)–A(Md) longer than 20 ms are targeted for ablation.

Keywords AV nodal reciprocating tachycardia · AVNRT · Complication · Junctional tachycardia · VA-block

Abbreviations

AVB	Atrioventricular conduction block
CL	Cycle length
CS	Coronary sinus
EGM	Electrocardiogram
FP	Fast pathway
JA	Junctional activity, i.e., junctional ectopy
RF	Radiofrequency
SP	Slow pathway
VAB	Ventriculo-atrial conduction block
XR	Radiological distance between the His- and the ablation catheter on fluoroscopy

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1 Introduction

Atrioventricular nodal reentry tachycardia (AVNRT) is the most common form of paroxysmal supraventricular tachycardia [1]. The underlying substrate of AVNRT is dual atrioventricular (AV) nodal physiology consisting of fast (FP) and slow pathway (SP) conduction [2]. Typical activation of the FP is recorded at the anterior aspect of the atrial septum close to the recording site of the His-bundle potential, whereas SP conduction extends at the infero-posterior septum between the tricuspid annulus and the coronary sinus (CS) ostium [3, 4]. Radiofrequency (RF) catheter ablation at the atrial input into the SP has evolved as first-line treatment of recurrent AVNRT [5]. SP ablation is usually guided by anatomic landmarks on fluoroscopy as well as intracardiac electrograms [6] and has a high acute success rate of 95–98% [7] as well as a rare incidence of recurrence during long-term follow-up [8]. However, permanent AV conduction block may be a serious complication of this therapy, which affects approximately 1% of patients during or after treatment [9].

SP modification as the primary endpoint of ablation is defined by non-inducibility of the tachycardia, whereas complete SP ablation is achieved, if additionally dual AV nodal physiology is abolished after RF energy delivery. A sensitive sign for primary success of the procedure is an accelerated junctional activity (JA) during RF ablation, which probably occurs due to thermal injury of the compact AV node and/or perinodal tissue [6]. By contrast, loss of ventriculo-atrial (VA) conduction during JA predicts impending AVB after ablation [10, 11]. Unfortunately, irreversible injury of AV conduction sometimes cannot be prevented by immediate termination of RF energy delivery as soon as VA block occurs. Moreover, JA is not observed during cryothermal ablation of AVNRT, which is increasingly used in electrophysiology laboratories for SP ablation [12]. Therefore, anatomic and electrophysiologic parameters to stratify the risk of AVB in SP ablation before the start of the ablation are needed. The visual distance between the ablation catheter and the electrode recording His-bundle signals (X-ray distance (XR)) on fluoroscopy is commonly used to judge the risk of AVB. However, fluoroscopy techniques have limited anatomic resolution, and this parameter highly depends on the slope of Koch's triangle [5].

We previously defined measurements of the A(H)–A(Md) interval as important electrophysiological markers to assess the risk of AV block in SP ablation [13]. A(H)–A(Md) is assessed by measuring the delay between the earliest atrial deflection on the His-bundle electrogram and the beginning of the atrial signal on the distal ablation catheter. Indeed, short A(H)–A(Md) intervals before the start of RF delivery were associated with a high risk of inadvertent AV block in our earlier report [13].

In the present study, we analyzed A(H)–A(Md) in a larger cohort of AVNRT patients, who underwent SP ablation. We sought to determine a cutoff for a critical A(H)–A(Md) interval in a large sample of AVNRT ablations. Furthermore, we compared the predictive value of this marker with the anatomical distance between the ablation- and the His-catheter (XR) and tested its predictive value for development of AVB prospectively.

2 Methods

2.1 Patients

Between 2000 and 2006, 392 consecutive patients (58% female; age 49.5±15.1 years) were diagnosed with typical (slow antigrade/fast retrograde) AVNRT in an electrophysiologic study at our center. A total of 1,585 RF impulses targeting the atrial input into the SP were delivered. All available ablation protocols, electronically stored fluoroscopy files, and intracardiac tracings of the RF deliveries were retrospectively analyzed. After the initial study, 118 consecutive patients (52% female; age 50.2±16.6 years) were examined prospectively during RF ablation of the slow pathway between 2007 and 2008. For this analysis, RF applications (n=335) were only delivered at locations, where the A(H)–A(Md) interval was longer than 20 ms based on our initial results. Again, all intracardiac tracings and electronic fluoroscopy files were analyzed.

Electrophysiological (EP) studies were performed in a fasting, non-sedative state after written consent had been obtained. Structural heart disease had been ruled out by physical exam and echocardiography. All antiarrhythmic agents were discontinued at least five half lives before the EP study. Twelve-lead surface ECGs were recorded before and right after each procedure as well as 1 day and 3 months after the ablation to rule out or to diagnose AVB. Furthermore, patients were contacted by telephone call 18–24 months after the procedure to evaluate tachycardia recurrence.

2.2 Electrophysiology study

Three 5-Fr electrode catheters were inserted through the femoral veins and positioned in the high right atrium (HRA), the right ventricular apex, and across the tricuspid valve to record the His-bundle potentials (all quadripolar). Furthermore, a decapolar 5-Fr luminal electrode was positioned in the CS via left subclavian vein access. Subsequently, a baseline EP study was performed for evaluation of typical AVNRT according to established criteria [14].

2.3 Radiofrequency ablation

Modification of the atrial input into the SP was guided by anatomical landmarks and local electrograms [5]. The mapping procedure started posteroseptally close to the CS ostium, where the most suitable local electrogram with an atrial to ventricular ratio of approximately 1:5 to 1:10 was recorded from the distal electrode of the ablation catheter. Ablation was subsequently continued at more midseptal sites if needed. 3-D mapping systems to locate ablation and/or His catheters were not used in any patients included in our study.

RF energy was delivered using 7-Fr quadripolar steerable 4-mm-tip ablation catheters and a temperature-controlled RF energy generator (Stockert EP shuttle®, Germany). Ablations were delivered for a maximum of 60 s at a target temperature of 55°C and maximum energy of 50 W [15]. A stable catheter position during RF energy application was confirmed by biplane fluoroscopy in RAO and LAO 45° views. Continuous intracardiac recordings were filtered (30–500 kHz), stored, and digitally analyzed on EP Control V14.0 (Biotronik®, Germany) and Axiom Sensis XP VC (Siemens®, Germany) systems. Occurrences of JA, loss of ventriculo-atrial conduction (i.e., VAB) during JA and AVB during the application of RF energy were registered. After RF application, atrial overdrive and extrastimulus pacing were repeated to refractoriness, both with and without the intravenous infusion of orciprenaline. RF energy application was repeated until AVNRT was no longer inducible. RF delivery was immediately stopped, however, if loss of VA conduction was observed during JA. Intra-procedural medications and anticoagulation management were applied at the discretion of the treating physician.

2.4 Measurement of the A(H)–A(Md) interval

The interval between the earliest deflection of the atrial component on the His-bundle electrogram (distinct and stable potentials on the pair of electrodes with the largest His signal amplitude) and the one of the atrial signal on the distal electrode of the mapping catheter [A(H)–A(Md) interval] was measured electronically in the intracardiac tracing 1–5 beats before the start of RF delivery [13]. Measurements were performed during maximal amplification of the signals on the mapping and on the His-catheter, and a paper speed of 200 mm/s was chosen. Examples for a typical A(H)–A(Md) measurements are shown in Fig. 1. The standard deviation of five different measurements in five consecutive beats right before the start of 55 ablations was 2.7 ms; the coefficient of variation of the measurements was 0.1.

2.5 Measurements of radiological distance between the His- and ablation catheter (XR)

For 57 RF ablations in the retrospective study, no fluoroscopy file was available due to technical problems. In the remaining 1,372 files of 373 patients, XR measurements were analyzed. XR was defined as the absolute distance (in millimeters) in RAO 45° view from the tip of the ablation catheter to the pair of electrodes on the His-bundle catheter that had been used for A(H)–A(Md) measurement in the corresponding intracardiac tracing. The known inter-electrode spacing of the ablation catheter was used as a scale for the measurements.

2.6 Statistical analysis

Continuous data are expressed as mean ± standard deviation unless otherwise indicated. Comparisons between groups were performed using one-way ANOVA and independent samples t test for continuous variables with normal distribution and χ^2 tests with Yates continuity correction for categorical variables. Multivariate logistic regression analysis was performed to investigate independent predictors for VA and AV conduction block. Two-sided p values <0.05 were considered statistically significant. All statistical analyses were performed using SPSS 16.0 statistical software (Chicago, IL).

3 Results

3.1 Retrospective analysis

3.1.1 Occurrence of JA with and without VA conduction block

Ablations at 1,043 of 1,429 sites (73.0% of all treatments) led to JA. A successful ablation endpoint was associated with induction of JA during the successful RF delivery in 373/392 patients (95.2%). Therefore, induction of JA was a reasonable indicator for ablation success. Three hundred forty-eight of all RF impulses (24.4% of all ablations; 33.4% of RF deliveries with JA) led to VAB during JA. The numbers and percentages of ablations leading to JA and/or VA block by quintiles of A

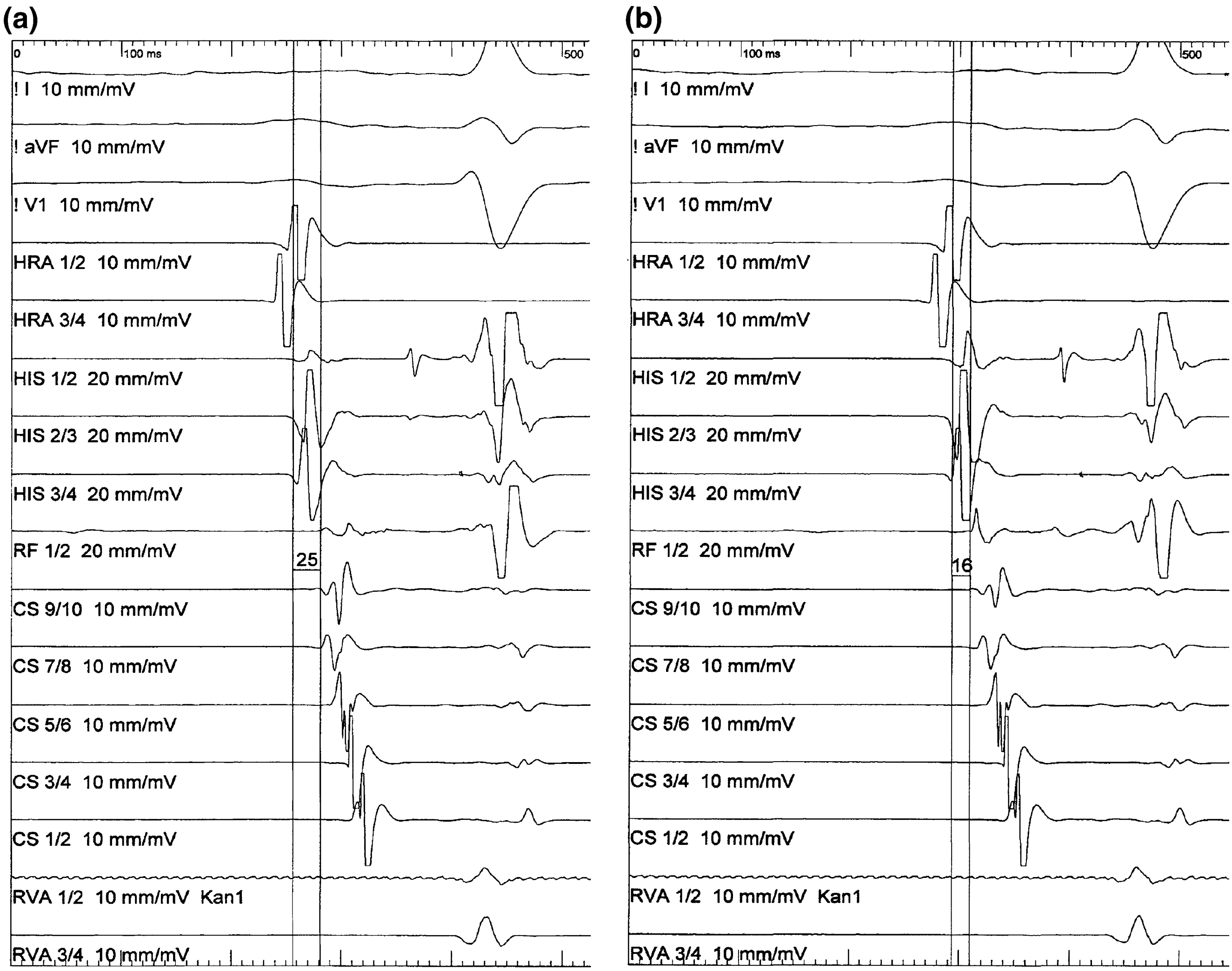

Fig. 1 Examples for measurement of the A(H)–A(Md) interval. The distance between the atrial endocardial electrograms visible on the His catheter electrode with the largest His signal and on the distal ablation catheter electrode was measured before the start of the RF delivery. The recordings show surface electrocardiograms of leads I, aVF and V1, followed by intracardiac EGM's of the diagnostic catheter in the *HRA*, of the electrodes of the His-catheter (*HIS*), the distal electrode of the ablation catheter (*RF*), the decapolar catheter in the *CS*, and the ones of the catheter positioned in the *RVA*. (**a**) Fairly long A(H)–A(Md) interval of 25 ms, measured at the posterior part of the coronary sinus ostium. (**b**) A short A(H)–A(Md) measurement in the same patient (16 ms) with the mapping catheter in a midseptal position (as illustrated by a small His-potential on the distal ablation electrode)

(H)–A(Md) interval, and XR distance are given in Table 1. Occurrence of JA with VA conduction block ($p<0.001$), but not JA without VAB ($p=0.09$), was associated with shorter A(H)–A(Md) intervals. XR was independent of JA and VAB (Table 1), and a higher number of ablations were associated with a higher rate of JA with ($p=0.04$) and without ($p=0.002$) VAB.

3.1.2 Occurrence of AV conduction block

Forty-six RF deliveries in 24/393 patients led to AV conduction disturbances during or after the procedure. Seven patients developed permanent 1st degree AVB, none of them permanent 2nd degree AVB, five patients developed permanent total AVB, nine transient 1st degree AVB, 12 transient 2nd degree AVB, and 13 transient 3rd degree AVB. Numbers and percentages of RF deliveries with AVB by quintiles of A(H)–A(Md) interval are given in Table 2. A clear increase of any kind of AVB was associated with a shorter A(H)–A(Md) interval ($p<0.001$); only the occurrence of permanent AVB was not significantly different ($p=0.07$) between the groups due to the rare incidence of these events.

Four patients developed multiple AVBs during different RF ablations within one session: one patient initially developed transient 1st degree AVB and during the following delivery transient 3rd degree AVB, two patients initially showed transient and in the following ablations permanent 1st degree AVB. Another one of the 24 patients underwent two

Table 1 Occurrence of junctional ectopy and VA-block during ablation of the slow pathway

A(H)–A (Md) [ms]	Total	≤21	22–26	27–29	30–35	≥36	*p* Value
Measurements	1429	286	403	217	275	248	
No JA (%)	386	53 (18.5)	97 (24.1)	51 (23.5)	80 (29.1)	105 (42.3)	<0.001
JA, no VAB (%)	695	149 (52.1)	196 (48.6)	108 (49.8)	134 (48.7)	108 (43.5)	0.09
JA+VAB (%)	348	84 (29.4)	110 (27.3)	58 (26.7)	61 (22.2)	35 (14.1)	<0.001
X-ray dist. [mm]	total	≤11.6	11.7–14.6	14.7–17.3	17.4–21.2	≥21.3	
Measurements	1372	276	275	281	270	270	
No JA (%)	374	77 (27.9)	78 (28.4)	59 (21.0)	73 (27.0)	87 (32.2)	0.40
JA, no VAB (%)	673	128 (46.4)	124 (45.1)	162 (57.7)	136 (50.4)	123 (45.6)	0.69
JA+VAB (%)	325	71 (25.7)	73 (26.5)	60 (21.4)	61 (22.6)	60 (22.2)	0.18

A(H)–A(Md) intervals (ms) and X-ray distance (mm) were measured in 393 patients with AVNRT. The occurrences and percentages of RF deliveries that did not lead to junctional ectopy (no JA), ablations that led to junctional ectopy but no ventriculo-atrial block (JA, no VAB) and deliveries that resulted in JA and ventriculo-atrial block (JA+VAB) are given separated into quintiles. Data are given in numbers and percent of all groups; quintiles were compared by Pearson's chi-square test

procedures and during both sessions, he developed AVB: in the first study, four deliveries led to transient 2nd degree ($n=1$) and 3rd degree ($n=3$) block, in the second study, five ablations led to transient 2nd degree ($n=2$) and 3rd degree ($n=3$) blocks. In the end, he fortunately did not show any permanent conduction disturbance.

During all of the 46 RF deliveries leading to AVB, JA was observed, but essentially in 15 of them (28.9%), no VAB occurred during JA before development of AVB: in 11/37 ablations that resulted in transient AVB and in 4/13 ablations that led to permanent AVB although regular VA conduction-induced JA was noted. Therefore, the negative predictive value (99.6% for permanent AVB and 98.8% for any AVB), but not the positive predictive value (2.6% for permanent and 9.2% for any AVB), of VAB for permanent AV-block is acceptable.

3.1.3 A(H)–A(Md) interval

The mean A(H)–A(Md) interval in all patients was 28.7±8.5 ms. The mean interval measured at the last SP ablation site in each patient, which led to the electrophysiological endpoint, was 27.5±7.4 ms. A(H)–A(Md) interval was

Table 2 Risk of occurrence of AVB depends on A(H)–A(Md) interval

A(H)-A (Md)	Total	<22 ms	22–26 ms	27–29 ms	30–35 ms	>35 ms	*p* Value
Measurements	1429	286	403	217	275	248	
Trans. AV-I	9	4 (1.4%)	4 (1.0%)	0 (0.0%)	1 (0.4%)	0 (0.0%)	n.s.
Trans. AV-II or III	28	15 (5.2%)	7 (1.7%)	1 (0.5%)	2(0.7%)	3 (1.2%)	0.001
Σ trans. AVB	37	19 (6.6%)	11 (2.7%)	1 (0.5%)	3(1.1%)	3 (1.2%)	<0.001
Perm. AV-I	8	4 (1.4%)	1 (0.2%)	1 (0.5%)	2 (0.7%)	0 (0.0%)	n.s.
Perm. AV-II or III	5	2 (0.7%)	1 (0.2%)	1 (0.5%)	1 (0.4%)	0 (0.0%)	n.s.
Σ perm. AVB	13	6 (2.1%)	2 (0.5%)	2 (0.9%)	3 (1.1%)	0 (0.0%)	0.07
All AV-I	18	7 (2.4%)	5 (1.2%)	2 (0.9%)	4 (1.5%)	0 (0.0%)	n.s.
All AV-II or III	28	15 (5.2%)	7 (1.7%)	1 (0.5%)	2 (0.7%)	3 (1.2%)	0.001
Σ all AVB	46	22 (7.7%)	12 (3.0%)	3 (1.4%)	6 (2.2%)	3 (1.2%)	<0.001

A(H)–A(Md) intervals (ms) were measured in 35 patients, who developed atrioventricular conduction disturbances during ablation of the SP; the total number of AV-blocks and the percentage relative to the total number of RF deliveries in each quintile are given. Separated quintiles were compared by Pearson's chi-square test with Yates continuity correction

perm. AVB permanent atrioventricular block; *trans. AVB* transient atrioventricular block

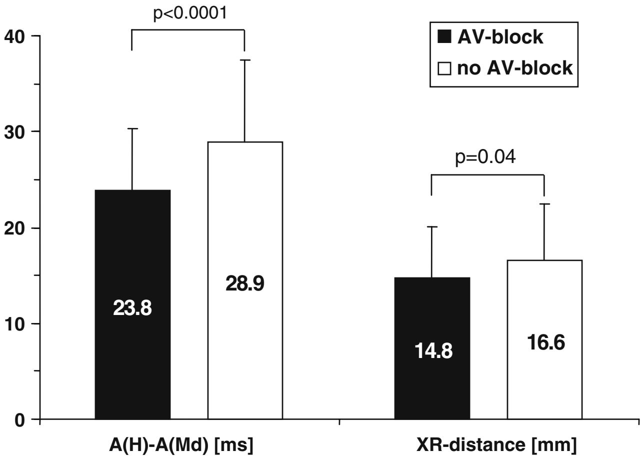

Fig. 2 Measurement of the A(H)–A(Md) interval and the X-ray distance in patients with and without AV conduction block: A(H)–A(Md) interval and X-ray distance are given for SP ablations that resulted in transient or permanent AVB (n=46) and that were not followed by AVB (n=1383). Data are given in mean ± SD. A(H)–A(Md) interval (p<0.0001) and X-ray distance (p=0.04) were significantly different

significantly shorter in RF deliveries that led to JA compared to the ones that did not (27.7±8.0 vs. 31.2±9.4 ms; p<0.0001). This effect was pronounced in patients, who developed VAB (26.8±7.1 vs. 29.2±8.8 ms without VAB; p<0.0001) during JA and in those, who developed AVB (23.8±6.4 vs. 28.9±8.5 ms without AVB; p<0.0001; Fig. 2).

Interestingly, the number and percentage of ablations that led to JA+VAB were significantly smaller in the groups with higher A(H)–A(Md) intervals, when the measurements were separated into quintiles (Table 1). Furthermore, the number of ablations that led to transient or permanent AVB was dependent on the quintile of the A(H)–A(Md) interval as shown in Table 2. This difference remained significant, when only cases with permanent AVB or only cases with permanent or transient AVB 2 or 3 were included into the analysis (Table 2).

3.1.4 Radiological distance between the His- and the ablation catheter (XR)

The mean XR was 16.6±5.9 mm in all scenes and 16.0±5.4 mm in scenes that led to the electrophysiologic endpoint. Of the 1,372 measured fluoroscopy scenes, JA occurred in 998, VAB in 325, and AVB in 41. In contrast to A(H)–A(Md), the radiological distance was not significantly different between deliveries that led to JA and those that did not (16.4±5.7 vs. 16.9±6.4 mm without JA; p=n.s.) and in RF ablations that led to JA with or without VAB (16.7±5.9 vs. 16.0±5.8 mm without VAB; p=n.s.). It was, however, significantly shorter in RF ablations that led to AVB (14.8±5.3 vs. 16.6±5.9 mm without AVB; p<0.05; Fig. 2). Measurements of XR with occurrence of JA with or without VAB divided into quintiles are given in Table 1. Interestingly, the occurrence of JA or VAB was not significantly different between these groups.

3.1.5 Number of RF deliveries

A mean of 2.9±2.3 RF deliveries were applied per patient. The number of RF impulses leading to JA (n=1043) was significantly higher than the ones leading to no JA (2.9±2.4 vs. 2.6±2.1; p<0.05). Furthermore, a higher number of RF deliveries were associated with VA conduction disturbances (2.9±2.5 vs. 2.6±2.1; p<0.05) and AVB (3.8±2.6 vs. 2.6±2.2; p<0.001). When the overall group with RF ablations was separated into groups with 1, 2, 3, 4, and 5 or more ablations, JA did not depend on the number of RF deliveries. By contrast, the risk for the occurrence of JA with VAB was higher in groups with more RF deliveries.

3.1.6 Comparison between A(H)–A(Md), XR distance, and number of ablations

A(H)–A(Md) was weakly though statistically significantly correlated with XR distance (R=0.165; p<0.0001) and with the number of ablations per patient (R=0.144; p<0.0001). However, we did not find associations between A(H)–A(Md) intervals and P-wave or PQ duration in the surface ECG. Age and sex, A(H)–A(Md) interval, XR, and the number of ablations were subsequently entered into a multivariate logistic regression model to calculate the predictive value of these parameters for the occurrence of VA or AV conduction disturbance. The results of these analyses are shown in Table 3. A(H)–A(Md) was the best predictor for VAB and/or AVB, followed by the number of ablation and XR distance. The predictive value of A(H)–A(Md) persisted when groups were stratified by gender of the patients. Finally, multiple regression analysis was repeated after separating the measurements into three groups based on tertiles of XR distance (<13.9/13.9–18.4/>18.4 mm). The predictive value of A(H)–A(Md) was highest in the intermediate XR group (Wald 9.18; p=0.002), followed by the tertile with the shortest XR distance (Wald 5.95; p=0.015) but was not significant in the upper XR tertile (Wald 1.57; p=n.s.). The only other significant variable was the age of patients in the tertile with the shortest XR distance (Wald 4.80; p=0.029).

3.2 Prospective analysis

Our initial results indicated that the highest risk of inadvertent AVB was confined to ablations with an A(H)–A(Md) interval of ≤21 ms. We therefore analyzed RF ablations in 118 consecutive patients at ablation targets with

Table 3 Multivariate logistic regression analysis for occurrence of ventriculo-atrial or atrio-ventricular conduction disturbances

Variable	Odds ratio (95% C.I.)	Wald	*p* Value
Occurrence of ventriculo-atrial or atrio-ventricular block			
X-ray distance	0.956–1.002	3.506	0.06
# of Ablations	0.984–1.101	3.628	0.16
Sex	0.532–0.891	3.890	0.05
Age	0.981–0.999	5.061	0.02
A(H)–A(Md)	0.951–0.983	15.596	<0.0001
Occurrence of transient or permanent atrio-ventricular block			
Age	0.980–1.026	0.058	0.81
Sex	0.648–2.311	0.388	0.53
X-ray distance	0.909–1.024	1.392	0.24
# of Ablations	1.018–1.246	5.350	0.02
A(H)–A(Md)	0.866–0.963	11.285	0.001
Occurrence of permanent atrio-ventricular block			
Sex	0.347–3.980	0.068	0.80
Age	0.966–1.060	0.242	0.62
X-ray distance	0.855–1.073	0.564	0.45
A(H)–A(Md)	0.839–1.026	2.137	0.144
# of Ablations	0.999–1.379	3.800	0.051

Patient age, patient sex, X-ray distance, number of ablations, and the A(H)–A(Md) interval were entered into the model; the relative predictive value of all parameters for the development of a ventriculo-atrial or any atrio-ventricular (n=348), of transient or permanent atrio-ventricular (n=46), or only permanent atrio-ventricular (n=13) conduction disturbances was calculated and arranged by Wald stat

A(H)–A(Md) intervals of >20 ms. Indeed, the occurrence of AVB was a very rare event: 7/335 RF impulses (2.1%) resulted in transient and 2/335 (0.6%) in permanent AVB

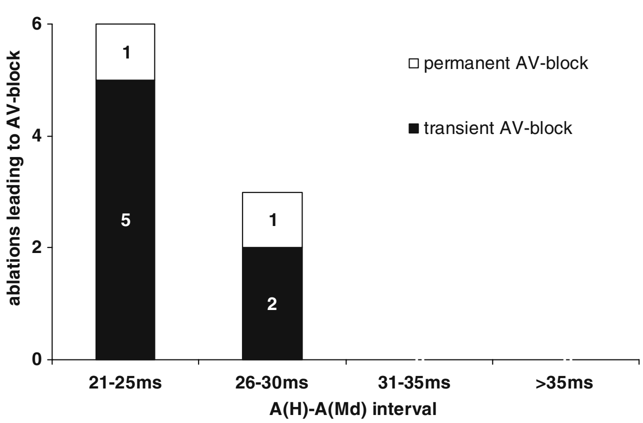

Fig. 3 Prospective analysis: occurrence of transient and permanent AV conduction block as a result of slow pathway ablation at sites with an A(H)–A(Md) interval >20 ms: Of 335 ablations, seven resulted in transient (1st degree during one, 2nd degree in four, and 3rd degree AVB in two RF impulses) and two in permanent AVB (all 1st degree AVB). Ablations with A(H)–A(Md) intervals longer than 30 ms did not result in any AV conduction disturbance

(Fig. 3). All permanent AVBs were 1st degree AVBs, and no patient required a pacemaker after a mean follow-up of 1.6 years after the intervention. Of interest, ablations with A(H)–A(Md) intervals longer than 30 ms did not result in any AV conduction disturbance at all. Due to the small number of AVBs, no significant statistical difference of A(H)–A(Md) intervals was found.

Importantly, SP ablations at locations with A(H)–A(Md) intervals of >20 ms did not affect the long-term efficacy of this technique. After a mean follow-up of 1.6 years, 3/118 patients had a second electrophysiologic study due to recurrence of sustained narrow complex tachycardia. In two patients, only an ectopic atrial tachycardia could be induced. However, 1/118 patient was diagnosed with recurrence of AVNRT in EPS 8 months after the initial procedure, and she was successfully ablated in the second attempt at similar target sites.

4 Discussion

Ablation of the SP is a highly successful treatment to cure AVNRT, but it may be complicated by AV conduction disturbances requiring implantation of a permanent pacemaker. Fortunately, development of persistent high-degree AVB due to SP ablation is a rare event occurring only in approximately 0.8–2% of patients, who are ablated [7, 9, 15]. In our current study, 5/392 patients (1.2%) developed permanent high-degree AVB, so the incidence is quite comparable to the one in earlier multicenter studies.

Success of the ablation can be judged during RF energy delivery by the occurrence of junctional tachycardia. By contrast, the risk of inadvertent AVB is usually anticipated by the appearance of VAB during JA. In an earlier study, persistent VAB associated with JA has been observed in each patient who developed AVB during RF ablation [16]. However, in our cohort, VAB during ablation was not a sensitive predictor for the risk of AVB, since VAB during JA did not occur in 4/13 ablations that led to permanent conduction block. Thus, VA block during JA does not seem to be a reliable indicator for inadvertent AVB, and additional and more sensitive signs are needed. Thakur et al. proposed that in addition to VA conduction during JA a longer duration and a shorter CL of JA during ablation might be related to the occurrence of AV conduction disturbances [10]. However, JA induced by RF energy applications characteristically occurs in irregular short runs and CL increases during the course of the ablation Therefore, it is sometimes difficult to measure the mean CL during ongoing RF delivery. Accordingly, we were able to measure CL of JA only in a small subset of all ablations in our initial study describing measurements of the A(H)–A(Md) intervals, and no association between the CL and the duration of JA and subsequent AVB was observed [13]. This observation was confirmed in another cohort that did not find significant differences in quantitative characteristics of JA between ablations that led to AVB and the ones that did not [16].

In the current analysis, we sought to find out whether measurements of A(H)–A(Md) intervals reliably predict the risk for development of AVB in a large sample of patients with AVNRT. Indeed a short A(H)–A(Md) interval was associated with the occurrence of JA, with and without VA conduction block as well as development of transient or permanent AVB during or after the ablation. Additionally, we tested the value of A(H)–A(Md) to predict AVB for the first time prospectively in 118 patients. We found that permanent high-degree AVB could be prevented, if only sites with A(H)–A(Md) intervals >20 ms were chosen for ablation. Finally, we compared the predictive value of A (H)–A(Md) to that of the radiological distance between the ablation- and the His-catheter. Interestingly A(H)–A(Md) was a stronger predictor for AVB than this anatomical parameter, which is frequently used to judge the risk of AVB in clinical practice. The inaccuracies of fluoroscopic distance estimation are well known, but we also speculate that due to the slope of the triangle of Koch in some patients, the radiological distance (in the RAO 45° plane) between the His and the ablation catheter can be misleading and does not reliably indicate the true 3-D spacing between the two catheters. This hypothesis is supported by the finding that continuous localization of the ablation catheter by 3-D mapping rather than by conventional (2-D) fluoroscopy improves safety of SP modifications in children [17]. As a 3-D mapping system (which was not used in our study) is able to measure the true anatomical distance, A(H)–A(Md) reflects the exact "electrical distance" between the ablation catheter and the His-bundle.

In the current study, we defined an A(H)–A(Md) delay of 20 ms to be a critical cutoff value indicating an increased risk for permanent AVB. Certainly, variations of local conduction velocities can potentially influence measurements of A(H)–A(Md). However, we did not find correlations between A(H)–A(Md) and P-wave and PQ durations; conduction block within the triangle of Koch could be excluded and conduction velocity was found to be very stable in a recent study [18]. This is the first prospective analysis demonstrating that high-degree AVB can be avoided by ablating only at targets with A(H)–A(Md) intervals above 20 ms. Another method to identify the FP region and to subsequently avoid damage to AV conduction is a pace mapping maneuver at the triangle of Koch to locate the shortest stimulus-to-His interval [19]. Using this technique, the occurrence of transient or persistent AVB could be reduced from 2.4% to 0.2% in a large sample of patients. Pace mapping of the FP is similar to our measurements of the A(H)–A(Md) interval in sinus rhythm, but it only eliminates injury of the fast pathway and not the one of the compact AV node. Furthermore, it is more time consuming and depends on the pacing output and tissue contact of the ablation catheter. However, both techniques are not exclusive, and pace mapping of the SP and the FP may be warranted in cases, where A(H)–A(Md) intervals >20 ms cannot be found at the posterior aspect of Koch's triangle. In this case, an unusual course of the FP has to be suspected, and RF energy application should be avoided at these target regions.

In our multiple regression analysis, patients' age and the number of delivered RF energy impulses were other predictors of development of VA and AV conduction disturbance. We always started our ablation at the CS ostium, and the ablation catheter was approximated in a stepwise approach to the midseptal aspect of the Koch's triangle, if earlier ablations were not successful. Thus, the higher risk of conduction block with a higher number of ablations was obviously a consequence of RF delivery at sites closer to the His-bundle (with shorter A(H)–A(Md) intervals) and can be explained by our approach of SP ablation. The higher risk of AVB as a complication of AVNRT ablation in older patients was also observed by other groups [20]. We speculate that this observation might be explained by the fact that due to the flat angle of the Koch's triangle in older patients, ablations are delivered closer to the FP. This hypothesis is currently under investigation in our laboratory.

5 Conclusion

Occurrence of VAB during JA is a sensitive, but not a specific marker for inadvertent AV-block in SP ablation. In contrast, the A(H)–A(Md) interval independently predicts AV conduction block during or after ablation of patients with AVNRT. The predictive value of A(H)–A(Md) was higher in tertiles with short and intermediate radiological distances between the His- and the ablation-catheter, suggesting that the predictive values of these two parameters are additive.

These findings have major implications for our clinical practice of SP ablations. The A(H)–A(Md) interval should be measured before starting deliveries of RF energy especially in mid-septal positions with radiological distances close to the His electrode. According to our data, ablation should not be started at sites, where an A(H)–A(Md) interval of ≤20 ms is determined, to avoid AVB. During ablation, it is still recommended to stop RF delivery, if VAB occurs during JA, even at sites with long A(H)–A(Md) intervals. However, it is reasonable to continue the ablation at the same site after another analysis of AV conduction in SR and confirmation of an A(H)–A(Md) interval >20 ms.

6 Limitations

We performed SP ablations and all measurements of A(H)–A(Md) in sinus rhythm (defined as earliest activation in HRA and positive P waves in surface leads I and II), but differences of atrial activation (i.e., wandering pacemakers or changes in intra-atrial conduction) could still have influenced the analysis of our A(H)–A(Md) measurements. For electrophysiologic and fluoroscopic measurements, we used the atrial signal in the His lead and the electrode with the largest His-bundle potential as a reference. This location might not necessarily reflect the point closest to the AV node. However, our technique is a reliable approximation that can be used in a regular RF ablation setup to treat AVNRT. Finally, catheter position could have unintentionally changed during ablation, which would obviously subsequently change A(H)–A(Md) values and distances on fluoroscopy.

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