Progress in radiofrequency catheter ablation

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CATHETER ABLATION OF ATRIAL TACHYCARDIAS

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Before the advent of catheter ablation, curative treatment for atrial tachycardia could only be performed using open chest surgery in highly selected patients. Catheter ablation was introduced in 1987 and aimed at performing a closed chest destruction of accessory connections or arrhythmogenic foci. It used initially direct current (DC) shocks under general anesthesia delivered between the tip of a catheter (cathode) and a back plate (anode). Since 1992, radiofrequency current has replaced DC ablation and allowed the procedure to be performed under conscious sedation. Catheter ablation has revolutionized the treatment of a number of supraventricular tachycardias to the point that it is considered the treatment of choice of a number of supraventricular tachycardias particularly those involving the atrioventricular junction[1,2] and more recently of a number of atrial tachycardias.

Atrial tachycardias have been defined as "regular atrial rhythms at a constant rate ≥ 100 b/min and originating outside the sinus node area"[5]. Their mechanism may be focal or reentrant and these tachycardias are difficult to classify using the ECG alone. Ablation of most cases of atrial tachycardias resistant to antiarrhythmic agents is presently feasible and safe. A classification of atrial tachycardias as designed by a group of experts[5] is shown in table I.

We will exclude from our discussion ablation of atrial fibrillation which is undergoing intensive clinical evaluation and which will be largely covered during this meeting.

Focal atrial tachycardia

Focal atrial tachycardia has been defined as "atrial activation starting rhythmically from a small area (focus) from where it spreads centrifugally"[5]. A number of ECG characteristics include variation in cycle length with a "warm-up" and "cool-down" phenomenon and response to adrenergic stimulation. Foci may be located in the right atrium, most commonly around the crista terminalis, the superior vena cava, right atrial appendage and coronary sinus ostium, or the left atrium particularly ostia of the pulmonary veins, left atrial appendage and mitral annulus. The ablation target site is the earliest site of activation prior to the P wave on the ECG using bipolar recordings and two mapping catheters, one being a reference. Recent sophisticated noncontact electroanatomical mapping techniques were found to be helpful in localizing the focus in difficult cases. The endpoint of ablation is termination and inability to re-induce the tachycardia. Acute success rates of ablation of atrial foci are 70-90% and complications are uncommon. The recurrence rate was about 8% among the relatively small number of patients treated. In the recommendations of ACC/AHA/ESC[2] catheter ablation is considered the preferred therapy for symptomatic recurrent atrial tachycardia and for incessant atrial tachycardias (class I level of evidence B).

Atriotomy (incisional) macroreentrant tachycardia

These tachycardias occur in patients who underwent open-heart surgery involving a right atrial incision such as correction of atrial septal defects and are often associated with typical atrial flutter. Atriotomy macroreentrant tachycardias involve complex reentrant circuits. The ablation targets are area of slow conduction and fragmented local activation preceding the onset of the P waves. The endpoint of ablation is tachycardia interruption and its noninducibility after radiofrequency application. Although the reported acute success rates average 85% and the complications are rare around 1%, the recurrence rates are high around 50%[1].

Table I. Classification of atrial tachycardias.

Sinus node tachycardia (appropriate)
Inappropriate sinus node tachycardia
Focal atrial tachycardia
Reentrant
Sino-atrial reentry
Atrial fibrillation
Macroreentrant atrial tachycardia
Atrial flutter (right atrium)
Atriotomy macroreentrant tachycardia
Left atrial macroreentrant tachycardia

Left atrial macroreentrant tachycardia

Left atrial macroreentrant tachycardia may be focal in origin or related to a reentrant circuit. Acquired anatomic barriers as shown by areas with double potentials and electrically silent areas, are often present. Combination with left atrial flutter is common. Sophisticated modern mapping techniques are necessary to achieve successful ablation[6].

Inappropriate sinus node tachycardia

This recently described syndrome is distinct from focal atrial tachycardia and sino-atrial node reentrant tachycardia. It is characterized by increased resting heart rate and exaggerated increase in sinus rate with minor exercise or emotion. This syndrome is usually responsive to beta-blocking agents. In drug-resistant patients, ablation is feasible under maximum autonomic stimulation. The ablation target sites are the superior area of the crista terminalis and the endpoint is 30% reduction in heart rate. The acute results are good approximately 80% but the recurrence rates are high.

Typical atrial flutter

Atrial flutter is an organized atrial tachycardia characterized by a "saw tooth" pattern of atrial activity called flutter waves particularly visible in ECG leads II, III and aVF, with a typical rate in the untreated state ranging from 250 to 350 b/min. In the common form, the P waves are negative ECG leads II, III and aVF and positive in lead V_1. In the uncommon form, the P waves are positive in leads II, III and aVF, and negative in lead V_1. In atrial flutter there is commonly 2:1 atrioventricular block resulting in a ventricular rate of 150 b/min. Intracardiac mapping of the right atrium using a multiple electrode catheter shows that the circuit activation is "counterclockwise", ascending in the septum and descending in the antero-lateral wall. In the uncommon form with positive waves, atrial mapping shows that atrial activation circulates in about 50% of cases in the "counterclockwise" direction despite difference in ECG aspect and in the other 50% in the "clockwise" direction. Both typical atrial flutter ("counterclockwise") and reversed typical flutter ("clockwise") use the isthmus between the tricuspid valve and the inferior vena cava and are called isthmus-dependent[7]. The same ablation technique is applied to both and consists at applying lesions between the tricuspid annulus and the inferior vena cava. Atrial flutter may be the primary arrhythmia (index arrhythmia). In a number of patients, atrial flutter is induced by drugs prescribed to prevent recurrences of atrial fibrillation. Ablation of drug-induced atrial flutter may be successful to prevent both arrhythmias. The success rates of ablation are > 80% provided the patients remains on the same antiarrhythmic therapy as before the procedure. Occurrence of atrial fibrillation is not uncommon (about 20%) even in patients in whom atrial fibrillation was not present before the procedure. The procedure is safe, the risk of complications low (< 1%) and recurrence rate averages 15%, requiring a repeat procedure.

Ablation of nonisthmus-dependent atrial flutter is complicated and the patient should be referred to an experienced center equipped with high-density mapping techniques.

Conclusion

Most atrial tachycardias are curable with catheter ablation in highly trained centers. Improvement of ablation technique including the use of new energy sources (cryoablation, laser, and microwave) and catheter development may improve the efficacy and safety of ablation techniques.

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Pacemapping of Koch's triangle avoids atrioventricular block during ablation of atrioventricular nodal tachycardia

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Some patients with atrioventricular nodal reentrant tachycardia (AVNRT) have the anterograde fast pathway (AFP) abnormally close to the slow pathway or it is absent. In these cases slow pathway ablation can provoke II-III degree atrioventricular (AV) block. In a previous paper we suggested that pacemapping of Koch's triangle, which is able to localize the AFP, can help to avoid this complication. This study evaluated in a large series the clinical usefulness of this method.

A total of 909 consecutive patients undergoing radiofrequency ablation of AVNRT were analyzed: 487 patients (group 1) had a conventional slow pathway ablation; 422 patients (group 2) had the ablation guided by pacemapping of Koch's triangle. The AFP was localized on the basis of shortest St-H interval obtained stimulating the anteroseptal, midseptal and posteroseptal aspects of Koch's triangle.

In group 2, AFP was anteroseptal in 384 (91%), midseptal in 33 (7.8%), posteroseptal or absent in 5 patients (1.2 %). In 32/33 patients with midseptal AFP, slow pathway ablation was strictly performed in the posteroseptal area. In 4/5 patients with posteroseptal/no AFP, retrograde fast pathway was ablated. Two patients refused ablation. Transient or persistent II-III degree AV block was induced in 12/487 (2.5%) of group 1 vs 1/422 (0.2%) of group 2 (p = 0.014). In particular persistent II-III degree AV block was provoked in 7/487 (1.4%) of group 1 vs 0/422 (0%) of group 2 (p = 0.038). Ablation was successful in all cases in whom it was performed.

Pacemapping of Koch's triangle identifies patients at risk of AV block and, guiding ablation, it allows to avoid AV block.

Slow pathway ablation, currently used to cure common atrioventricular nodal reentrant tachycardia (AVNRT), has 0.5-2% risk of inadvertent II-III degree atrioventricular (AV) block[1-7]. Although the risk of block is low, it is difficult to tolerate in patients with a benign arrhythmia, especially when they are young.

AV block can be provoked by inadvertent damage of the AV node-His junction or by the injury of both fast and slow pathways during serial attempts at ablation of both pathways. In other cases, however, we have suggested the existence of an atypical anatomy of the AV node. In fact, in a previous study[8] we demonstrated that anterograde fast pathway is abnormally located in the midseptal region in about 8% of patients, while it is located in the posteroseptal region or it is not able to conduct in about 3% of cases. In our paper we suggested to perform pacemapping of Koch's triangle to disclose these cases and to guide ablation reducing the risk of block.

In this multicenter study we compared the incidence of II-III degree AV block in two groups of patients who had a conventional slow pathway ablation and an ablation guided by the results of the pacemapping of Koch's triangle, respectively.

Methods

A total of 909 consecutive patients with AVNRT were submitted to radiofrequency ablation by five medical teams (six centers) from April 1992 to July 2003: 487 patients (group 1) had a conventional slow pathway ablation; 422 (group 2) had the ablation guided by pacemapping of Koch's triangle. The two groups had similar clinical characteristics (Table I). The distribution of cases in the five teams are summarized in table II. Two teams (A and B) had a common experience of 137 cases with the conventional ablation.

In all cases a complete electrophysiological study was performed, followed, in the same session, by radiofrequency ablation. Antiarrhythmic drugs had been discontinued at least 5 half-lives before the study.

In group 1 a conventional slow pathway ablation was performed as suggested by Haissaguerre et al.[1] or by Jackman et al.[2].

Table I. Clinical characteristics of patients.

	Group 1 (n = 487)	Group 2 (n = 422)	p
Sex (F/M)	429/58	381/41	NS
Age (years)	51 ± 14	52 ± 16	NS
No heart disease	390	318	NS
Heart disease	97	84	NS
MVP	53	43	NS
HHD	39	37	NS
Aortic insufficiency	5	4	NS

HHD = hypertensive heart disease; MVP = mitral valve prolapse.

Table II. Incidence of persistent atrioventricular (AV) block in the five teams.

Teams	Group 1	Group 2	Persistent AV block		Transient AV block	
			Group 1	Group 2	Group 1	Group 2
A	167*	216	2 (1.2%)*	0	0	1 (0.4%)
B	184*	148	2 (1.1%)*	0	0	0
C	146	0	1 (0.7%)	0	2 (1.4%)	0
D	61	29	1 (1.6%)	0	1 (1.6%)	0
E	66	29	2 (3%)	0	2 (3%)	0
Total	487*	422	7 (1.4%)*	0	5 (1%)	1 (0.2%)

* teams A and B had a common experience with 137 cases, with 1 III degree persistent atrioventricular block.

In group 2 pacemapping of Koch's triangle was first performed. The rationale of the pacemapping of the Koch's triangle is to localize the site of the anterogradely conduction fast pathway on the basis of the shortest St-H interval. Indeed on stimulating the site where fast pathway is present, a short St-H interval is recorded and, conversely, the greater the distance between the stimulating catheter and the anterograde fast pathway the longer the St-H interval. The technique is extensively described in a previous paper[8]. Briefly, at least three main regions of the Koch's triangle were mapped: the anteroseptal, midseptal and posteroseptal. Pacemapping was performed utilizing the ablating catheter by stimulating at a rate slightly faster than the sinus one (generally 100/min) with an output twice of the diastolic threshold. Stimulation of the anteroseptal aspect of the triangle of Koch was obtained by first placing the catheter where the highest His deflection was recorded. During continuous stimulation, the catheter was then slowly withdrawn until the atrium was captured. The first 2-3 beats were used for calculations and the shortest St-H interval was finally chosen. Stimulation of the posterior aspect of the triangle of Koch was obtained by placing the catheter in front of the ostium of the coronary sinus. Finally, the midseptal aspect of the triangle of Koch was stimulated by placing the catheter in an intermediate position between the anteroseptal and posteroseptal regions.

To localize the site of the retrograde fast pathway the ventriculo-atrial interval was calculated in the abovementioned anteroseptal, midseptal and posteroseptal regions by pacing the right ventricle at a rate slightly faster than the sinus one.

At the end of the electrophysiological study, the ablation of the slow or fast pathway was performed. When the anterograde fast pathway was located in the anteroseptal region a conventional slow pathway ablation was performed. In patients with midseptal anterograde fast pathway, radiofrequency delivery was performed only in a strictly posteroseptal area. In patients with posteroseptal or absent anterograde fast pathway, retrograde fast pathway ablation was performed. Fast pathway ablation was carried out by a conventional method[8].

A persistent II-III degree AV block was defined as a block occurring during the energy delivery and which was still present at the end of the procedure.

A transient II-III degree AV block was defined as a block which occurred during the energy delivery but disappeared before the end of the procedure.

Results

In all cases AVNRT was inducible in the basal state (n = 759) or during isoproterenol infusion (n = 150). No differences were observed between the two groups regarding AH interval in sinus rhythm (65 ± 35 vs 68 ± 40 ms), RR interval during tachycardia (398 ± 70 vs 400 ± 65 ms) and evidence of dual AV nodal conduction curves (70 vs 68%).

In group 2, anterograde fast pathway was anteroseptal (group 2A) in 384/422 (91%), midseptal (group 2M) in 33/422 (7.8%) and posteroseptal or absent (group 2P) in 5/422 (1.2 %). Retrograde fast pathway was anteroseptal in all cases of group 2A and C and in 11/33 of group 2M. In the remaining cases of group 2M retrograde fast pathway was midseptal.

In 32/33 patients with midseptal fast pathway, slow pathway ablation was strictly performed in the posteroseptal area, 1 out of 33 refused ablation. In 4/5 patients with posteroseptal or non-anterogradely conducting fast pathway, retrograde fast pathway was ablated, 1 out of 5 refused ablation.

Transient or persistent AV block occurred in 12/487 (2.4%) of group 1 vs 1/422 of group 2 (p = 0.014). In particular persistent II-III degree AV block was created in 7/487 (5 III degree, 2 II degree) (1.43%) of group 1 vs 0/422 (0%) of group 2 (p = 0.038). Only 2 persistent blocks occurred during the learning curve (first 20 cases) while 3/7 blocks occurred after a very long experience (after first 100 cases). No transient AV block occurred during the learning curve, while 1 block occurred after a long experience.

Ablation was successful in all cases in which it was performed.

At the end of the first week after the procedure the block was still present in all 5 patients with persistent III degree AV block and in these cases a pacemaker was implanted; in 2 patients with persistent II degree AV block a pacemaker was not implanted owing to the good heart rate.

Discussion

Slow pathway ablation in AVNRT can be complicated by II-III degree AV block[1-7]. AV block can be provoked owing an anatomical variant of the AV node. In fact we demonstrated, by performing pacemapping of Koch's triangle, that about 10% of patients with AVNRT have the anterograde fast pathway abnormally located in the midseptal or posteroseptal region or it is not able to anterogradely conduct. Our observation is in accordance with anatomical studies[9] who have demonstrated that the morphology of the AV node is quite variable in man.

Such a variability accounts for the possibility, in selected cases, of unexpected AV block during slow pathway ablation. Indeed, the lesion of the slow pathway can also damage the anterograde fast pathway if the latter is located close to the slow pathway itself. Furthermore, AV block can follow slow pathway ablation in cases in whom the anterograde conduction of the fast pathway is absent and AVNRT has as its retrograde limb a fast pathway which is capable of retrograde conduction only.

On the basis of our results we suggested to employ the pacemapping of Koch's triangle to disclose these cases and to guide ablation in order to reduce the risk of block.

In this multicenter study we compared the incidence of II-III degree AV block in two groups of patients who had a conventional slow pathway ablation and an ablation guided by the results of the pacemapping of Koch's triangle, respectively.

The results of the present study demonstrate that guiding the ablation by the results of pacemapping of Koch's triangle it is possible to significantly reduce the risk of block. That is, delivering the energy in a strictly posteroseptal area in patients with midseptal anterograde fast pathway or performing the ablation of the anteroseptal retrograde fast pathway in patients with posteroseptal or absent anterograde fast pathway.

Using this strategy we found a significantly different incidence of transient or persistent AV block (2.5 vs 0.2%) when comparing the group which had a conventional ablation to the one which had the ablation guided by pacemapping of Koch's triangle, respectively. In particular a persistent II-III degree AV block was induced in 1.4% of the former and in no case of the latter group.

In conclusion, this study confirms that some patients with AVNRT have an atypical location of the anterograde fast pathway, close to the slow pathway, or the absence of its conduction. The pacemapping of Koch's triangle is able to disclose these cases and can guide the ablation avoiding AV block. In patients with midseptal fast pathway the risk of AV block can be reduced by performing slow pathway ablation in a site sufficiently far form the site of the anterograde fast pathway. In patients with shortest St-H interval in the posteroseptal region the ablation of the anteroseptal retrogradely conducting fast pathway appears the best choice.

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ATRIOVENTRICULAR CONDUCTION DISTURBANCES AS COMPLICATIONS FOLLOWING CATHETER ABLATION OF SUPRAVENTRICULAR TACHYCARDIAS

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Radiofrequency catheter ablation of supraventricular tachycardias is effective in most cases and relatively safe.

Serious complications are very rare. The most common complication is the development of either transient or permanent atrioventricular block. The development of an inadvertent atrioventricular block is related to the ablation anatomic site. On one hand the block may be transient without any sequelae, on the other hand late occurrence of high degree atrioventricular block, requiring pacemaker implantation, may follow an uneventful ablation procedure or only slight PR interval prolongation. A careful follow-up is required in all cases with any atrioventricular conduction disturbance seen during the procedure.

Introduction

Inadvertent atrioventricular block has been induced by radiofrequency ablation of several types of supraventricular tachycardias: atrioventricular nodal tachycardia, atrioventricular reciprocating tachycardia, atrial tachycardia, and atrial flutter[1]. Most frequently it is a complication of the ablation of one or both atrionodal inputs to the atrioventricular node, the fast or the slow pathway, or accessory pathways of septal location.

The rate of unintended atrioventricular block creation during ablation depends on the anatomic site of the radiofrequency energy application, experience and aggressiveness of the operator, patient's age, and concomitant structural heart disease.

Initially the fast pathway was targeted for ablation of atrioventricular nodal reentrant tachycardia. This technique was effective, however, it was associated with a considerable risk of atrioventricular block. Its incidence was 5.3% in a big study[2], but it ranged from 0 to 23% in smaller studies[3,4]. Though the refinement of the technique nearly eliminated this complication[5], fast pathway ablation is nowadays used very rarely.

Slow pathway ablation is considered to be a safer approach and has been, therefore, widely used during the last 10 years. The risk of unintentional high degree atrioventricular block is up to 1.3%[6]. Nowadays it should be < 1%[7]. Ablation of accessory pathways is rarely connected with atrioventricular block. However, if only midseptal and anteroseptal pathways are considered, this complication is much more common[8]. Inadvertent atrioventricular block is a very rare complication of ablation of atrial tachycardia or atrial flutter (< 0.2%)[1].

Factors influencing the rate of inadvertent atrioventricular block creation during ablation

Experience. The role of experience in performing ablation procedures is very important. Both individual experience of the operator as well as the experience of the team plays a role. The complication rate of an institution is very different if the initial results are included or not. In a registry centers treating ≥ 30 patients with atrioventricular nodal reentrant tachycardia had much lower incidence (2.3%) of complete atrioventricular block than less experienced centers (6.3%)[2]. The development of special techniques (anatomically and electrogram-guided stepwise approach in fast pathway ablation[5], angiographically determined location of the distal end of the atrioventricular nodal artery in slow pathway ablation, precise mapping and careful power titration in septal accessory ablation[9]) reduces the rate of unintended atrioventricular blocks to a minimum.

Age. Complete atrioventricular block complicating ablation of the slow pathway seems to have age dependence. In a study the risk in patients > 65 years was 8%, whereas no patient < 45 years developed atrioventricular block[10].

A pediatric registry revealed 1.6% risk of atrioventricular block during ablations for atrioventricular nodal reentrant tachycardia and 2.9% during ablations in the right septal region. One third of blocks were transient[11].

Gender. There was no sex difference noted regarding atrioventricular block as complication of ablation[12].

Concomitant diseases. Structural heart disease represents a risk factor. In the above-mentioned study 2 patients between 45 and 65 years who experienced complete heart block complicating slow pathway ablation had significant cardiac abnormalities. Similar findings were found in other studies[6,12].

Anatomical risk factors. It was shown that the distal end of the atrioventricular nodal artery (demonstrated angiographically) represents the anatomical location of the atrioventricular node. The patients with a wider distance between the His bundle recording site and the distal end of the atrioventricular nodal artery are at risk of developing atrioventricular block, because the ablation target site is very near to the distal end of the artery[13]. It has also been speculated that in the patients at risk the fast pathway may be situated toward the posterior portion of the interatrial septum, or conversely, the slow pathway may be located more anteriorly than the usual posterior location. In this way, during ablation, both pathways could be damaged[14].

Multiple ablation targets. Multiple ablation targets were identified as an independent risk factor of ablation complications[6]. Multiple ablation targets are connected with longer procedures, greater catheter manipulation, and physician fatigue[6].

Prediction of atrioventricular block during ablation

The following electrophysiologic markers are predictors of atrioventricular block creation:

- the interval between the atrial signals in the His bundle catheter and in the distal mapping catheter. The interval < 20 ms signifies a high risk for atrioventricular block[15];

• fast junctional tachycardia with cycle lengths < 350 ms seen during slow pathway ablation is a predictor of atrioventricular block and suggests proximity to the compact node[16].

The onset and duration of atrioventricular block

Usually the atrioventricular block is noted during the radiofrequency pulse delivery. Prompt termination of the pulse when the first signs of block are seen is of utmost importance. In this way permanent atrioventricular block can often be avoided.

Less often strange and unexpected course of atrioventricular block creation or termination can be observed. We report here three illustrative cases.

Case 1. A 20-year-old woman was referred for paroxysmal supraventricular tachycardias. At electrophysiologic study atrioventricular node reentrant tachycardia was induced. Radiofrequency ablation of the slow pathway resulted in creation of complete atrioventricular block with a long initial ventricular asystolic pause (Fig. 1). Though the lesion of the atrioventricular node seemed to be very severe, the atrioventricular conduction recovered completely in some minutes and the PQ interval was normal at the end of the study (Fig. 2). There were no atrioventricular conduction disturbances noted during 7 months of follow-up.

Case 2. A 20-year-old woman was referred for atrial tachycardias. The focus was found to be near the fast pathway ablation site. It was successfully ablated. No atrioventricular conduction disturbances occurred, but a slight PR prolongation (210 ms) was noted at the end of the study. The same was seen in the electrocardiogram next day. She was discharged. One week later she returned to our outpatients department and complained of slow pulse, which she noted soon after discharge. The electrocardiogram revealed complete monofascicular block with idioventricular rhythm 48/min. Holter monitoring showed that complete block was present during the whole time of recording. We explained to the patient that implantation of a pacemaker was necessary, but the patient refused the procedure. Unexpectedly the complete atrioventricular block disappeared 2 weeks later, the patient had 1:1 atrioventricular conduction, and only slight PR prolongation persisted. However, some weeks later (55 days after ablation) the patient complained of fatigue, mainly on exertion. Complete atrioventricular block was noted (though not constantly) in the electrocardiogram again. A VDD pacemaker was eventually implanted.

Case 3. A 47-year-old woman was referred because of the Wolff-Parkinson-White syndrome with frequent attacks of orthodromic tachycardias. During the electrophysiologic study the anteroseptal location of the accessory pathway was confirmed. Radiofrequency ablation was successful. No atrioventricular conduction disturbances were noted during the procedure; however, incomplete right bundle branch block was noted after the ablation. Electrocardiogram next day showed normal PR interval. Two weeks later she felt occasional fatigue and dizziness. The patient was readmitted 3 weeks after ablation. Electrocardiogram

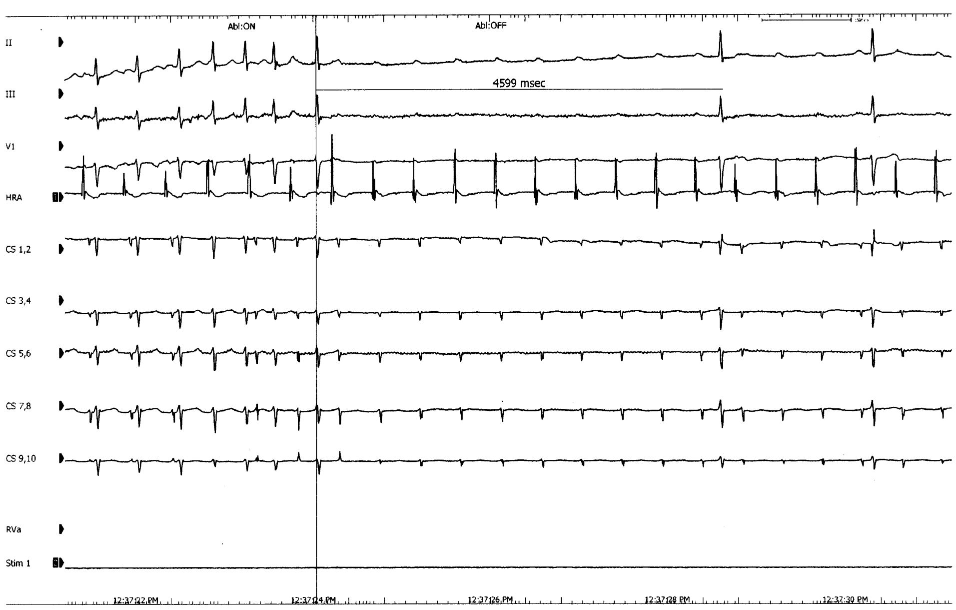

Figure 1. *Electrophysiologic tracings of a 20-year-old woman undergoing ablation of the atrioventricular nodal reentrant tachycardia. Atrioventricular block as complication of radiofrequency ablation of the slow pathway. Electrocardiographic leads II, III, and V_1, intracardiac electrograms from the high atrium (HRA) and coronary sinus (CS). The start and termination of radiofrequency energy delivery are marked as "ABL ON" and "ABL OFF". There is a ventricular asystolic pause of > 4.5 s at the beginning of atrioventricular conduction block*

Figure 2. *Tracings of the same patient as in figure 1. Less than 10 min later normal atrioventricular conduction.*

revealed second degree atrioventricular block with 2:1 conduction during higher frequency of sinus rhythm and 1:1 conduction with normal PR interval at slower frequency (< 70/min). A VDD pacemaker was put in place. About 1 year later 1:1 conduction at low sinus rate could still be demonstrated.

From this experience we can conclude that the course of atrioventricular conduction impairment after radiofrequency ablation is very variable. In a group of 4 patients, who developed atrioventricular block either during (1 case) or after (3 cases) ablation, the block disappeared after a maximum delay of 7 days and did not reappear. Similarly, in 3 patients with late occurrence of complete atrioventricular block after slow pathway (2 cases) and accessory pathway (1 case) ablation, the conduction disturbances resolved uneventfully in 1 to 2 weeks[17]. On the other hand, there are many reports of development of permanent atrioventricular block during or after ablation. Late occurrence (> 24 hours) of atrioventricular block is exceptional. However, some case reports can be found in the literature. Two patients developed symptomatic atrioventricular block, requiring permanent pacemaker implantation, several months after slow pathway ablation[18]. A patient developed permanent complete atrioventricular block next day after left posteroseptal accessory pathway ablation[19]. Two cases of delayed atrioventricular block were described by Fenelon et al.[14]. One patient developed second degree atrioventricular block as late as 3 months after slow pathway ablation. Another patient is cited who had transient block during ablation and developed complete block 24 hours after the procedure. Two cases of late atrioventricular block after fast pathway ablation were described too[20,21].

Pathogenesis of inadvertent atrioventricular block creation

During ablation procedures in the anterior and mid septum the coagulation necrosis extends into the compact atrioventricular node or the bundle of His. Sometimes atrioventricular block in a patient with another target location is a consequence of unsuspected ablation catheter movement during the radiofrequency energy application. Whether vascular injury or anomalously placed atrioventricular conduction axis play a role is not known[11]. Late occurrence of atrioventricular block could be a consequence of extensive ablation attempts with numerous applications and/or midseptal applications[17].

Techniques to avoid inadvertent atrioventricular block during ablation

Catheter stability is very important for safe radiofrequency ablation in septal locations[22]. Careful radiofrequency energy titration is important too[9]. It has been proposed that an "auto cut-off" facility for cycle lengths < 350 ms should be built into radiofrequency ablation generators[16]. Pacemapping of the triangle of Koch was proposed as a simple method to reduce the risk of atrioventricular block during ablation of atrioventricular nodal tachycardia[23]. Atrial pacing during ablation of junctional ectopic tachycardia is a useful method for avoiding atrioventricular block.

Conclusions

Inadvertent atrioventricular block during or after radiofrequency ablation is a serious complication, especially in a young patient with a possible lifetime pacemaker dependency. Every effort should be done to avoid this complication. A careful follow-up is required in all cases with any atrioventricular conduction disturbance seen during the procedure.

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Clinical usefulness of nonfluoroscopic intracardiac navigation system LocaLisa: from radiological risk reduction to high procedural accuracy during catheter ablation

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The LocaLisa system can increase the accuracy of transcatheter ablation allowing the visualization of position and motion of the electrocatheters in relation to the heart electroanatomical maps generated during the mapping phase of ablation. These features are particularly useful in performing ablation of focal arrhythmia located near the atrioventricular node-His bundle conduction axis, in case of mechanical bumping or transient thermal damage and abrupt dislocation, and namely in case of atypical macroreentry to define the complete circuit path.

The LocaLisa system is a nonfluoroscopic intracardiac navigation system that allows the three-dimensional reproduction of the explored electroanatomic structures, of the position and motion of the leads and namely of the ablation catheter during diagnostic or ablation electrophysiologic procedures.

The electronatomical sites are stored and marked on the screen as different tags provided with a color code in the "three-dimensional virtual space". The leads are visualized in their distal active portions. The LocaLisa system allows to relocate in a before mapped site the leads with a very high spatial accuracy (of 1-2 mm). Up to 8 diagnostic electrodes and the ablation lead electrodes can be simultaneously visualized, whatever are the dimension or the shape of the leads (circular, linear, basket, Lasso catheters) or their building firm. These positions can be stored to mark different relevant electroanatomical regions, the pacing sites and the radiofrequency delivery sites.

The system is based on the physical Ohm' law and the theoretical principle that each electrode offers a specific impedance to a linear electrical field and so therefore represents a location sensor. In fact, the voltage induced at a determined site in each electrode can precisely identify its location in the three-dimensional space. Thus a three-dimensional electrical field is produced by delivering three subthreshold (1 mA) high-frequency alternating currents in the three directions of the space using three pair of cutaneous adhesive patches. The change in position of each single electrode will result in a corresponding change in potential which is proportional to the distance between the different sites, thus allowing to reproduce the motion of each electrode. After a proper adaptation of the system spatial filter, the displacement of the catheters is accurately visualized without a significant temporal delay. This is very important especially during radiofrequency ablation, where it could be critical for the safety and efficacy of the procedure.

The components of the system are the position sensory unit provided with a monitor for the operator and the workstation where are located the computer for the generation of an integrated virtual map and a monitor for the visualization of the three-dimensional cardiac image.

Other fittings are three pair of cutaneous adhesive patches useful to generate an intrathoracic electrical field and a reference electrical lead. This lead represents the common spatial reference for all the points of the map. In fact, the position of each other electrode is computed compared to this reference site. Every stable position in the heart can be used to position this reference lead. Although a coronary sinus lead, introduced by a superior route, can represent a valid alternative, we prefer the use of a screw-in 3.5F bipolar electrode catheter (Medtronic, model 6416) introduced through a J-shaped long guide introducer (6F outer diameter), inserted in the left femoral vein. The tip of this lead provided with a microscopic (1 mm long) screw can be fixed to the right atrial auricle or to the right ventricular apex allowing a stable temporal reliability during all the procedure.

This atraumatic screw-in lead is positioned and fixed to the heart with a very low radiologic exposure time (< 2-3 min) representing however a cheep bipolar diagnostic atrial or ventricular lead provided with recording and pacing capabilities.

The use of the system is rapid after marking only a point in the heart and it does not include any geometrical assumption. In fact, the learning curve phase during the use of the system consists of no more than 20 cases. The representation of the motion of the leads in the virtual three-dimensional space is more effective than the fluoroscopy-guided visualization reducing the periodic oscillations and motion artifacts due to the cardiac and respiratory cycles.

For these reasons, the LocaLisa system enables to improve the quality of the ablation procedure by enhancing the ability to visualize the catheters during the electrophysiologic procedure, helping to understand where the catheter is prior to perform an ablation procedure.

The points on the screen are marked using a color code related to each particular electroanatomical region. The activation time and voltage amplitude are associated with each marked point after manually calculating them on the polygraph. So doing, the activation loop can be visualized after mapping the sites which are relevant for the delineation of a macroreentry circuit or a focal tachycardia. This function is very helpful in defining the effective pathway of a circuit when their anatomical or functional anchors are not clearly visible or preventable, as in case of atypical flutter. But it is also useful in defining the radial spread activation of a focal arrhythmia as in the case of atrial tachycardia where the early activated regions have to be determined with high density spatial mapping.

Standard or nonstandard monoplane view projections can be visualized on the screen by optimizing the angle and orientation of the LocaLisa view projection. In the incoming version of the system the biplane visualization (two simultaneous views) will also be available on the screen.

In the atrioventricular node reentry tachycardia ablation, the LocaLisa system allows to perform the procedure without any fluoroscopic additional exposure, increasing both the safety and efficacy of the ablation especially in case of small Koch's triangle or posterior displacement of the atrioventricular node-His bundle axis.

In case of focal arrhythmias (ectopic atrial tachycardia, idiopathic ventricular tachycardia), the system allows to relocate each point of the activation map with an accurate repositioning on the best site of mapping and ablation. This is very useful in case of parahissian ectopic arrhythmias when the hissian points of recording and/or the hissian catheter visualization have to be accurately analyzed in their relation to the optimal mapping site in order to avoid any damage of the normal atrioventricular conduction axis.

In case of atrioventricular accessory pathways, the system can be very useful especially when an abrupt displacement, a mechanical bumping or a transient thermal stunning of the fibers occur, so avoiding a long waiting time to restore the accessory conduction and to relocate the site of the Kent or Mahaim fibers.

During typical atrial flutter ablation, when the isthmus has a particular difficult anatomy or in case of analysis of complex local electrograms, the LocaLisa system can assist in the accurate mapping of the isochrone lines adjacent to the lesion line, in the analysis of the spatial relationships between the ablation and the diagnostic electrode catheters and in performing the maneuvers of validation of isthmus complete conduction block (differential or positional pacing). Moreover its importance is very high in case of post-incisional or scar-related atrial macroreentry in whom in the anatomical and/or functional barriers (double potentials, border fractionated sites, scars) must be determined to analyze the effective path of the circuit (constructing a map in whom “end meets tail”), the protected isthmus of the circuit and the quiescent alternative loops. These preliminary phases are needed especially to reduce the attempts of entrainment mapping and the conversion of the flutter in an undesirable episode of atrial fibrillation.

During linear ablation of atrial fibrillation (in the right or left chamber) the LocaLisa system allows to visualize the points of lesion lines in order to critically abate the voltage of these lines (< 0.05 or < 0.1 V). So doing it is very useful in performing linear conduction block everywhere in the heart.

During isolation procedure of pulmonary veins, the visualization of the Lasso catheter and of its relation to the ablation catheter can be obtained. In this case the fluoroscopy time has been shown to be dramatically reduced of more than 70%.

In our experience of more than 200 consecutive cases of ablation procedures (including atrial tachycardia, idiopathic ventricular tachycardia, typical, atypical and post-incisional atrial flutter, accessory pathway, atrial fibrillation ablation) by using the LocaLisa navigation system to guide ablation, we could document a reduction of > 70% of radiological exposure in different arrhythmic substrates, but namely an increase in the efficacy and safety of the procedure. This was particularly useful during more complex procedures that require accurate or extensive mapping, as in the case of parahissian or paranodal substrate or of macroreentry tachycardia.

In conclusion, three-dimensional catheter localization with the LocaLisa system allows quick mapping and marking of target sites, it does not require extensive electroanatomical maps before starting a procedure, and it needs a minimum set-up time. It is conceived for everyday use in the electrophysiologic Lab for virtually every case. The LocaLisa system allows to navigate the electrode catheters without fluoroscopy. It can assist in improving our electrophysiologic knowledge of arrhythmic substrates in each patient.

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THE ROLE OF THE LOCALISA THREE-DIMENSIONAL NAVIGATION SYSTEM IN THE MODERN TREATMENT OF ARRHYTHMIAS

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Catheter ablation has become the standard therapy for many arrhythmias. Recent insights into the mechanisms of many complex tachycardias emphasize the role of substrate modification. For this purpose catheter navigation guided by fluoroscopy is often not sufficiently precise. Nonfluoroscopic catheter navigation methods have been developed to allow more precise and detailed mapping and ablation and to reduce radiation exposure. The LocaLisa system uses stable electrical fields applied across the thorax of a patient to calculate and display the three-dimensional position of any electrode. The use of LocaLisa has been shown to reduce total radiation exposure by 35-59%.

In conclusion, the LocaLisa system enables real-time, three-dimensional navigation of multiple standard catheters. It significantly reduces radiation exposure for the patient and the operating physician and is of value during detailed mapping and ablation of complex arrhythmogenic substrates.

Background

Catheter ablation with radiofrequency or cryo-energy has become the standard therapy for many arrhythmias. One of the most decisive arguments in favor of catheter ablation is that, if successful, the treatment is often curative.

Recent insights into the mechanisms of many complex tachycardias emphasize the role of modification of the arrhythmogenic substrate. Continuous lesions figure in the treatment of common or post-incisional atrial flutter, atrial fibrillation (AF) and post-infarction ventricular tachycardias. In this regard, the characterization of the substrate plays a crucial role.

The catheters are usually maneuvered in the heart with the help of fluoroscopy. However, catheter positioning is often not sufficiently precise owing to the inherent limitations of fluoroscopy. Nonfluoroscopic catheter navigation methods have been developed to allow more precise and detailed mapping and ablation of arrhythmia substrates. These methods are based on magnetic (Carto®), ultrasound (RPM® system) and electric techniques (Navex®, LocaLisa®)[1-4].

The LocaLisa technique

When a small (1 mA) alternating electrical current is externally applied through the thorax, a voltage drop occurs across the heart. The resulting voltage can be recorded by any electrode inside the heart. If three currents with slightly different frequencies of about 30 KHz are applied in three orthogonal directions, the three-dimensional position of the electrode can be calculated and displayed relative to a stable reference catheter[4].

Reduced radiation exposure

The more complex arrhythmogenic substrates often require detailed catheter mapping and ablation, resulting in long-lasting procedures with relatively high exposure to ionizing radiation. This is of potential risk for the patient and for the operating physician.

During ablation of supraventricular tachycardias, the use of LocaLisa has been shown to reduce total radiation exposure by 35%[5] (Fig. 1). In this substudy of the European safety and efficacy clinical trial the prototype of the LocaLisa system was used that could only measure the position of two electrodes simultaneously. Later studies have demonstrated a 59% decrease of fluoroscopy dosage during ablation of common type atrial flutter, and a significantly lower fluoroscopy time needed for disconnection of the pulmonary veins when using the LocaLisa system during catheter ablation for AF[6,7].

Advantages of the LocaLisa three-dimensional catheter navigation

One of the main advantages of the LocaLisa system is that it can be used on a routine basis in all ablation procedures. The system is easy to set up and the procedural costs are low. All standard catheters can be connected to the system and the actual version can display 10 electrodes simultaneously. This can be extremely helpful in pulmonary vein disconnection during catheter ablation of AF, when electrodes of the perimetric mapping catheter inside the pulmonary vein are used as a target for the ablation catheter (Fig. 2). Theoretically, the number of electrodes that can be visualized by the system is only limited by the soft- and the hardware. The system can be used to delineate anatomical and electrical landmarks in the region of interest and to mark mapping and ablation sites, for example during the application of continuous linear radiofrequency lesions. It is also very helpful in guiding the catheter back to a

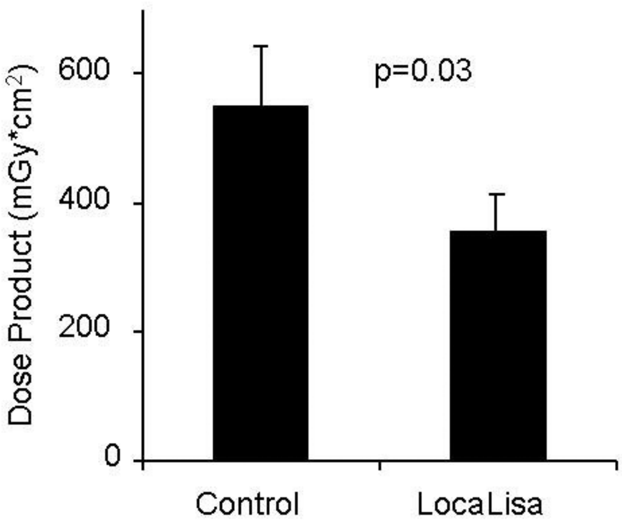

Figure 1. *Mean radiation dose product (mGy*cm²) in a control group and in the LocaLisa group. Dose product meters measured radiation dose. The average total radiation dose per procedure is shown (biplane fluoroscopy, sum of doses measured at each of the two X-ray tubes).*

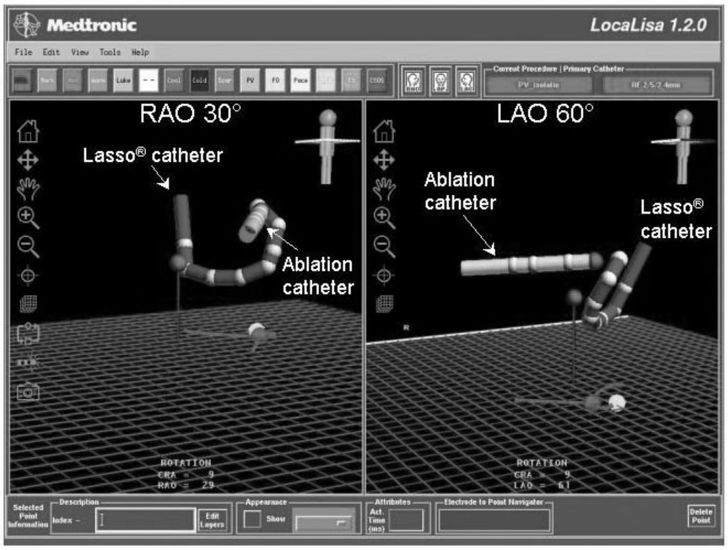

Figure 2. *LocaLisa catheter navigation during pulmonary vein disconnection. The Lasso® catheter is positioned in the left inferior pulmonary vein. The ablation catheter targets electrode 1 of the Lasso catheter. On the split screen, a 30° right anterior oblique (RAO) and a 60° left anterior oblique (LAO) projection are shown.*

"lost" position after sudden catheter dislocation. All marked positions will remain identifiable with an error of 1 to 2 mm throughout the procedure[4].

Future developments

Also the LocaLisa system is often referred to as a mapping system, it does not allow to display activation time. Hopefully, this important feature will be implemented in a future version. Other important issues are anatomic rendering of the endocardial surface and integration of anatomic information from prior computed tomography or magnetic resonance imaging. Developmental work needs to be done to fuse information from different sources to further facilitate catheter navigation.

In the near future, features like split screen with different projections (Fig. 2) and automatic termination of radiofrequency energy upon catheter dislocation will be available[8].

Conclusion

The LocaLisa system enables real-time, three-dimensional navigation of multiple standard catheters in electrophysiologic, diagnostic and ablation procedures. Its easy handling and the low procedural costs allow the use on a day-to-day basis for all procedures. LocaLisa catheter navigation significantly reduces radiation exposure for the patient and the operating physician and is of value during detailed mapping and ablation of complex arrhythmogenic substrates.

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