STATE-OF-THE-ART METHODS FOR ABLATION OF VENTRICULAR TACHYCARDIA

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Catheter ablation of ventricular tachycardia (VT) has become a standard therapeutic method both in patients with idiopathic VT and VT associated with structural heart disease. With the advent of novel technologies such as electroanatomical mapping, image integration, intracardiac echocardiography, and/or irrigated tip ablation catheter with or without contact force assessment, VT ablation procedure can be performed safely and efficiently. This paper reviews state-of-the-art techniques and strategies used in catheter ablation of ventricular arrhythmias.

Key words: catheter ablation, ventricular tachycardia, ventricular fibrillation, electroanatomical mapping.

Introduction

The method of catheter ablation has developed over last two decades into a routine therapeutic method with enormous curative potential in patients with a broad spectrum of cardiac arrhythmias in the absence of significant heart disease. In addition, this method has irreplaceable place also in treatment of different arrhythmias in the setting of structural heart disease. Both paradigms can be demonstrated in the example of ventricular arrhythmias. This paper reviews state-of-the-art techniques used in catheter ablation of ventricular arrhythmias.

The spectrum of ventricular arrhythmias

Ventricular arrhythmias could be divided into two major groups, depending on the absence or presence of structural heart disease [1]. In this respect, we recognize idiopathic ventricular arrhythmias and ventricular arrhythmias associated with structural heart disease, mostly associated with the presence of myocardial scars. Prognostically, idiopathic ventricular tachycardias (VTs) are considered benign. The exemptions are idiopathic ventricular fibrillation and/or polymorphic VT associated with various channelopathies (e.g. VTs in long QT syndrome, catecholaminergic VT, etc). On the other hand, VTs accompanying structural heart disease are regarded as potentially malignant or malignant. Depending on the category of VT, the role of catheter ablation could vary from entirely curative (e.g. in idiopathic VTs) to more or less symptomatic therapy focused on decreased rate of VTs (in structural heart disease). We still lack hard data on prognostic benefit of catheter ablation in the latter category. However, some studies suggest improved survival in patients after catheter ablation. In cases of electric storm in subjects with focally triggered polymorphic VT or ventricular fibrillation is catheter ablation considered a life saving procedure.

Techniques of catheter ablation in idiopathic ventricular tachycardia

Since the majority of these VTs are focal in origin, conventional techniques of mapping of activation sequence could be used [2–5]. However, electroanatomic mapping is more and more often used in order to facilitate search for the earliest activation site and reduce fluoroscopic exposure. We prefer to use electroanatomic mapping system to build virtual anatomic map of the chamber of interest and use this anatomic shell for annotation of sites with earliest activation as measured from the conventional recording system (Fig. 1).

This is particularly true when mapping isolated ectopic beats. Others like to employ mapping of activation using display of activation times on 3D map. The disadvantage of
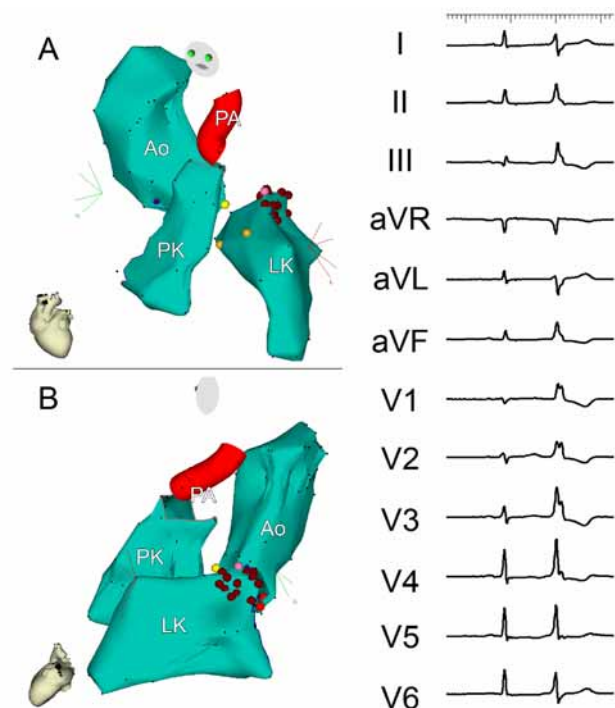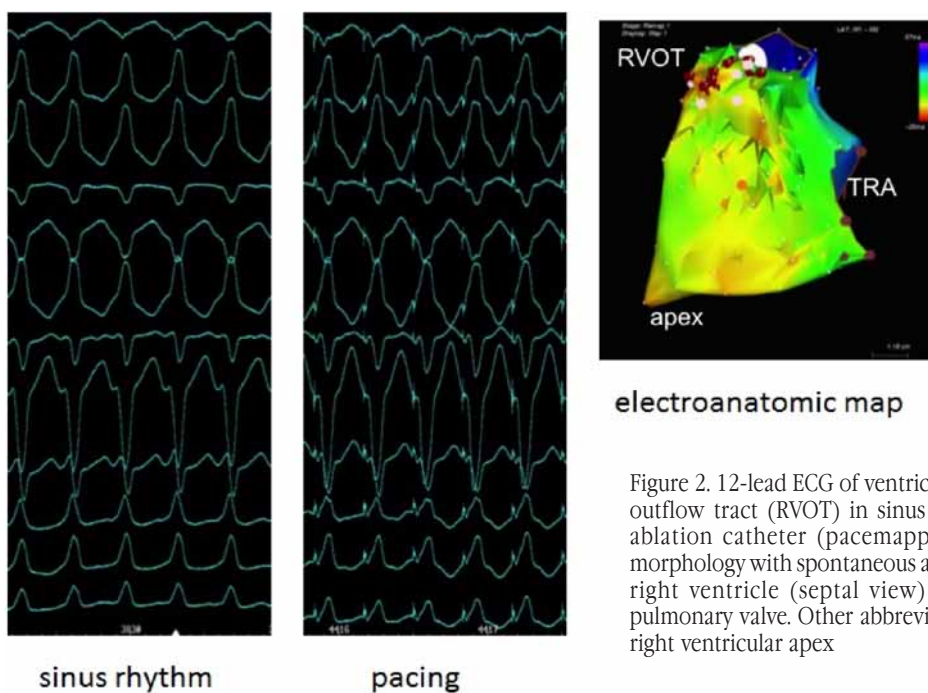

Figure 1. An example of partial electroanatomic maps of both ventricles (PK- Right ventricle, LK – left ventricle), pulmonary artery (PA) and aortic root (Ao) in RAO (A) and LAO (B) projections. 12 lead ECG documents ventricular ectopy from aortomitral continuity. Dark red points represent ablation points

sinus rhythm   pacing

electroanatomic map

Figure 2. 12-lead ECG of ventricular tachycardia from right ventricular outflow tract (RVOT) in sinus rhythm and during pacing from the ablation catheter (pacemapping). Note similarity of paced QRS morphology with spontaneous arrhythmia. Electroanatomic map of the right ventricle (septal view) documents ablation region below pulmonary valve. Other abbreviations: TRA- tricuspid annulus, apex – right ventricular apex

such approach is possibility to incorporate mapping points at sites where irritation was caused by the catheter tip. This can result in misleading results in pinpointing the earliest activation site. Another mapping strategy is the so-called pacemapping – i.e. pacing from the distal electrode bipole of the mapping catheter with the lowest possible output in order to reproduce morphology of QRS complexes as in arrhythmia (Fig. 2). Some technologies help to make more objective comparison of QRS morphology. One is used in the BARD electrophysiology system, the other, called PASO, is employed in the CARTO 3 system. In addition, various combinations of image integration can be used to improve understanding of anatomy. This is particularly true when mapping aortic root or papillary muscles. Another option is to engage intracardiac echocardiography to facilitate mapping and control catheter contact with the tissue [6]. This is especially true when arrhythmia focus is localized within the cusps of the aortic valve or on papillary muscles or moderator band. When ablation in ventricular myocardium, one can often see lesion formation due to fleeting microcavitation in the heated tissue.

For ablation of idiopathic fascicular VT, the main advantage of the electroanatomic mapping system is that the site of mechanical termination of the arrhythmia can be annotated and used for ablation when mechanical trauma results in subsequent non-inducibility of arrhythmia [7, 8]. In addition, location of the conduction system could be annotated in the left ventricular map along with areas of diastolic potentials in sinus rhythm. The latter could be the alternatively used to guide catheter ablation. Some operators use pragmatic approach and design ablation line across the terminal part of the posterior fascicle.

Techniques of catheter ablation in idiopathic ventricular fibrillation

Catheter ablation has been demonstrated as the method of choice to terminate electrical storm in subjects with various

Figure 3. 12-lead ECG during sinus rhythm and ectopic beat of the same morphology that triggered ventricular fibrillation. Note morpohology of the ectopic beat that suggests origin in the conduction system of the left ventricular septum (posterior fascicle). Electrograms from ablation catheter (Abl d and Abl p) show sharp signal preceding local ventricular activation (Purkinje potential) in sinus beat and even much more during the ectopy (left arrow). Right arrow shows the same signal without conduction to ventricle (blocked ventricular extrasystole)

forms of idiopathic ventricular fibrillation [9]. Since the majority of arrhythmic events are triggered from localized ectopic focus within the Purkinje fibres, activation mapping is the best strategy (Fig. 3). More and more operators support this strategy by electroanatomic mapping system [10]. Again, it allows annotation of the site when "bumping" of the ectopic focus occurs during mapping and leads to disappearance of arrhythmia. For foci originating from papillary muscles or the moderator band, intracardiac echocardiography is again very useful [11].

Techniques of catheter ablation in ventricular tachycardia in structural heart disease

Arrhythmias associated with structural heart disease are mostly related to scar tissue and reentrant in origin. Before the advent of electroanatomical mapping, conventional methods of mapping of activation sequence and/or entrainment mapping were used. However, mapping and ablation during VT was limited to tolerated or relatively tolerated arrhythmias. In 2000, the so-called substrate mapping and modification were described for the first time by the Philadelphia group [12]. It was based predominantly on delineation of a dense scar tissue with bipolar signal amplitude of <0.5 mV, while regions with amplitude >1.5 mV corresponded with normal tissue. Voltage between 0.5–1.5 mV was used to determine scar border zone areas between dense scar and normal tissue. Ablation lesions were placed across the exit zones for different reentrant circuits. Over time, multiple variants of substrate mapping and ablation have been added. In 2003, we described strategy called an integrated approach. In essence, bipolar voltage maps obtained in sinus rhythm or right ventricular pacing are used to annotate all possible sites of interest such as fractionated signals, late potentials and/or pacing spots [13]. Bipolar pacing with the lowest possible output is frequently used in the region of low voltage and/or fractionated or late potentials to assess slow conduction channels and preferential conduction towards the exit site of the scar. Areas of non-capture are annotated in gray in the map by dedicated software when no local bipolar pacing capture is observed at 10 mA (Fig. 4).

In cases of spontaneous occurrence or inducibility of hemodynamically tolerated VT, limited activation mapping can be performed to confirm participation of previously identified slow conducting channels in reentrant circuit. Entrainment mapping is used in different regions of the circuit. Alternative strategies rely mainly on assessment of late potentials or local abnormal ventricular activities [14]. Catheter ablation then targets such regions in order to abolish all late potentials or LAVA. Some operators use predominantly pacemapping and analysis of similarity of QRS morphology at different sites of the substrate with clinical arrhythmia [15, 16]. Others propose image integration of electroanatomical maps with 3D reconstruction of a substrate using MRI with late gadolinium enhancement. More recently, intracardiac echocardiography is more and more often used to visualize myocardial substrate on line [17]. (Fig. 5).

Based on our experience, intracardiac echocardiography is particularly advantageous in patients after correction of congenital heart disease [18].

Since some disease entities (eg arrhythmogenic right ventricular dysplasia or dilated cardiomyopathy) have substrate localized mainly epicardially, technique of epicardial puncture and mapping has been developed [19]. Electroanatomical mapping of epicardial surface is often performed to display regions of the scar tissue and annotate points of interest [20, 21]. When an epicardial approach was used, coronary angiogram is performed to avoid application of radiofrequency energy in the vicinity of the epicardial coronary vessels. Alternatively, image integration could be used
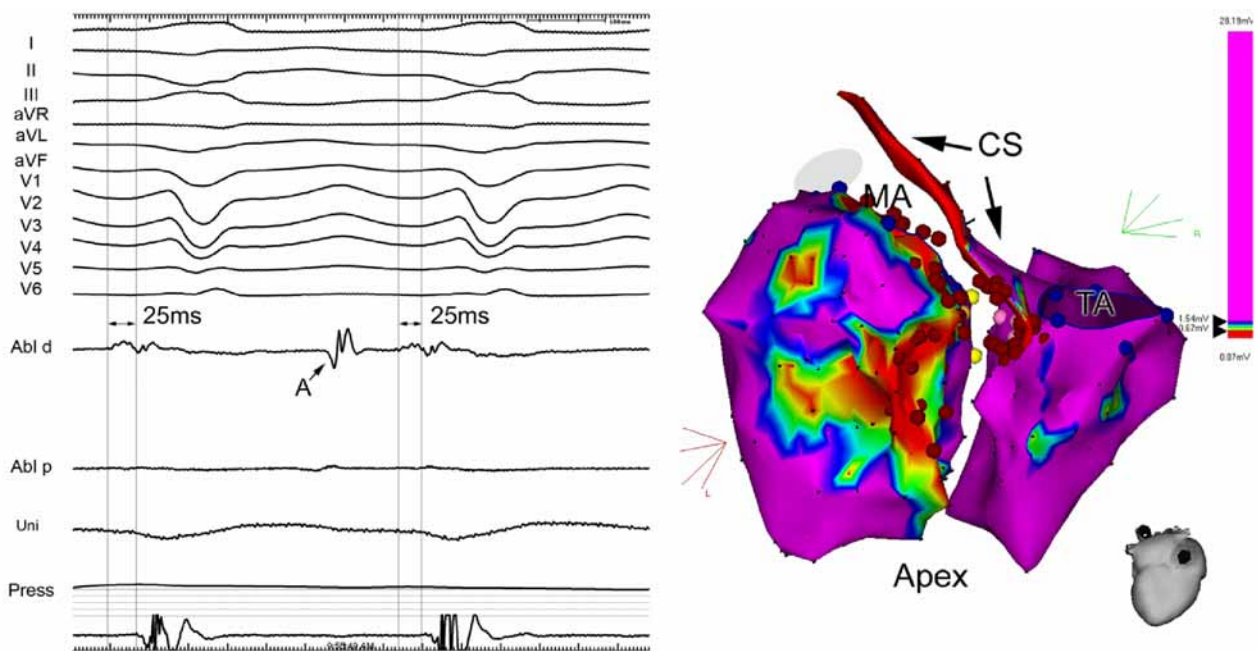

Figure 4. Electroanatomic voltage map of the left ventricle (RAO view) showing large substrate after anteroseptal myocardial infarction (red-gren color). Minimum voltage is as low as 0.23 mV, allowing to delineate channels of surviving tissue within the scar (yellow to green regions). Grey zones show sites of non-capture. Arrows depict 4 critical isthmuses for 4 different morphologies of ventricular tachycardia that were induced (corresponding morphologies are below). Dark red points depict lines of ablation leading to homogenization of the substrate and non-inducibility of all ventricular tachycardias. Abbreviations: MA – mitral annulus, Apex – apical region, Anterior – anterior wall
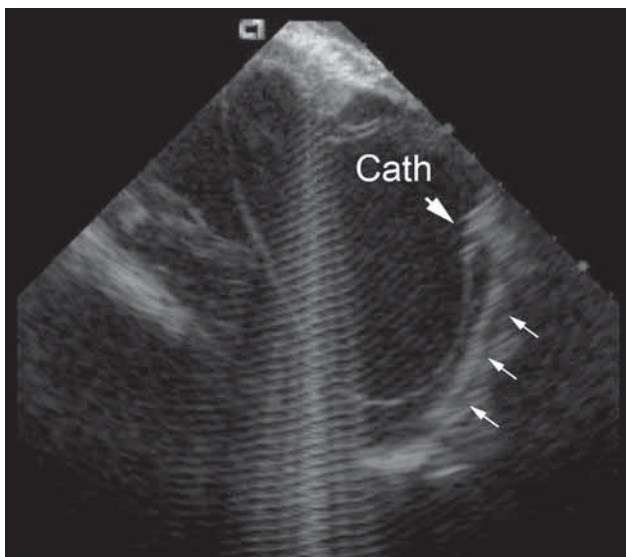
Figure 5. Intracardiac echocardiogram of the left ventricle (obtained from the right ventricular cavity) depicting large aneurysm of the anterior wall with endocardial scar replacing the half of the thickness of myocardium (small arrows). Ablation catheter is introduced retrogradely and bended against the wall (Cath with arrow)
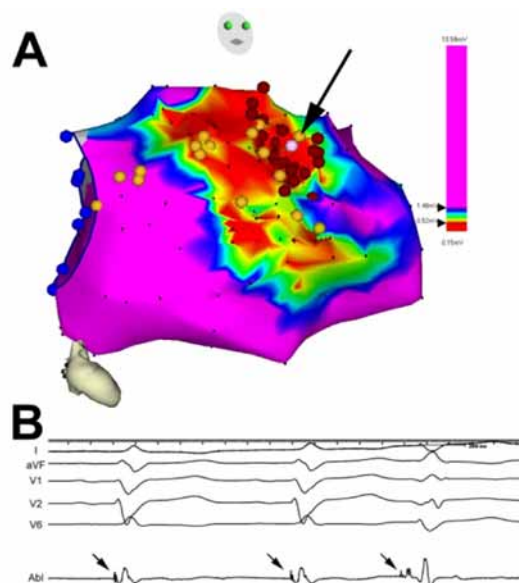

Figure 6. A. Electroanatomic voltage map of the left ventricle (RAO) in subacute stage of anteroseptal myocardial infarction complicated by electrical storm due to focally triggered ventricular fibrillation. Red color depicts necrotic region, yellow points delineate conduction system. Large arrow shows the site of triggering focus in anterior fascicle, dark red points correspond to ablation points around to modify the region. B. ECG leads I, aVF, V1,2,and 6 together with signal from ablation catheter (Abl) during endocardial mapping. Arrows depict sharp Purkinje potential that is earliest during triggering ectopic beat (third beat from left)

with fusion of prerecorded CT image of the left ventricle and coronary arteries. The use of catheter with contact force sensing and vector of force display allows to confirm adequate contact force with epicardium. Indication for epicardial mapping could arise from endocardial unipolar maps of either right or left ventricles [22, 23]. Suspicion on epicardial substrate can be Epicardial substrate could be assessed also by intracardiac eachocardiography [24].

Techniques of catheter ablation in ventricular fibrillation associated with structural heart disease

Catheter ablation has been demonstrated as the method of choice to terminate electrical storm in subjects with various forms of ventricular fibrillation in patients with structural heart disease, especially ischemic heart disease. Also in such cases, the majority of arrhythmic events are triggered from the Purkinje fibres surviving within the region of myocardial necrosis or scar. Such arrhythmic focus is usually localized close to the borderzone with normal tissue. For this reason, the use of electroanatomic mapping system proved to be very useful [25, 26]. It allows annotation of the site when "bumping" of the ectopic focus occurs during mapping and leads to disappearance of arrhythmia (Fig. 6). Empirical ablation could be performed around the borderzone of the scar or necrosis.

Technology focused on more efficacious ablation

Regarding energy sources, radiofrequency current remains still the most widely used. To improve the efficacy of ablation, several modifications of the catheter tip electrode have been introduced.

Large-tip electrodes. One approach to enlarge the lesion size is to increase the electrode surface area exposed to the blood. The result is higher convective cooling of the catheter tip, allowing delivery of more energy to the tissue. Today, catheters with electrode tip of 8–10 mm are available and used in clinical practice [27, 28]. On the other hand, nonuniform heating around the electrode increases a risk of coagulum formation at the base of the electrode. Additionally, large-tip electrodes decrease accuracy of mapping due worse spatial resolution.

Gold-tip electrodes. Another strategy to achieve larger lesions is to use gold electrodes. Gold exhibits a thermal conductivity of nearly four times greater than platinum-iridium (3.17W/cm Kelvin vs. 0.715W/cm Kelvin). RF ablation with such electrode results in broader and deeper lesions as a result of a better heat conduction from the tissue-electrode interface and additional cooling of the gold electrode by "heat loss" to the intracardiac blood [29].

Irrigated tip electrodes. An alternative strategy to create larger RF lesions comprises active cooling of the electrode tip at the tissue inter- face. This can be accomplished by irrigation of the electrode tip with saline solution. When the electrode-tissue interface is cooled, power can be increased without concern about the surface temperature exceeding 100 °C and coagulum form- ing. This effect does not directly lead to increased lesion dimension. Convective cooling of the electrode tip results in energy dissipation into the circulating blood pool. When the energy loss is not matched by increased energy delivery from the RF generator, lower net energy is transmitted to the tissue, and lesion size could be smaller [30].
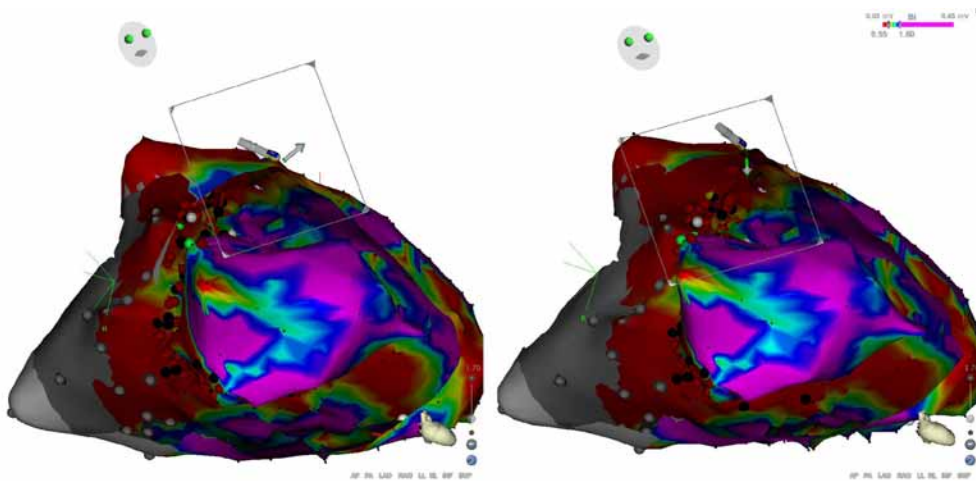
Figure 7. Electroanatomic maps of endocardial and epicardial surface of the left ventricle (RAO views, epicardial map partly cut to open view inside) during catheter ablation with Smart Touch catheter. Small vector (grey arrow) shows direction of the force – on left panel pointing away from epicardial surface and on right panel towards epicardial surface

Needle tip electrode. Recently, early clinical work was introduced to increase lesion size, especially depth. So far, only feasibility studies have been performed [31].

Contact force technology. Recently, contact force (CF) between the catheter tip and the myocardium has been identified as one of the important determinants influencing RF lesion size [34, 35]. Currently, three novel technologies are available to assess real-time catheter-tissue CF. Historically the first one, called Intellisense, was implemented in the electromechanic robotic system Sensei (Hansen Medical, inc, Mountain View, CA), and consisted of indirect assessment of catheter tip-tissue contact through measurement of friction in the proximal part of catheter shaft [36]. In principle, the remote catheter manipulator directly controls a hollow robotically steered sheath (Artisan Catheter, Hansen Medical) that can accommodate any mapping or ablation catheter. Small catheter movements inside the sheath create friction. The intensity of the friction is proportional to the CF.

Two other technologies use direct measurement of the catheter tip contact through a specific sensor. One system employs 3 optical fibers to measure microdeformation of a deformable body in the catheter tip (TactiCath; St Jude Medical, Inc) [34, 37]. The second type of catheter uses a small spring connecting the ablation tip electrode to the catheter shaft with a magnetic transmitter and sensors to measure small deflections of the spring (Theromocool SmartTouch; Biosense Webster, Inc). This technology allows construction of 3D electroanatomical maps of CF distribution.

Currently, there is little evidence on clinical utility of CF for VT ablation. Our experience showed that retrograde approach to the left ventricle results in high CF in the region of the lateral and posterolateral wall. On the other hand, transseptal approach allows for better distribution of CF along the interventricular septum, inferior wall and the outflow tract. The above observations were quantified in a technical study in which both antegrade-transseptal and retrograde-transaortic LV-mapping approach were compared in 10 patients undergoing VT ablation by using CF-sensing catheters [38]. Operators were blinded to CF data and data were analysed according to 11 predefined left ventricular segments. CF was significantly higher antegradely in mid-anteroseptum, mid-lateral, and apical segments, and significantly higher retrogradely in basal-anteroseptum, basal-inferoseptum, basal-inferior, and basal-lateral segments. Contact force did correlate with impedance, unipolar, and bipolar electrogram amplitudes; however, there were large overlaps. For epicardial ablation, CF vector that is available in SmartTouch technology clearly identifies whether the tip of the catheter is in a contact with epicardial surface (Fig. 7).

Conclusion

Catheter ablation of ventricular arrhythmias has developed over last two decades significantly. With current mapping, imaging and catheter technologies, catheter ablation can be considered as highly efficient in treatment of idiopathic VTs. In this indicaton, it is considered curative. In subjects with structural heart disease, current technologies allow successful modification of arrhythmogenic substrate in a high proportion of patients, regardless of hemodynamic tolerability of arrhythmias. It is preferred therapeutic method in patients with electrical storm. This is particularly true in cases of focally triggered ventricular fibrillation. Some preliminary data suggest that catheter ablation can be performed in patients with structural heart disease even prophylactically.

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СОВРЕМЕННАЯ ТАКТИКА ВЕДЕНИЯ ПАЦИЕНТОВ МОЛОДОГО ВОЗРАСТА С СИНДРОМОМ УДЛИНЕННОГО ИНТЕРВАЛА QT: ОТ РАННЕЙ ДИАГНОСТИКИ К ИМПЛАНТАЦИИ КАРДИОВЕРТЕРА-ДЕФИБРИЛЛЯТОРА И МОНИТОРИНГУ МАРКЕРОВ РИСКА ВНЕЗАПНОЙ СМЕРТИ

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MODERN TACTICS IN MANAGEMENT OF YOUNG PATIENTS WITH LONG QT SYNDROME: EARLY DIAGNOSIS, IMPLANTATION OF CARDIOVERTER-DEFIBRILLATOR, AND MONITORING OF SUDDEN CARDIAC DEATH RISK MARKERS

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Актуальность первичных электрических заболеваний сердца у детей и лиц молодого возраста в настоящее время крайне высока, так как они являются основной причиной злокачественных желудочковых аритмий и внезапной сердечной смерти (ВСС). К этой группе заболеваний относится синдром удлиненного интервала QT, распространенность которого, по последним данным, достигает 1:2500–3000 новорожденных. Клинические проявления заболевания и эффективность лечения больных зависят от конкретного молекулярно-генетического варианта синдрома. Стратификация риска внезапной смерти (ВС) у больных синдромом удлиненного интервала QT основывается на клинических, электрокардиографических и молекулярно-генетических факторах и маркерах. Общепринятый подход к лечению синдрома удлиненного интервала QT заключается в назначении бета-адреноблокаторов. Эффективным методом профилактики ВС при синдроме удлиненного интервала QT является имплантация кардиовертера-дефибриллятора.
Ключевые слова: внезапная сердечная смерть, удлинение интервала QT, кардиовертер-дефибриллятор.

The study of primary electrical diseases of the heart in children and young people is of high demand because these diseases are the main cause of malignant ventricular tachycardias and sudden cardiac death (SCD). This group of diseases includes long QT syndrome with estimated prevalence rate of 1 in 2500 to 3000 in new-borns according to recent data. Clinical manifestation of the disease and efficacy of treatment depend on particular molecular-genetic variant of the syndrome. Sudden cardiac death risk stratification in patients with long QT syndrome is based on clinical, electrocardiography, and molecular-genetic factors and markers. Common approach to treatment of long QT syndrome consists in administration of beta-adrenoblockers. Efficacious method of SCD prevention in patients with long QT syndrome is implantation of cardioverter-defibrillator.
Key words: sudden cardiac death, long QT syndrome, cardioverter-defibrillator.