Effects of Internal Cardioversion on Electrophysiological Properties of the Right Atrium

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Abstract

Aim of this study is to investigate the effects of low energy internal cardioversion (LEIC) on the electrophysiological properties of the right atrial tissue. Thirteen patients were studied, selected a priori for LEIC (increasing energy levels: 1, 2, 3, 5, 7, 10, 15 and 20 J) and monitored by a multipolar basket catheter (32 intra-atrial recordings each patient). The atrial period, the levels of organization and the synchronization have been estimated for each electrogram, over 10-second windows, 10 seconds before and 10 seconds after each shock. Our results suggest that ineffective shocks do not affect the electrophysiological properties of the atria. This is consistent with the hypothesis that even though electrical activation ceases after the shock it spontaneously regenerates within few milliseconds and that the propagation pattern is expression of the organic substrate, which is not affected by an electric shock.

1. Introduction

Atrial fibrillation (AF) is the most common, sustained arrhythmia that occurs in humans and presents a number of therapeutic choices, both pharmacologic and nonpharmacologic. A widely used nonpharmacologic therapeutic approach in patients with AF is the Low Energy Internal Cardioversion (LEIC), obtained either via percutaneous catheters and an external generator or using an implanted device.

Over the last years investigations on the minimal energy requirements and on the electrophysiological substrate sustaining the fibrillatory phenomenon mainly focused on correlation with clinical parameters. The reduction of the energy is particularly important in implanted devices because of the discomfort caused by the shock. A large extent of researches aimed at reducing the energy shock by optimizing variables such us catheter position, duration and morphology of the shock waveform and drug therapy [1][2][3].

Main attention should be devoted to the investigation of the effects of shock energy on the electrophysiological substrate sustaining the fibrillatory phenomenon.

Aim of this study is to investigate the effects of internal cardioversion energy on the electrophysiological properties of the right atrial tissue. We focused our attention on three electrophysiological measures, each one reflecting a specific property of the atrial substrate: the local atrial period (AP), the level of organization, which measures the percentage of points laying on the signal baseline (i.e., number of occurrences, NO) [4], and the index of synchronization (IS) which estimates the probability that two depolarizations detected in two adjacent electrograms belong to the same propagating wavefront. In order to perform an extensive mapping of the entire atrial tissue, we used a multipolar basket catheter (MBC) inserted in the right atrium, thus obtaining 32 intra-atrial simultaneous recordings from a single atrium.

2. Methods and materials

2.1. Experimental protocol

Bipolar electrograms were obtained from MBC (Constellation, Boston Scientific, MA, USA) in right atrium in 13 haemodynamically stable patients with documented persistent AF, selected a priori for LEIC. Informed consent was obtained in all cases. Antiarrhytmic drugs were suspended >5 half-lives before the study.

The MBC is composed of 64 platinum-iridium equally-spaced electrodes mounted on 8 flexible, self-expanding splines, 8 electrodes each spline. Each spline is identified by a letter (from A to H), the electrodes on each spline are identified by numbers (from 1 to 8).

MBC was advanced via the left or right femoral vein. Position and stability of the catheter were assessed by fluoroscopy (anteroposterior and lateral views), each minute. From the 64 electrodes, 32 bipolar electrograms were derived by combining electrodes 1and 2, 3 and 4, 5 and 6, 7 and 8, for each spline and were labeled A12, A34, ..., H78. These electrograms were filtered (pass-band 10-300Hz), digitized (1-kHz, 16 bit) and stored on magneto-optical disk, using a Bard Labsystem polygraph. Surface leads (I, II, III, aVR, aVL, aVF and V1) were also recorded.

On arrival at the electrophysiological laboratory, all patients were in sustained AF. After a 10-minutes long basal monitoring, a step-up protocol was used for LEIC. It started with a nominal shock energy of 0.5 J, then increased at the following levels: 1, 2, 3, 5, 7, 10, 15 and 20 J. The procedure was stopped when a stable sinus rhythm was observed (>1 minute). Two 6F decapolar catheters were used for the internal cardioversion: one with the distal tip positioned in the right atrial appendage; the other inserted into the coronary sinus.

2.2. Electric-anatomic relation

The definition of anatomic locations is necessary to relate the electrophysiological properties associated to each bipole to the anatomical site of that bipole in each patient and to statistically compare the data from different patients. By combining the information from the fluoroscopic projections taken during the study and from the electrogram morphologies, the right atrium was divided into 32 anatomic regions. Particularly fluoroscopically identifiable markers (1 on spline A and 2 on spline B) furnished the orientation of the basket, while the presence of significant V-waves artifacts identifies those electrograms close to the tricuspid valve circumference [5][6]. V waves artifacts were quantified in terms of ventricular signal-to-noise ratio (SNR_V). Signals with SNR_V lower than 10 dB were considered likely to come from bipoles close to the tricuspid valve region. No discrepancies were obtained between fluoroscopic and morphological data [7].

The 32 anatomical regions have been obtained as follows: first, each spline has been associated to 8 anatomic 'vertical' regions of the right atrium (figure 1) namely, anterior free wall (AFW), lateral free wall (LFW), postero-lateral free wall (PLFW), posterior free wall (PFW), posterior atrial septum (PAS), atrial septum (AS), tricuspid valve (TV) and anterior tricuspid valve (ATV). Second, each region was further divided into high (bipoles 1-2), mid-high (bipoles 3-4), mid-low (bipoles 5-6) and low (bipoles 7-8) segments (figure 1).

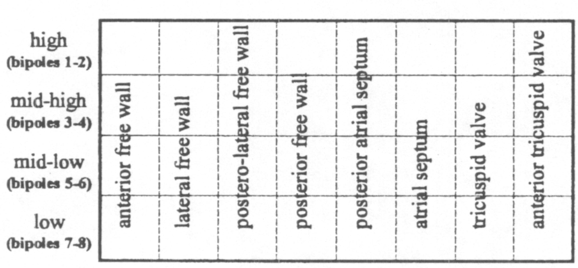

Fig. 1. Definition of 32 anatomic regions. See text for details

2.3. Electrophysiological parameters

Electrophysiological measures consisted on the estimation of the local AP, of the level of organization (measured by the NO) and of the IS.

AP has been calculated after a peak-detection procedure featuring an adaptable threshold algorithm. Atrial electrograms have been first band-pass filtered (40-250Hz, order 40, Kaiser window) to remove baseline shift and high-frequency noise. The absolute value of the output of the band-pass filter was then low-pass filtered (FIR, 0-30Hz, order 40, Kaiser window). This process extracts a time-varying waveform proportional to the amplitude of the high-frequency components of the original atrial electrograms [8]. The AP series were obtained by averaging the atrial cycle lengths over 10 seconds. Further details on the mathematical procedures can be found in [4].

NO was computed on each bipolar recording by estimating the percentage number of points along the baseline, over 10-second windows. This parameter turned out to reliably classify AF organization according to Wells' criteria [4][9].

After a reliable estimation of the activation times, IS is computed from a couple of series of activations of atrial depolarizations as follows: a propagation delay is defined as the difference between each activation time of the first series and the time of the closest activation in the second series. If no activation is found within a ±1-second window, the delay is set to 1 second. The propagation delay is computed for each detected depolarization of the first series. This sequence of delays is then transformed by using a sigmoid function $s(x)$ ranging between 0 and 1, so that long delays return values close to 0, while short delays return values close to 1.

The IS is based on the assumption that two depolarizations closely spaced in time are likely to belong to the same propagating wavefront (i.e. synchronized): the smaller the delays, the higher the probability of synchronization.

Since independent series have a not null probability of occurring close in time, IS results to be biased. To ensure a correct interpretation of the IS values, for each electrograms couple we give an IS value and the significance level of the test (i.e. the probability of error in case of rejecting the hypothesis that the measured IS originates from independent series, even though it is true).

2.4. Estimation of the effects of internal shocks

In order to evaluate the effects of internal cardioversion shocks on the electrophysiological properties of the right atrium, we estimated averaged AP, NO and IS values over 10-second long windows, 2 seconds before and 2 seconds after each ineffective shock.

We thus evaluated the electrophysiological parameters values after each shock, for all the anatomical regions mapped by the MBC. Also, we estimated the differences of AP, NO and IS values (ΔAP, ΔNO, ΔIS), immediately before and after each shock (10 seconds), for all the anatomical regions.

3. Results

All the patients were succesfully cardioverted, at different energy levels.

Figure 2 shows the values obtained for the AP after each ineffective shock (upper panel) as a function of the shock energy, and the ΔAP calculated at each shock (lower panel), for one patient. The AP of all the anatomic regions mapped by the MBC are shown. Similarly, figures 3 and 4 show the values obtained for NO and ΔNO, and for IS and ΔIS, respectively, for the same patient. (The confidence intervals for the IS values are not shown).

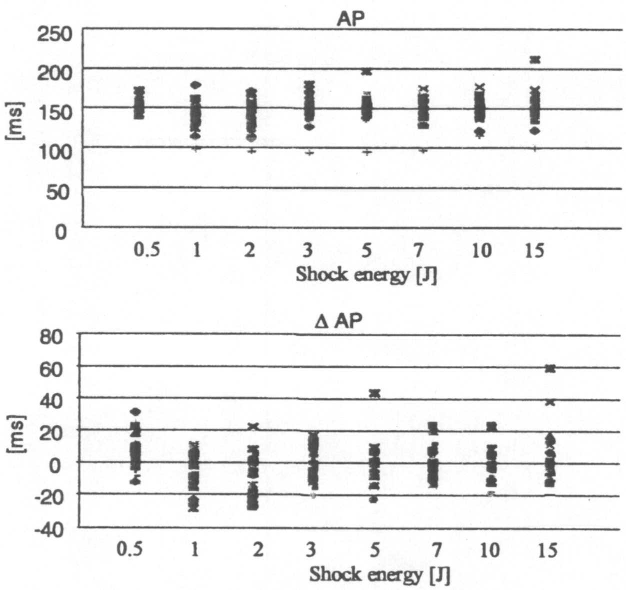

Fig. 2. AP and ΔAP values as a function of ineffective shocks energy, for one patient and for all the 32 anatomic regions.

After each shock no significant differences (Kruskal-Wallis test) were observed in AP, NO and IS values in the various atrial zones, for all patients. Similar results have been obtained for ΔAP, ΔNO and ΔIS at each shock. Particularly, the differences of AP, NO and IS values immediately before and after each shock, randomly fluctuate spanning positive and negative values. In addition no significant trend characterizes these differences vs. the increasing energy levels of cardioversion.

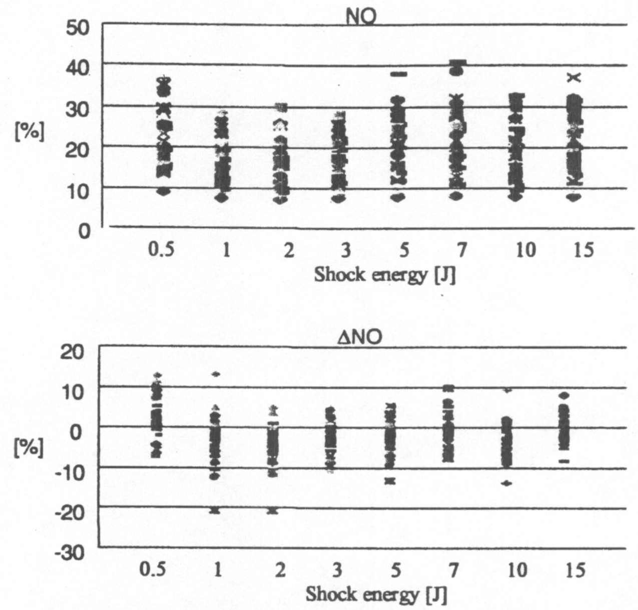

Fig. 3. NO and ΔNO values as a function of ineffective shocks energy, for one patient and for all the 32 anatomic regions.

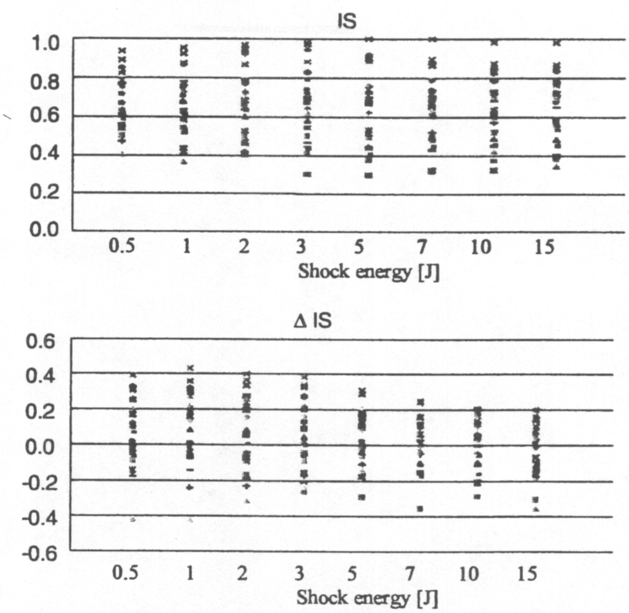

Fig. 4. IS and ΔIS values as a function of ineffective shocks energy, for one patient and for all the 32 anatomic regions.

Also the regional distribution of the parameter values did not change during the LEIC protocol and did not correlate to the successful cardioversion energy.

Figure 5 shows the regional distribution of the organization, in one patient, after 3,5 and 7 J shocks.

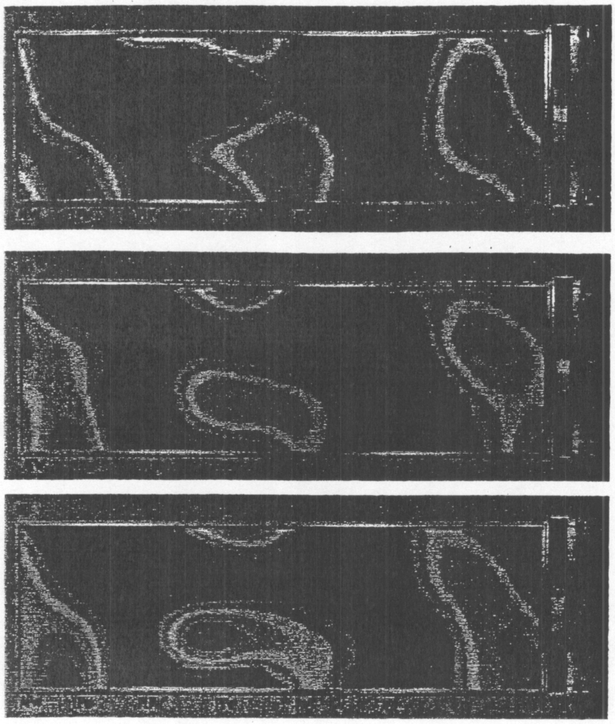

Fig. 5. NO as a planar map in one subject after ineffective shoks at 3, 5 and 7 J. Different atrial regions show different electrophysiological behaviors with the simultaneous presence of areas with disorganized atrial activity (light gray) and other regions with relatively regular activations (dark gray). These organized and disorganized regions differ among the patients, but individual pattern are stable in time and do not change after the shocks.

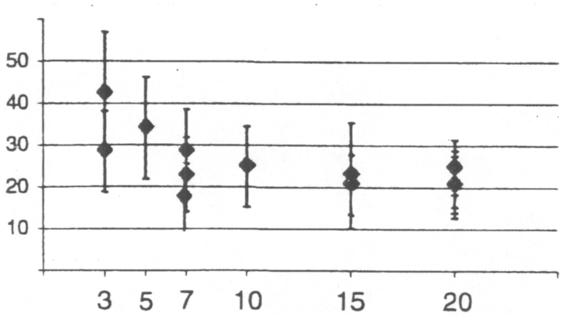

Fig. 6. NO as a function of effective shocks energy, for all patients. A single grand averaged value and its standard deviation is plotted for each patient.

4. Discussion

The electrophysiological properties of the right atrium were investigated by 3 descriptors. No difference were observed after the delivery of ineffective shocks. These results support the hypothesis that the organization and the synchronization of the depolarization wavefronts ar expression of the modification of the electrical properties of the underling substrate, which is not affected by ineffective shocks. We found that the energy required for successful cardioversion is higher for those patients with low values of organizations. This last results needs further confirmation on a larger population.

References

[1] Tomassoni G, Newby KH, Kearney MM, Brandon MJ, Barold H, Natale A. Testing different biphasic waveforms and capacitances: effect on atrial defibrillation threshold and pain perception. J Am Coll Cardiol 1996,28(3): 695-9.

[2] Harbinson MT, Allen JD, Imam Z, Dempsey G, Anderson JM, Ayers GM, Adgey AA. Rounded biphasic waveform reduces energy requirements for transvenous catheter cardioversion of atrial fibrillation and flutter. Pacing Clin Electrophysiol. 1997;20(1 Pt 2): 226-9.

[3] Mathew TP, Moore A, McIntyre M, Harbinson MT, Campbell NP, Adgey AA, Dalzell GW. Randomised comparison of electrode positions for cardioversion of atrial fibrillation. Heart 1999;81(6): 576-9.

[4] Barbaro V, Bartolini P, Calcagnini G, Morelli S, Michelucci A, Gensini G. Automated classification of human atrial fibrillation from intraatrial electrograms. Pacing Clin Electrophysiol. 2000;23(2):192-202.

[5] Pitschner HF, Berkovic A, Grumbrecht S, Neuzner J. Multielectrode basket catheter mapping for human atrial fibrillation. J. Cardiovasc. Elecrophysiol 1998; 9(8):S48-56.

[6] Triedman JK, Jenkins KJ, Colan SD, et al. Multipolar endocardial mapping of the right heart using a basket catheter: acute and chronic animal studies. Pacing Clin Electrophysiol. *1997;*20(1 Pt 1):51-9.

[7] Barbaro V, Bartolini P, Calcagnini G, Censi F, Morelli S, Michelucci A. Mapping the organization of atrial fibrillation with basket catheters - part I: validation of a real-time algorithm. Pacing Clin Electrophysiol. 2001 Jul;24(7):1082-8.

[8] Botteron GW, Smith JM. A technique for measurement of the extent of atrial activation during atrial fibrillation in the intact human heart. IEEE Trans. Biomed. Eng. 1995;42(6):579-586.

[9] Wells JL, Karp RB, Kouchoukos NT, Maclean WAH, James TN, Waldo AL. Characterization of atrial fibrillation in man: studies following open-heart surgery. Pacing Clin Electrophysiol.1978;1:426-438.

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