Characterization of the impact of catheter–tissue contact force in lesion formation during cavo-tricuspid isthmus ablation in an experimental swine model

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Aims

Catheter–tissue contact is critical for effective lesion creation. The objective of this study was to determine in an experimental swine model the pathological effects of cavo-tricuspid isthmus ablation using two systems that provide reliable measures of the pressure at the catheter tip during radiofrequency ablation procedures.

Methods and Results

We performed the procedure in eight pigs in our experimental electrophysiology laboratory after right femoral vein dissection and insertion of a 12 Fr. introducer during general anaesthesia and endotracheal intubation. The target contact force during the applications was <10 grs. (axial or lateral), 10–20, 20–30, and >30 grs. in two pigs each. The power was set at 40 W and maximum target temperature at 45 °C. We performed a radiofrequency line dragging from the tricuspid valve to the inferior vena cava in the eight pigs. Euthanasia of the animals was carried out a week after the procedure and a pathological examination of the lesions was performed. In the endocardial macroscopic analysis the extent of lesions, presence of thrombus, transmurality, and endothelial rupture was assessed. External surface was examined searching for transmural lesions. The mean contact force applied was 18.7 ± 8.4 grs. and the mean depth of the lesions was 3.6 ± 2 mm. Lesions were never transmural with average forces <10 grs., and the mean depth was very low (0.75 mm). To achieve transmural lesions contact forces of at least 20 grs. were required. We found a positive correlation (r = 0.85, P < 0.05) between the average force during the applications and depth of the lesions.

Conclusion

When ablating the cavo-tricuspid isthmus in a swine model, contact forces of at least 20 grs. are required to achieve transmural lesions. Catheter–tissue contact is critical for effective lesion creation. This information is important for improving ablation efficacy.

Keywords

Ablation • Radiofrequency • Isthmus

Introduction

Catheter–tissue contact is critical for effective lesion creation. Despite its importance, contact force (CF) assessment has been largely subjective so far. Currently, we have monitoring systems that provides a reliable measure of the pressure at the catheter tip.1 The required force when ablating the cavo-tricuspid isthmus (CTI) is not well defined and the recurrences after ablation may be explained by the use of a low force of contact that produces transitory lesions. The aim of this study was to assess in an experimental swine model the pathological effects of CTI radiofrequency catheter ablation using two contact systems that provides continuous pressure monitoring.

Material and methods

Experimental preparation

Experimental protocol was approved by the ethics committee in the University Hospital Ramón y Cajal following standard guidelines for...
the use and care of laboratory animals. Ablation procedure was performed in eight pigs. They were anaesthetized with ketamin 10 mg/kg (ketolar*) and sodium thiopental 20 mg/kg (Tiobarbital Braun*), and received mechanical ventilation after endotracheal intubation. General anesthesia was maintained with isoflurane 2–3%. A 12 Fr. sheath was introduced in the right femoral vein after its dissection. Surface electrocardiogram (EKG) and intracardiac electrograms were visualized and recorded in a multichannel polygraph (Cardiac-Pathways Corp.). Any clinically significant change as well as ST segment alteration were recorded, arrhythmia incidence during and after the procedure was also monitored.

### Ablation catheters

Endosense’s TactiCath® (TactiCath, Endosense SA) and ThermoCool SmartTouch® ( Biosense Webster Inc.) catheters were used for ablation in four animals each. They both are 7 Fr, four electrodes, 3.5 mm saline irrigated tip catheters. They were used with the corresponding radiofrequency generator.

Endosense’s TactiCath® has a force sensor joined in the distal part of the catheter, between the second and third electrode. The force sensor is made up of an elastic polymeric material deformable section and three optical fibres (0.125 mm diameter) to measure microdeformations, which correlate to the applied catheter force. An infrared laser light (wavelength 1520–1570 nm) is sent out through the proximal tip of the three optical fibres. The light is then reflected by Fiber Bragg Gratings (FBG) over a deformable section in the optical fibre distal tip next to the catheter tip. When CF is made against the catheter tip a microdeformation is produced in the deformable material, and the FBG is pressed or narrowed, which makes the reflected light wavelength to change. The wavelength change is proportional to the CF applied to the catheter tip. To monitor the reflected light wavelength in the three fibres, the system is able to calculate and show the CF vector (magnitude and angle) in a 100 ms time interval.

ThermoCool SmartTouch® catheter is supplied with a force sensor in its distal extreme. The proximal axis consists of a helicoidal metallic cylinder or spring connected to the 3.5 mm irrigated electrode. The spring measures the CF with a less than 1 gr. resolution. For this purpose it uses a magnetic transmitter in the catheter tip and three magnetic sensors in the catheter axis. To calculate the catheter angulation changes and CF, sensors position change is used. Within this sensor the applied force during the ablation procedure is measured every 50 ms. All the parameters are visualized in the electroanatomic mapping system (Carto 3D XP, Biosense Webster Inc.).

### Radiofrequency ablation protocol

The ablation catheter was advanced into the right ventricle using fluoroscopic guidance. Catheter–tissue contact was evaluated with the corresponding CF measurement system to achieve the target force defined in the protocol. We established a target CF < 10 grs. (axial or lateral), 10–20, 20–30 and > 30 grs. in each pair of consecutive cases. Each catheter was calibrated to assess the correlation between the tip CF and the reflected wavelength change.

A line of sequential lesions were created from the tricuspid valve annulus moving the catheter back step by step to the inferior vena cava during apnea. Sequential ablation atrial sites were carefully selected by the morphology and range of the potentials registered in the distal electrode of the ablation catheter. The objective was to do a unique continuous ablation line in the CTI with each catheter in each animal. Radiofrequency current was applied between the distal electrode of the ablation catheter and an adhesive external patch for 60 s in a temperature control mode, with target temperature of 48°C, at 40 W during 30 mL/min saline solution irrigation. The cooling system was an atmosphere temperature heparinized normal saline infusion (0.9%).

Application of radiofrequency was stopped if impedance or temperature rise or complications were noted. Voltage, temperature, and impedance were continuously monitored and registered in each ablation procedure. Surface 12 leads EKG was analysed during and after each radiofrequency application and also at the end of the procedure to monitor the ST segment changes. After catheters removal, the tip was carefully inspected to check for clots or carbonization.

### Anatomopathologic study

Heart specimens were removed after one week to analyse subacute changes. The walls of the right atrium were dissected to display the area between the inferior cava vein and the tricuspid valve. Each lesion was examined to analyse the macroscopic appearance and the thrombus presence in the endocardial surface. After inspection of the epicardial surface to assess transmurality, we performed the dissection of the lesion in the area of endocardial hyperemia to measure lesion depth. In transmural lesions the maximum distance between the endocardial and epicardial surface in the cross section of the lesion was measured. In cases with no transmural lesions, the maximum distance between the endocardial and epicardial surface and the lesional border was determined. The tissue was examined to assess pericardial or vascular damage evidence.

### Statistical analysis

Continuous variables were expressed as mean and standard deviation. Correlation was analysed with Pearson test. The analysis was performed using SPSS 15.0 (SPSS Inc.).

### Results

#### Ablation data

Mean procedures length were 61.7 ± 56.4 min. This experimental study purpose was to create a unique ablation line, not to repeat multiple applications in the same position. A total of 27 radiofrequency applications were done in eight procedures with an average of
3.3 ± 1.1 applications per procedure. Sixteen applications were made with ThermoCool SmartTouch™ catheter and 11 using EndoSense’s TactiCath™ catheter.

The parameters reached during the ablation were 39.8 ± 1.5°C, 38.3 ± 1.24 W, and 130 ± 50.2 Ω. Mean pressure employed was 18.7 ± 8.4 grs. (Table 1). No steam pops were heard in all the 27 applications. No char was found on the catheter tip. There were no obvious myocardial ischemic complications during or after the procedure, assessed by 12 leads EKG. Two impedance rises were noted (280 and 264 V) during 35 and 26 grs. average force applications. In this latter case ventricular fibrillation occurred and was effectively defibrillated to continue the study.

The macroscopic analysis showed the presence of a deep ventricular lesion.

### Table 1 Parameters during the radiofrequency application

<table>
<thead>
<tr>
<th>Case</th>
<th>TCF (grs.)</th>
<th>CF (grs.)</th>
<th>Depth (mm)</th>
<th>Ablation time (s)</th>
<th>Number of applications</th>
<th>Power (W)</th>
<th>Temperature (°C)</th>
<th>Impedance (V)</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ST</td>
<td>&lt;10</td>
<td>7.4 ± 1.5</td>
<td>1</td>
<td>300</td>
<td>5</td>
<td>38 ± 2.4</td>
<td>38.6 ± 0.4</td>
<td>95 ± 4.4</td>
<td></td>
</tr>
<tr>
<td>2 TC</td>
<td>&lt;10</td>
<td>9 ± 2</td>
<td>0.5</td>
<td>120</td>
<td>2</td>
<td>37.5 ± 2.5</td>
<td>33.5 ± 0.5</td>
<td>90 ± 0</td>
<td></td>
</tr>
<tr>
<td>3 ST</td>
<td>10–20</td>
<td>12.6 ± 0.9</td>
<td>2</td>
<td>124</td>
<td>3</td>
<td>37 ± 0.5</td>
<td>38.5 ± 0.5</td>
<td>110 ± 0</td>
<td></td>
</tr>
<tr>
<td>4 TC</td>
<td>10–20</td>
<td>16 ± 0.8</td>
<td>4</td>
<td>134</td>
<td>2</td>
<td>36.8 ± 1.4</td>
<td>38.5 ± 0.5</td>
<td>122.5 ± 2.5</td>
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<tr>
<td>5 ST</td>
<td>20–30</td>
<td>21.6 ± 2.8</td>
<td>6</td>
<td>220</td>
<td>5</td>
<td>41.2 ± 1.6</td>
<td>42 ± 2.4</td>
<td>163.7 ± 4.1</td>
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</tr>
<tr>
<td>6 ST</td>
<td>20–30</td>
<td>23 ± 2.1</td>
<td>5.6</td>
<td>162</td>
<td>3</td>
<td>40 ± 0</td>
<td>44.5 ± 0.4</td>
<td>128 ± 10.1</td>
<td></td>
</tr>
<tr>
<td>7 TC</td>
<td>&gt;30</td>
<td>27 ± 2.1</td>
<td>5.4</td>
<td>226</td>
<td>3</td>
<td>36.3 ± 0.9</td>
<td>35.6 ± 1.7</td>
<td>174.6 ± 63.3</td>
<td>Impedance rise, VF</td>
</tr>
<tr>
<td>8 TC</td>
<td>&gt;30</td>
<td>33 ± 2.5</td>
<td>5</td>
<td>204</td>
<td>4</td>
<td>46.5 ± 2</td>
<td>39 ± 0.8</td>
<td>227 ± 70.4</td>
<td>Impedance rise</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td></td>
<td>18.7 ± 8.4</td>
<td>3.6 ± 2</td>
<td>186.2 ± 58.6</td>
<td>3.3 ± 1.1</td>
<td>38.3 ± 1.24</td>
<td>39.8 ± 1.5</td>
<td>130 ± 50.2</td>
<td></td>
</tr>
</tbody>
</table>

TCF, target contact force; CF, contact force; ST, ThermoCool SmartTouch™; TC, EndoSense’s TactiCath™; VF, ventricular fibrillation; SD, standard deviation.

**Figure 1** Left: Endocardial surface of the cavotricuspid isthmus. This lesion was produced with a TactiCath™ catheter with a power of 40 W, 45°C, and average force of 33 grs. The lesion presented small extent cratering (arrow). Right: Epicardial cardiac surface of the lateral cavotricuspid isthmus. Transmural lesion produced with ThermoCool™ Smarttouch™ catheter with a power of 40 W, 45°C, and an average force of 23 grs. (arrow). SVC, superior vena cava; IVC, inferior vena cava.
well-defined lesional area was observed, allowing an accurate measurement of depth.

No mural thrombus, myocardial perforation, or pericardial effusion was observed. No structural variations were observed on the right coronary artery or tricuspid valve.

Average isthmus dimensions were 22 ± 7 mm in length, with a maximum thickness in the injured area of 4.8 ± 1.4 mm. Mean lesions depth was 3.6 ± 2 mm. Mean lesions depth was < 1 mm when less than 10 grs. of CF was applied, 3 mm with CF between 10 and 20 grs., and over 5 mm with CF above 20 grs. (Table 2). There was a positive correlation between the average CF and the lesions depth ($r = 0.85, P < 0.05$) (Figure 2).

**Discussion**

The main finding of our study was the requirement of ablation CF of at least 20 grs. to achieve transmural lesions at the CTI. We found a good correlation between the average CF and lesion depth. Experimental and clinical studies have shown that CF is one of the main factors to determine lesion size²,³ and efficacy during radiofrequency catheter ablation procedures.⁴,⁵ In these studies the optimal CF for an appropriate catheter—tissue contact varied from 10 to 40 grs. Our findings agree with previous data suggesting that low CF decrease the efficacy and too much CF can be deleterious.

This is the first time that the pathological effects of performing CTI lesions by means of CF catheters are evaluated in an in vivo study. In vivo models have the added value of evaluating the pathological effects of the ablation under conditions similar to those present in clinical practice such as respiratory and cardiac motion, blood flow, and technical aspects specific of each particular ablation substrate.⁶

Radiofrequency ablation is an effective treatment for typical atrial flutter, aimed to the region between the tricuspid valve and the inferior vena cava-Eustachian valve.⁷–⁹ The ablation target is the creation of transmural lesions to achieve isthmus bidirectional block.¹⁰,¹¹ However, there is a group of patients where the CTI ablation is not achieved and at least 10% of the patients have subsequent recurrences after successful initial complete isthmus ablation. This may be related to insufficient CF during the ablation or anatomical factors such as myocardial thickness or recesses that prevent transmural lesion formation.¹² There may be considerable variations in the human anatomy in CTI, with isthmus thickness that can reach up to 7 mm.¹³,¹⁴ In our work, CF of at least 20 grs. was needed to achieve transmural lesions. This fact agrees with clinical observations in others substrates. Reddy et al. found during catheter ablation for AF that CF correlates with clinical outcome. Arrhythmia control was best achieved when ablation lesions were placed with an average CF of > 20 grs., and clinical failure was universally noted with an average CF of < 10 grs.⁴ Our findings highlight the importance of achieving adequate CF to achieve transmural lesions and prevent flutter recurrences.

Contact force also influences safety since excessive pressure can result in severe complications, including perforation and tamponade.¹⁵ It has been suggested that the optimal CF ranges between 10 and 40 grs. since excessive force is associated with an increased incidence of thrombus formation, steam pops, or perforation.²,¹⁶,¹⁷ In our series two impedance rises were noted during 35 and 26 grs. average force applications but no mural thrombus, myocardial perforation or pericardia effusion was observed. No structural variations were observed on the right coronary artery¹⁸,¹⁹ or tricuspid valve.

**Limitations of the study**

In our study subacute changes were assessed 1 week after the ablation. Chronic changes could have also been assessed 2 months after ablation. Nonetheless this was not logistically possible in our centre, so we decided to do the pathological study 1 week after ablation.

**Table 2** Characteristics of the lesions caused according to contact force

<table>
<thead>
<tr>
<th>Target contact force (grs.)</th>
<th>Achieved contact force (grs.)</th>
<th>Depth (mm)</th>
<th>Transmural</th>
<th>Cratering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1 ST</td>
<td>&lt;10</td>
<td>7.4 ± 1.5</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Case 2 TC</td>
<td>&lt;10</td>
<td>9 ± 2</td>
<td>0.5</td>
<td>No</td>
</tr>
<tr>
<td>Case 3 ST</td>
<td>10–20</td>
<td>12.6 ± 0.9</td>
<td>2</td>
<td>Yes</td>
</tr>
<tr>
<td>Case 4 TC</td>
<td>10–20</td>
<td>16 ± 0.8</td>
<td>4</td>
<td>No</td>
</tr>
<tr>
<td>Case 5 ST</td>
<td>20–30</td>
<td>21.6 ± 2.8</td>
<td>6</td>
<td>Yes</td>
</tr>
<tr>
<td>Case 6 ST</td>
<td>20–30</td>
<td>23 ± 2.1</td>
<td>5.6</td>
<td>Yes</td>
</tr>
<tr>
<td>Case 7 TC</td>
<td>&gt;30</td>
<td>27 ± 2.1</td>
<td>5.4</td>
<td>Yes</td>
</tr>
<tr>
<td>Case 8 TC</td>
<td>&gt;30</td>
<td>33 ± 2.5</td>
<td>5</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Figure 2 Correlation between the average force and depth.
Although the swine is a good animal model for heart studies, there may be anatomical differences of the swine CTI compared with the human, and therefore the clinical applicability of the results could be limited.

Conclusions
When ablating the CTI in a swine model, CFs of at least 20 grs. are required to achieve transmural lesions. We found good correlation between the applied force and depth. The information provided by these systems may be important for improving ablation efficacy.

Conflict of interest: none declared.

References