



# Internal atrial shock delivery by standard diagnostic electrophysiology catheters in goats: effects on atrial electrogram amplitude and tissue architecture

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Received 20 July 2006; accepted after revision 9 December 2006

## KEYWORDS

Goat;  
Internal atrial shock delivery;  
Cardiac electrophysiology;  
Endocardial;  
Shock tissue damage

**Aims** In this study, we evaluated the effects of atrial shock delivered via diagnostic electrophysiology catheters.

**Methods and results** In 11 anaesthetized goats, decapolar catheters were positioned in the right atrial appendage (RAA) and coronary sinus (CS). Three different catheters and two cardioversion protocols were evaluated. In four goats, 50 J shocks were delivered using catheters with 1 mm electrodes (surface area 70 mm<sup>2</sup>). In 6 goats, catheters with 2 mm electrodes (area 140 mm<sup>2</sup>) were used. In three of the six goats, 50 J shocks were given while in the other 3, 10 J shocks were delivered. In 1 goat 50 J shocks were delivered via 5 mm electrode catheters (area 310 mm<sup>2</sup>). No persisting adverse effects occurred. However, the electrogram amplitude at the RAA and CS decreased by >50–98% ( $P < 0.01$ ). The amount of amplitude decrease was most pronounced at the CS site and for 50 J shocks. Goats were sacrificed after  $9 \pm 1$  days. Macroscopy revealed endocardial lesions at the electrode locations. Microscopy showed endocardial thrombosis, and necrosis with formation of granulation tissue. Changes were most marked with diagnostic catheters and 50 J shocks.

**Conclusions** Atrial shock delivery via diagnostic catheters causes local ablation lesions. The amount of amplitude decrease, macroscopic and microscopic damages were related to the energy applied and electrode surface area.

## Introduction

In the early 1960s, external electrical cardioversion was introduced as a highly effective and safe method to treat atrial fibrillation (AF).<sup>1,2</sup> However, this method requires high energy shocks (150–360 J) and can only be performed under general anaesthesia or deep sedation. More recently, the technique of internal cardioversion using catheters embracing the right and left atria was introduced. Studies in sheep<sup>3,4</sup> and humans<sup>5–9</sup> showed that with specialized catheters, AF usually can be safely and effectively cardioverted with biphasic shocks of <10 J. In addition, internal cardioversion is more successful especially in adipose patients and in patients with dilated atria or pulmonary disease (emphysema).<sup>10–12</sup>

Atrial fibrillation may interfere significantly with electrophysiological studies and/or ablation procedures. If AF is long-lasting, either pharmacological or electrical cardioversion is necessary. A major drawback of pharmacological cardioversion is that antiarrhythmic drugs change the electrical properties of the heart, prohibiting a correct electrophysiological evaluation. For this reason, internal cardioversion under light sedation may be preferred. Although internal cardioversion by specially designed catheters has been shown to be safe and effective in humans,<sup>5–9</sup> an alternative would be to deliver shocks via previously introduced diagnostic electrophysiology catheters. However, due to large differences in catheter design [cardioversion catheters typically have multiple large (e.g. 5 mm) electrode poles or incorporated shocking coils]<sup>5–7,13</sup> data from these cardioversion studies cannot be extrapolated to cardioversion with standard diagnostic catheters. Because only very limited data about the efficacy and safety of cardioversion via diagnostic catheters are available,<sup>14,15</sup> it was the aim of our

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present study to evaluate the safety and the electrophysiological and histological effects of intracardiac shock delivery performed by conventional diagnostic electrophysiology catheters in goats.

## Methods

### Instrumentation and handling of animals

Eleven female goats weighing between 49 and 82 kg ( $63 \pm 11$  kg) were used for this study. Animal handling was performed according to the Dutch Law on Animal Experimentation and the European Directive for the Protection of Vertebrate Animals used for experimental and other scientific purposes. The protocol was approved by the Animal Investigation Committee of Maastricht University. Goats were anaesthetized with thiopental (Nesdonal<sup>®</sup> 10–15 mg/kg i.v., Merial, Velsbroek, The Netherlands), intubated and ventilated with halothane (1–2%) and a 1:2 mixture of O<sub>2</sub> in N<sub>2</sub>O. During the experiments, animals were monitored by ECG and expiratory CO<sub>2</sub> content. Through the external jugular and hind leg veins 2–3 sheaths (7 French) were introduced by a modified Seldinger technique. Two 6 French steerable decapolar diagnostic electrophysiology catheters (Livewire<sup>™</sup>, St Jude Medical, Daig Division, Minnetonka, MN, USA) were positioned in the right atrial appendage (RAA) and coronary sinus (CS) under fluoroscopic guidance. In the first three animals, a third multipurpose diagnostic catheter was introduced via the jugular vein to visualize the CS by contrast injection. To prevent volume depletion, intravenous fluid (Ringers lactate) was given during the experiment (250 mL/h). In addition, sodium-ampicillin (Pentrexyl<sup>®</sup> 1000 mg, Bristol-Myers Squibb, Woerden, The Netherlands) was given intravenously once directly before and once after surgery. Post-operatively the animals received buprenorfine (Temgesic<sup>®</sup> 0.015 mg/kg i.m., Reckitt & Colman, Hull, England).

### Electrophysiological study and protocols for shock delivery

After induction of anaesthesia and positioning of the catheters in the RAA and the CS, the electrodes were connected to a custom-built switch box. This switch box allowed connection of the electrodes to either the output of an external defibrillator (Ventitrex HVS-02, division of St Jude Medical, Sunnyvale, CA, USA.) or to a customized acquisition system (PC-EMS 3.0 Cardiovascular Research Institute, Maastricht, The Netherlands) for off-line analysis of electrograms. A total of 10 QRS-synchronized shocks (biphasic, duration 6/6 ms) were administered in all goats. The time interval between the shocks was 1 min.

As can be seen in *Table 1*, three different decapolar catheters and two cardioversion shock protocols were tested. In the first four goats, diagnostic electrophysiology catheters consisting of 10 parallel 1 mm electrode rings with an electrode spacing of 2–5–2 mm and an active surface area of 70 mm<sup>2</sup> (Livewire<sup>™</sup>, St Jude Medical) were used and 10 shocks of 50 J were given. In another six goats, similar catheters with 2 mm electrode rings and an active surface area of 140 mm<sup>2</sup> were used (Livewire<sup>™</sup>, St Jude Medical). In 3 of these 6 goats, 10 shocks of 50 J were given while in the other 3, 10 shocks of only 10 J were delivered. In the remaining goats, cardioversion catheters consisting of 10 parallel 5 mm electrode rings with an active surface area of 310 mm<sup>2</sup> were used (Elecath<sup>™</sup> Electro-Catheter Corp., Rahway, NJ, USA) and 10 shocks of 50 J were given. For each shock, the impedance and effective amount of energy applied was measured (*Table 1*). The effect of shocks on local electrogram amplitude was analysed off-line, for one of the bipolar electrodes at the middle of the RAA and CS catheters. The average electrogram amplitude of three consecutive beats was measured directly before the first shock and 1 min after the last (10th) shock was given. Catheters and sheets were removed, and

a compressive bandage was applied to the puncture site for several hours.

### Microscopic and macroscopic evaluation

One week ( $9 \pm 1$  days, range 7–10 days) after the experiments, animals were sacrificed by Euthesate<sup>®</sup> (200 mg/kg i.v., Apharmo, Arnhem, The Netherlands) and the heart was excised by a lateral left thoracotomy. The atrium was opened, and the RAA and CS regions were inspected for macroscopic damage. In all goats, representative tissue samples were taken from areas with an abnormal macroscopic appearance (e.g. haematoma or thrombus). Tissue samples were fixed in 4% zinc-buffered formalin and embedded in paraffin. Sections (4  $\mu$ m) were cut and processed for haematoxylin and eosin staining and evaluated by light microscopy.

### Statistical analysis

Data are presented as mean  $\pm$  SD. Statistical analysis was performed by either a unpaired Student's *t*-test (*Table 1*, comparison between shock voltage for 10 and 50 J shocks and shock impedance for 1 and 2 mm electrode catheters), a Wilcoxon signed-rank test (comparison electrogram amplitude before and after shock delivery) or by a Mann-Whitney *U* test (comparison post-shock electrogram amplitude between RA and CS and between 10 and 50 J shocks). A *P* value of  $<0.05$  was considered to be statistically significant.

## Results

### Safety of internal atrial shocks and effect on electrogram amplitude

The delivery of intracardiac shocks did not result in persistent or serious complications and all animals survived the procedure. Temporary adverse effects were almost exclusively observed during the acute experiments in animals receiving high energy shocks of 50 J. Non-sustained episodes of AF and atrioventricular (AV) block of  $<5$  s occurred immediately after the delivery of a 50 J shock in two of four goats, in which the 1 mm electrode catheters were used, and in 1 of 3 goats in which the 2 mm electrode catheters were used. These effects were not observed in animals receiving lower energy shocks of 10 J. Because asystole (caused by complete AV block) never lasted  $>5$  s, ventricular pacing was not required. Although in none of the animals (sustained) ventricular tachycardia was seen, several ventricular beats with a widened QRS complex were seen immediately after shock delivery in 3 of 4 goats, in which 50 J shocks were applied via the 1 mm electrode catheters, and in 2 of 3 goats receiving 50 J shocks and in 1 of 3 goats who had 10 J shocks via catheters with 2 mm electrodes. At morbid anatomical examination, no signs of perforation were present.

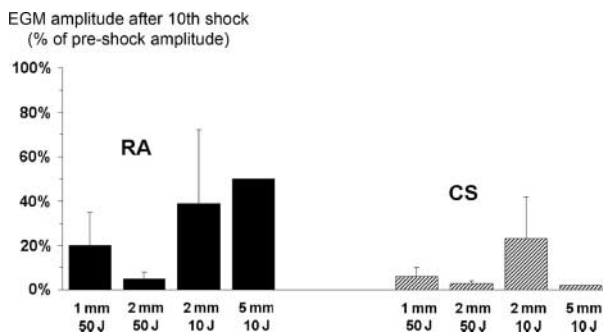
In *Figure 1*, the effects of internal atrial shocks on the RAA and CS electrogram amplitude are shown according to the type of decapolar catheter and shock protocol used. In all the experiments and at both locations, the electrogram amplitude decreased markedly after atrial shock delivery (RAA,  $P = 0.003$ ; CS,  $P = 0.005$ ). The decrease in electrogram amplitude was larger for the CS ( $-92\%$ ) compared with the RAA site ( $-76\%$ ) ( $P = 0.024$ ) and for 50 J shocks ( $-89\%$ ) compared with 10 J shocks ( $-67\%$ ) ( $P = 0.023$ ). *Figure 2* shows an example of the effect of 10 intracardiac 50 J shocks on the amplitude of local RAA and CS electrograms. Importantly, we observed that a single shock of

**Table 1** Shock parameters for the three different decapolar catheters and two shock protocols

Goat number	Electrode ring size (mm)	Active surface area (mm <sup>2</sup> )	Shock protocol	Shock energy (Joule)	Shock voltage (Volt)	Shock impedance (Ohm)
1	1	70	10 × 50 J	46 ± 5	734 ± 47	143 ± 31
2	1	70	10 × 50 J	52 ± 1	746 ± 1	103 ± 2
3	1	70	10 × 50 J	47 ± 5	695 ± 56	112 ± 22
4	1	70	10 × 50 J	47 ± 3	655 ± 0	97 ± 16
1-4			Average ± SD	48 ± 2.6	707 ± 41	114 ± 20 <sup>b</sup>
5	2	140	10 × 50 J	50 ± 2	606 ± 19	58 ± 3
6	2	140	10 × 50 J	50 ± 2	618 ± 10	62 ± 2
7	2	140	10 × 50 J	50 ± 1	609 ± 5	59 ± 4
5-7			Average ± SD	50 ± 0.3	611 ± 6	60 ± 2
8	2	140	10 × 10 J	10 ± 0.3	275 ± 11	57 ± 1
9	2	140	10 × 10 J	10 ± 0.1	257 ± 4	49 ± 1
10	2	140	10 × 10 J	10 ± 0.2	264 ± 3	53 ± 2
8-10			Average ± SD	10 ± 0.1	265 ± 9 <sup>a</sup>	53 ± 4
11	5	310	10 × 50 J	50 ± 5	563 ± 24	33 ± 1

<sup>a</sup>*P* < 0.001 compared with shock voltage for all 50 J shocks (goat number 1-7 and goat number 11).

<sup>b</sup>*P* < 0.001 compared with shock impedance for catheters with 2 mm electrodes (goat number 5-10).

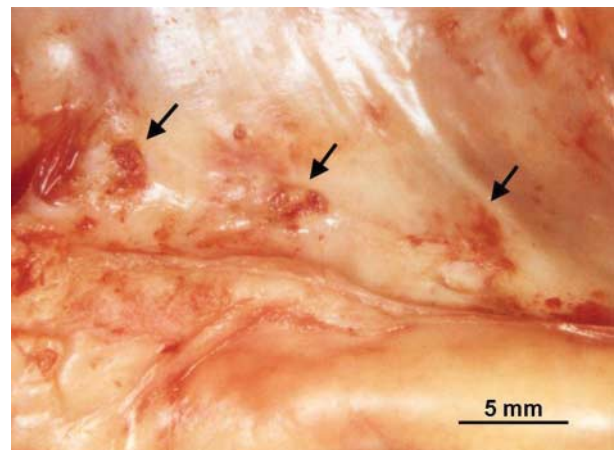


**Figure 1** Effect on the RAA and CS electrogram amplitude for the three different decapolar catheters and two shock protocols. Values represent the electrogram (EGM) amplitude after 10 atrial shocks as a percentage of the pre-shock EGM amplitude (mean ± SDs). For all catheters and shock protocols, the electrogram amplitudes decreased markedly after 10 atrial shocks (*P* = 0.003 for the RAA and *P* = 0.005 for the CS). This decrease was most pronounced at the CS (*P* = 0.024 compared with the RAA) and for high-energy shocks of 50 J (*P* = 0.023 compared with 10 J shocks).

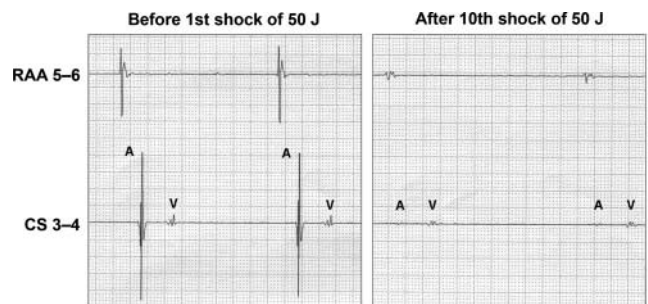
10-50 J reduced electrogram amplitude to <10-30% of baseline amplitude in most goats. Again, this decrease was less marked at the RAA compared with the CS (data not shown).

**Macroscopic and microscopic evaluation**

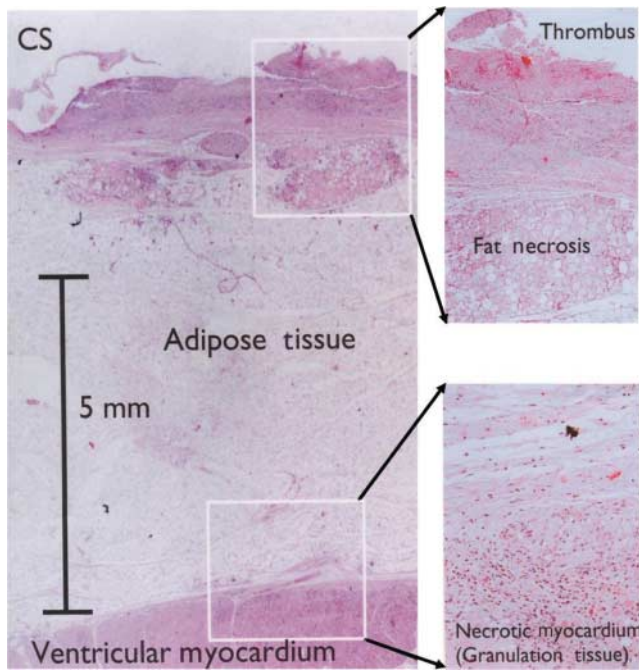
After 9 ± 1 (range 7-10) days, goats were sacrificed and the heart excised. Opening of the right atrium showed several endocardial lesions in all but one goat (number 2). These lesions, found at the predicted location of the RAA and CS electrodes, had a typical size of 1-2 mm and a typical separation between lesions of about 5 mm ('skip lesions'; *Figure 3*), which corresponded with the design of the catheters used. Although there were no clear differences in the number of endocardial lesions found between the goats tested with the different electrodes (1 vs. 2 mm) or different shock protocols (50 vs. 10 J), they were less pronounced in animals in which only shocks of 10 J were



**Figure 2** Example of the effect of 10 shocks of 50 J delivered by diagnostic electrophysiology catheters with 1 mm electrode rings on the electrogram amplitudes at the RAA (electrode pair 5 and 6) and the CS (electrodes pair 3 and 4). The amplitudes of the atrial electrogram decreased to <15% of its initial value at the RAA and to about 1% of its initial value at the CS. Note that the ventricular far-field signals (v) at the CS electrode also show a slight decrease in amplitude.



**Figure 3** Typical skip lesions in the CS as found on macroscopy corresponding to the electrode sites on the catheter. In this goat, 10 shocks of 50 J had been given 1 week before the goat was sacrificed.



**Figure 4** Microscopy of the CS lesion (Figure 3) showing partly organized luminal thrombus, necrosis of the superficial adipose tissue (top right) and granulation tissue of deeper ventricular myocardium (bottom right). All these findings were compatible with necrosis approximately 1 week earlier.

applied. In the single goat, in which the Elecath™ catheters were used the lesions were more elongated and superficial. Additionally, in several animals endocardial haematomas were observed, often in the CS or close to the ostium of the CS, which may have been caused by catheter manipulation rather than by the effect of the shocks applied.

Microscopy of the lesions showed an endocardial, partly organized thrombus and necrosis of the underlying adipose tissue in atrial and even more deeply in ventricular myocardium (Figure 4). Formation of granulation tissue was present, compatible with myocardial necrosis caused 1 week earlier. These changes were most marked in goats in which diagnostic catheters and high energy shocks of 50 J were used, whereas they were less prominent for the 5 mm Elecath™ catheters and almost absent in the goats in which shocks of only 10 J were applied.

## Discussion

Several studies have shown that internal cardioversion of AF in humans by specialized catheters is effective and safe.<sup>5-9</sup> In the present study in anaesthetized goats, we showed that internal atrial shock delivery, especially at relatively high energy (50 J) and with standard decapolar diagnostic electrophysiology catheters, was safe but resulted in a marked decrease in electrogram amplitude which was related to local ablation of the (atrial) myocardium and underlying adipose tissue.

## Adverse events and effect on electrogram amplitude

Although we did not observe that DC shocks via standard decapolar electrophysiology catheters caused serious

(persistent) adverse effects, our results indicate that intracardiac shocks at 50 J can cause local damage to the endocardium, (atrial) myocardium and fat tissue. In all the experiments, using different electrode designs (1 and 2 mm electrode rings) and different shock energies (10–50 J), we observed a marked decrease in electrogram amplitude. However, this effect was most obvious with high energy shocks of 50 J and for the CS site (Figure 1). The most likely explanation for the latter observation is that the position of the catheter in the CS was much more fixed compared with the RAA. Although the tip of this catheter had its position in the RAA, the tissue contact of the more proximal electrodes may have been less stable due to movements caused by contraction of the heart, respiration and shocks. Interestingly, also in the animals in which the specialized cardioversion catheters were used (Elecath™), a marked decrease in local electrogram amplitude was found (RAA –50% and CS –98%). As far as we know, no study on internal cardioversion using these catheters in animals or humans has ever reported such an effect. Although it can be argued that this is caused by the use of lower energy shocks, it is more likely that it has never previously been systematically evaluated. A decrease in electrogram amplitude probably remained unnoticed, because atrial amplitudes are in general smaller during AF (before cardioversion) than during sinus rhythm (after cardioversion).

## Effects on macroscopy and microscopy

Macroscopic evaluation 7–10 days after the acute experiments showed several endocardial lesions corresponding to the position of the electrodes on the decapolar catheters. Although the sample size of our study was too small to allow precise quantification of these lesions, we observed the most pronounced effects in goats in which small electrode rings (1 vs. 2 or 5 mm) associated with higher shock impedances and higher shock intensities (50 vs. 10 J) were used. Microscopy of these lesions showed endocardial thrombus formation and necrosis of the superficial atrial myocardium, the underlying adipose tissue and even of the deeper ventricular myocardium. In animals in which shocks of 10 J were given (2 mm electrode rings), only superficial macroscopic abnormalities were seen (discolouration) and microscopic signs of necrosis were minimal. For this reason, the decrease in electrogram amplitude observed in these animals is most likely caused by (reversible) oedema rather than by ablation of the underlying tissue. Although, as far as we know, no previous study has ever evaluated macroscopic and/or microscopic damage caused by internal atrial cardioversion shocks, our findings are not very unexpected for several reasons. Before the introduction of radiofrequency ablation, intracardiac DC shocks have been used for ablation of the His bundle and accessory pathways,<sup>16,17</sup> indicating that these shocks may cause considerable myocardial damage. This was confirmed in a study in dogs, showing that high energy DC shocks (50–400 J) applied to the left ventricle resulted in haemorrhagic areas and contraction band necrosis.<sup>18</sup> In addition, several studies in patients showed that internal cardioversion with relatively low energies (up to 16 J) and specialized catheters resulted in a slight elevation of cardiac biomarkers suggesting minor myocardial injury.<sup>19,20</sup>

## Clinical implications

Previous studies on cardioversion with diagnostic catheters are limited and did not evaluate the effects of internal shocks on electrogram amplitude or (macroscopic or microscopy) damage to underlying tissues.<sup>14,15</sup> We believe that our findings have important clinical implications. The smaller the electrode surface area which is related to a higher shock impedance (see *Table 1*) and the higher the shock intensity used, the higher the current density will be and the more likely that significant local damage of the endocardial, myocardial, and adipose tissues will occur. Further supported by the finding of thrombus formation on the lesions we strongly feel that cardioversion with regular diagnostic catheters should not be performed with catheters have an even smaller active surface area (e.g. quadripolar catheters) and should be limited to lower energies only (e.g. <15 J). However, even with the use of such a conservative approach, and illustrated by our observation that even after a single shock of 10 J electrogram amplitude could be reduced markedly, it should be realized that information on local electrogram characteristics may be modified and partially lost. For instance, in patients with a left-sided accessory pathway, cardioversion with a catheter in the CS may cause loss of electrogram amplitude which may make it more difficult to localize the optimal site for ablation.

## Limitations of the study

It was the aim of this study to evaluate the safety and the electrophysiological and histological effects of internal shock delivery via diagnostic electrophysiology catheters. For this reason, we used a protocol with several shocks of a fixed intensity and did not evaluate the feasibility of internal cardioversion to restore sinus rhythm. The feasibility to cardiovert AF with diagnostic electrophysiology catheters has been described by others and was not the purpose of our study.<sup>14,15</sup>

Because our histological analysis was limited to RAA and CS areas showing macroscopic damage, we cannot exclude that less obvious histological abnormalities (limited to the microscopic level) were missed in some goats.

Finally, we are aware of the fact that the number of animals used is quite limited. However, our findings are consistent and logical in such a way that high energy shocks, a small electrode size, and high shock impedance resulted in the most prominent tissue damage. We were primarily not interested in quantifying these effects in more detail and believed that increasing the number of experiments would not change our conclusions.

## Conclusions

Our study indicates that intracardiac shock delivery via diagnostic decapolar electrophysiology catheters did not result in serious side effects and for this reason appears to be safe. However, the smaller the size of electrodes used for shock delivery and the higher the shock impedance and intensity, the more likely that cardioversion results in a marked decrease in electrogram amplitude and ablation of underlying (myocardial) tissues. These findings may have implications for clinical practice, suggesting that internal cardioversion via regular diagnostic electrophysiology

catheters should preferably be limited to delivery of a limited amount of low energy shocks.

## Acknowledgements

The authors would like to thank S. Philippens, E. van der Veen, and T. van der Nagel for their support during the experiments and St Jude Medical (The Netherlands) for their material and financial support.

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