Changes of electrophysiological parameters of the heart after the destruction of the epicardial nerve subplexuses of the right atrium

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Received 17 August 2004; accepted 3 September 2004

Summary

Objectives: of the present study were to verify the topography of the intracardiac nerve subplexuses (INS) by using electrophysiological methods, its relations with sinoatrial (SA) node function and investigate the possibility of selective surgical SA node denervation.

Design, Methods and Results: 32 mongrel dogs were used for electrophysiological studies. Nervus subplexuses destructions were performed by electrocoagulation or cryoablation in three zones located around the right superior vena cava: ventral, lateral and dorsal. The sinus rhythm, SA node function recovery time, atrioventricular (AV) node conductivity, the AV node and the atrial effective refractory period were measured. Eight experiments in each of the three zones were performed. The average changes of electrophysiological parameters before and after INS destruction have shown that the destruction of the ventral and lateral zones modifies the effects of sympathetic tone to SA node activity. The destruction of the dorsal zone modifies the effects of the vagus nerve to the SA node.

Conclusions: The function of the SA and AV nodes can be modified by the destruction of the ventral, lateral and dorsal zones of the right atrium. It is necessary to point up that while performing interventions and radiofrequency ablations in the zones of nerve plexuses surgeons must be aware of possible changes in SA node's function because of the impairment of these nerve plexuses and, if possible, to avoid surgical manipulations in these zones.

Seminars in Cardiology 2004; 10(3): 152–160

Keywords: ablation, autonomic nervous system, atrioventricular node, heart rate, sinoatrial node

The autonomic nervous system (ANS) controls the function of the heart and coronary vessels. Changes in ANS activity influence the function of the sinoatrial (SA) and atrioventricular (AV) nodes and are related to disturbances of cardiac rhythm [1–3]. With the development of surgical and radio frequency ablation methods for the treatment of cardiac arrhythmia or the revascularization of the myocardium, it has become necessary to evaluate the influence of the ANS on the myocardium and the conductive system of the heart.

On one hand, the heart structure is unequally affected during the operation. On the other hand, all surgery procedures impact and change the entity of nerve plexuses and ganglion fields, and make a background for various rhythm disorders, which are hardly corrected with pharmaceuticals [4,5]. It happens because of the ambiguity of separate parts of the heart anatomical innervations. Due to this, more intensive researches are being carried out on electrophysiological features of the whole heart, separate structures and the influence of the autonomic nervous system to the heart's functions.

Scientists pay great attention to the researches of the anatomy and electrophysiology of the autonomic innervation of the heart because there...
is no explanation on the impact of the ANS on the work and pathology of the heart. Heart innervation resources, organization of the intracardial nerve plexuses’ structure, topographical allocation, and variable of varieties, age and individuals are found due to morphological researches.

It is hard to imagine modern attitude to heart’s work without any knowledge of innervation of a “model animal” and its influence on heart rhythm. From neurocardiological aspect, a dog is the most researched object. Its heart is chosen because it is widely used as an experimental model while investigating organ mechanics and electrical parameters [6–8]. A dog is widely used in intracardial stimulation of nerves and ablation experiments [9–11].

The newest anatomical research data have shown that the nerves entering the right atrium are located in the area near the superior right pulmonary vein and the vena cava superior. After entering the endocardium, the nerves form a plexus, and its ganglia are widely scattered around the vena cava superior. These epicardial ganglia are divided into five zones (Figure 1) [12].

The contributions of the neural structures from the five zones to SA node innervation are not the same, because unequal amount of nerves and ganglia supplying the SA node has been found in these zones.

In the dorsal zone of all the investigated hearts, functionally not differentiated intracardiac nerves and ganglia were found, whereas in the lateral zone, such nerves and ganglia were found only in 34% of cases [12]. These data show that ganglia of the nerves innervating the SA node are scattered more widely than it was earlier supposed [13,14]. Therefore, in order to obtain a selective and/or total denervation of the SA node, it is necessary to destruct the whole zone around the root of the vena cava superior. These data explain the different and/or controversial data, obtained by the above-mentioned explorers.

After anatomical studies and localization of the nerves entering the right atrium [12,15] it is possible to evaluate the effects of the destruction of the intracardiac nerves on electrophysiological parameters of the heart (EPH).

The aim of the study was to evaluate the impact of the destruction of intracardiac nerve subplexuses and nerve ganglia, which widely surrounded the region of the basis of the superior vena cava in the right atrium of the canine heart, on the function of the sinoatrial node (SAN) and electrophysiological parameters of the heart.
using electrophysiological methods of investigation, and to investigate the possibility of selective surgical sympathetic or parasympathetic denervation of the SA node.

**Design and Methods**

The experiment was performed on adult mongrel dogs of both sexes, weighing from 7 to 15 kg. The experiments were performed according to the regulations of the Declaration of Helsinki, adopted in June 1964 at the 18th Assembly of the World Medical Association and in compliance with the rules of the Ethics Commission of Lithuania on the treatment of experimental animals, permission N. 0027/2001-02-14.

The animals were premedicated with fentanyl (20 µg/kg) and ketamine (2 mg/kg). Venesection was performed on the inner side of the leg, and an intravenous catheter was inserted for 400–600 ml Ringer solution infusion. Anaesthesia was performed with sodium pentobarbital (initial bolus of 30 mg/kg, and 50 to 100 mg for maintenance). The dogs were endotracheally intubated and ventilated with ambient room air using RO-6 equipment, (Russia). The dogs were placed in the supine position and the thoracotomy was performed in the fourth intercostal space. The hearts were exposed in a pericardial cradle.

The left and the right vagosympathetic trunks (LVST and RVST) were divided. In order to eliminate the influence of the central nervous system to the heart, the vagosympathetic trunks were cut. A bipolar electrode was fixed to the distal end and it was used for the stimulation of the nerves. Electrostimulation was performed using an electrostimulator “ZeSL-50” (Russia).

Three bipolar electrodes were fixed to the right auricle in the SA node region and to the apex of the heart for the recording of epicardial electrograms (EG). The EG and lead II of the surface ECG were recorded using a HELLIGE EK 36 multiscriptor. Electrostimulation was performed using a cardiostimulator ERA-6 (Russia) and a stick-like electrode.

Electrophysiological parameters were recorded before and after the destruction of the intracardiac nerve. The destruction of nerve pathways of the right atrium was performed by electrocoagulation or cryoablation. The effect of destruction was evaluated by electrostimulation.

The intracardiac nerve destruction was performed in the following areas (Figure 1):

1. in the ventral zone of the right atrium (VRA);
2. in the lateral zone of the right atrium (LRA);
3. in the dorsal zone of the right atrium (DRA);
4. in the dorsal–lateral (VRA and LRA) zones of the right atrium, in addition.

The total number of the experiments was 32: eight experiments of nerve destruction in each of the zone.

Each experiment consisted of three stages:

1. Recording of EPH before the destruction of the intracardiac nerve;
2. Recording of EPH after the destruction of the intracardiac nerve;
3. Recording of EPH after intravenous atropine sulphate injection (0.5–1.0 mg/kg, 30 min before the recording).

Five of the electrophysiological parameters were registered: the heart rate (HR), SA node recovery time (SNRT), conductivity of the AV node (AVNC), the effective refractory period of the AV node (AVERP), the effective refractory period of the atria (AERP).

The electrophysiological parameters of the heart were evaluated without and with the stimulation of the left and right vagosympathetic trunks.

**Results**

The impact of the ventral zone of the right atrium of canine heart destruction on electrophysiological parameters of the heart

In the first group of experiments, baseline electrophysiological parameters of the heart were evaluated during the first stage (Table 1).

Electrophysiological parameters of the heart before the destruction of the intracardiac nerve, when stimulating the LVST, have changed: the HR decreased on the average by 11 ± 6 bpm (10.4%), SNRT prolonged by 48 ± 19 ms (7.2%), AV node conductivity decreased by 24 ± 5 bpm (11.7%), AVERP prolonged by 30 ± 15 ms (13%), and AERP shortened by 10 ± 6 ms (6.1%).

EPH, when stimulating the RVST, have changed: the HR decreased on the average by 17 ± 5 bpm (16%), SNRT prolonged by 58 ± 23 ms (10%), AV node conductivity decreased by 19 ± 4 bpm (9.2%), AVERP prolonged by 22 ± 13 ms (9.6%), and AERP shortened by 21 ± 16 ms (12.9%).

During the second stage, the destruction of nerve pathways in the ventral zone of the right atrium was performed. The destruction of the ventral zone of the canine heart right atrium had determined EPH, shown in Table 1.

EPH, when stimulating the LVST, have changed in comparison with EPH after local destruction of
nerve pathways in the ventral zone of the right atrium as shown: the HR decreased on the average by 10 ± 4 bpm (10.5%), SNRT prolonged by 39 ± 17 ms (5.5%), AV node conductivity decreased by 17 ± 9 bpm (9.3%), AERP prolonged by 48 ± 23 ms (18.2%), and AERP shortened by 16 ± 8 ms (11.1%).

EPH, when stimulating the RVST, have changed: the HR decreased on the average by 18 ± 6 bpm (18.9%), SNRT prolonged by 77 ± 35 ms (10.8%), AV node conductivity decreased by 5 ± 3 bpm (2.7%), AERP prolonged by 16 ± 10 ms (6.1%), and AERP shortened by 24 ± 13 ms (16.7%).

While comparing the data of these experiments with EPH before the destruction of epicardial nerve plexuses in the VRA zone (when stimulating parasympathetic trunks), the data show, that the stimulation of the LVST and the RVST after the destruction increases parasympathetic impact on the SA node.

The experiments to evaluate EPH after intravenous infusion of atropine sulphate, without the stimulation of VST and with the stimulation of the left and right vagosympathetic trunks, in order to exclude the parasympathetic nervous system (PNS) and to investigate the relation between the nerve plexuses of the ventral zone of the right atrium and the sympathetic nervous system, were performed during the third stage (Table 1).

EPH, when stimulating the LVST, have changed in comparison with EPH after intravenous infusion of atropine sulphate as shown: the HR increased on the average by 5 ± 2 bpm (4.6%), SNRT shortened by 5 ± 1 ms (0.8%), AV conductivity increased by 7 ± 4 bpm (3.2%), AERP shortened by 16 ± 7 ms (7.3%), and AERP prolonged by 8 ± 3 ms (5%).

EPH, when stimulating the RVST, have changed: the HR increased on the average by 9 ± 3 bpm (8.2%), SNRT shortened by 14 ± 6 ms (2.1%), AV conductivity increased by 2 ± 1 bpm (0.9%), AERP shortened by 8 ± 4 ms (3.6%), and AERP prolonged by 10 ± 5 ms (6.3%).

While stimulating vagosympathetic trunks after intravenous infusion of atropine sulphate and comparing the data obtained with EPH after intravenous infusion of atropine sulphate without the stimulation of vagosympathetic trunks, one can see that sympathetic impact on SAN function increases. However, the changes are not so vivid and this phenomenon suggests that the influence of the sympathetic nervous system is decreased.

**The impact of the lateral zone of the right atrium of canine heart destruction on electrophysiological parameters of the heart**

In the second group of experiments, baseline electrophysiological parameters of the heart were evaluated during the first stage (Table 2).

Electrophysiological parameters of the heart before the destruction of the intracardiac nerve, when stimulating the LVST, have changed: the HR decreased on the average by 9 ± 3 bpm (8.2%), SNRT prolonged by 51 ± 22 ms (8.4%), AV node conductivity decreased by 27 ± 6 bpm (13.8%), AERP prolonged by 33 ± 13 ms (13.9%), and AERP shortened by 15 ± 6 ms (10.3%).

EPH, when stimulating the RVST, have changed: the HR decreased on the average by 15 ±
4 bpm (13.6%), SNRT prolonged by 64 ± 27 ms (10.5%), AV node conductivity decreased by 20 ± 4 bpm (10.2%), AERP prolonged by 19 ± 12 ms (8%), and AERP shortened by 22 ± 15 ms (15.1%).

During the second stage, the destruction of nerve pathways in the lateral zone of the right atrium was performed using a knife for electrocoagulation. The destruction of the lateral zone of the canine heart right atrium had determined EPH, shown in Table 2.

EPH, when stimulating the LVST, have changed in comparison with EPH after local destruction of nerve pathways in the lateral zone of the right atrium as shown: the HR increased on the average by 4 ± 1 bpm (4%), SNRT prolonged by 34 ± 12 ms (5.2%), AV node conductivity decreased by 22 ± 9 bpm (12.1%), AERP prolonged by 40 ± 21 ms (15.3%), and AERP shortened by 9 ± 3 ms (6.7%).

EPH, when stimulating the RVST, have changed: the HR decreased on the average by 16 ± 5 bpm (15.8%), SNRT prolonged by 62 ± 24 ms (9.5%), AV node conductivity decreased by 8 ± 10 bpm (4.4%), AERP prolonged by 12 ± 9 ms (4.6%), and AERP shortened by 15 ± 6 ms (11.2%).

While comparing the data of these experiments with EPH before the destruction of epicardial nerve plexuses in the LRA zone (when stimulating parasympathetic trunks), one can see, that the stimulation of the LVST and the RVST after the destruction increases parasympathetic impact on the SA node.

The experiments to evaluate EPH after intravenous infusion of atropine sulphate, without the stimulation of VST and with the stimulation of the left and the right vagosympathetic trunks, in order to exclude the PNS and to investigate the relation between the nerve plexuses of the lateral zone of the right atrium and the sympathetic nervous system, were performed during the third stage (Table 2).

EPH, when stimulating the LVST, have changed in comparison with EPH after intravenous infusion of atropine sulphate as shown: the HR increased on the average by 4 ± 1 bpm (3.4%), SNRT shortened by 3 ± 1 ms (0.5%), AV conductivity increased by 10 ± 3 bpm (4.8%), AERP shortened by 16 ± 6 ms (7.1%), and AERP prolonged by 6 ± 3 ms (3.9%).

EPH, when stimulating the RVST, have changed: the HR increased on the average by 7 ± 2 bpm (5.9%), SNRT shortened by 11 ± 4 ms (1.9%), AV conductivity increased by 4 ± 1 bpm (1.9%), AERP shortened by 10 ± 5 ms (4.4%), and AERP prolonged by 8 ± 3 ms (5.2%).

While stimulating vagosympathetic trunks after intravenous infusion of atropine sulphate and comparing the data obtained with EPH after intravenous infusion of atropine sulphate without the stimulation of vagosympathetic trunks, one can see that sympathetic impact on SAN function increases. However, the changes are not so vivid and this phenomenon suggests that the influence of the sympathetic nervous system is decreased.

The impact of the dorsal zone of the right atrium of canine heart destruction on electrophysiological parameters of the heart

In the third group of experiments, baseline electrophysiological parameters of the heart were evaluated during the first stage (Table 3).

Table 2.

<table>
<thead>
<tr>
<th>Parameters Heart rate SNRT AV node ERP of the ERP of the</th>
<th>Heart rate</th>
<th>SNRT (ms)</th>
<th>AV node conductivity (ms)</th>
<th>ERP of the ERP of the</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before the destruction:</td>
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<td></td>
</tr>
<tr>
<td>without stimulation of VST</td>
<td>110 ± 13</td>
<td>610 ± 40</td>
<td>196 ± 14</td>
<td>237 ± 33</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>101 ± 18</td>
<td>661 ± 92</td>
<td>169 ± 27</td>
<td>270 ± 48</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>95 ± 12</td>
<td>674 ± 76</td>
<td>176 ± 25</td>
<td>256 ± 55</td>
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<tr>
<td>After the destruction:</td>
<td></td>
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</tr>
<tr>
<td>without stimulation of VST</td>
<td>101 ± 12</td>
<td>650 ± 58</td>
<td>182 ± 16</td>
<td>262 ± 42</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>97 ± 19</td>
<td>684 ± 104</td>
<td>160 ± 20</td>
<td>302 ± 33</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>85 ± 15</td>
<td>712 ± 77</td>
<td>174 ± 42</td>
<td>274 ± 67</td>
</tr>
<tr>
<td>After atropine sulphate:</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>without stimulation of VST</td>
<td>118 ± 13</td>
<td>593 ± 87</td>
<td>210 ± 21</td>
<td>225 ± 43</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>122 ± 14</td>
<td>590 ± 79</td>
<td>220 ± 19</td>
<td>209 ± 38</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>125 ± 18</td>
<td>582 ± 92</td>
<td>214 ± 24</td>
<td>215 ± 56</td>
</tr>
</tbody>
</table>

AV – atrioventricular; ERP – effective refractory period; LVST – left vagosympathetic trunk; RVST – right vagosympathetic trunk; SNRT – sinoatrial node recovery time; VST – vagosympathetic trunk.

$p ≤ 0.05.$
Before the destruction:  
without stimulation of VST  
stimulating the LVST  
stimulating the RVST  

After the destruction:  
without stimulation of VST  
stimulating the LVST  
stimulating the RVST  

After atropine sulphate:  
without stimulation of VST  
stimulating the LVST  
stimulating the RVST  


<table>
<thead>
<tr>
<th>Parameters</th>
<th>Heart rate (b/min)</th>
<th>SNRT (ms)</th>
<th>AV node conductivity (b/min)</th>
<th>ERP of the AV node (ms)</th>
<th>ERP of the atrium (ms)</th>
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<tr>
<td>Before the destruction:</td>
<td></td>
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</tr>
<tr>
<td>without stimulation of VST</td>
<td>109 ± 18</td>
<td>599 ± 79</td>
<td>200 ± 25</td>
<td>228 ± 32</td>
<td>140 ± 24</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>99 ± 16</td>
<td>658 ± 92</td>
<td>178 ± 22</td>
<td>263 ± 41</td>
<td>127 ± 17</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>93 ± 15</td>
<td>664 ± 103</td>
<td>181 ± 29</td>
<td>255 ± 52</td>
<td>121 ± 13</td>
</tr>
</tbody>
</table>

After the destruction:  
without stimulation of VST  
stimulating the LVST  
stimulating the RVST  

After atropine sulphate:  
without stimulation of VST  
stimulating the LVST  
stimulating the RVST  


<table>
<thead>
<tr>
<th>Parameters</th>
<th>Heart rate (b/min)</th>
<th>SNRT (ms)</th>
<th>AV node conductivity (b/min)</th>
<th>ERP of the AV node (ms)</th>
<th>ERP of the atrium (ms)</th>
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<tr>
<td>without stimulation of VST</td>
<td>111 ± 14</td>
<td>598 ± 94</td>
<td>203 ± 29</td>
<td>227 ± 39</td>
<td>144 ± 23</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>117 ± 11</td>
<td>568 ± 85</td>
<td>217 ± 21</td>
<td>209 ± 43</td>
<td>156 ± 21</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>120 ± 13</td>
<td>560 ± 87</td>
<td>211 ± 23</td>
<td>213 ± 41</td>
<td>159 ± 18</td>
</tr>
</tbody>
</table>

After atropine sulphate:  
without stimulation of VST  
stimulating the LVST  
stimulating the RVST  


<table>
<thead>
<tr>
<th>Parameters</th>
<th>Heart rate (b/min)</th>
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<td>Before the destruction:</td>
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<tr>
<td>without stimulation of VST</td>
<td>112 ± 17</td>
<td>596 ± 74</td>
<td>205 ± 19</td>
<td>224 ± 28</td>
<td>142 ± 23</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>128 ± 20</td>
<td>540 ± 82</td>
<td>231 ± 21</td>
<td>197 ± 38</td>
<td>168 ± 19</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>133 ± 22</td>
<td>534 ± 77</td>
<td>229 ± 17</td>
<td>200 ± 31</td>
<td>170 ± 21</td>
</tr>
</tbody>
</table>

AV – atrioventricular; ERP – effective refractory period; LVST – left vagosympathetic trunk; RVST – right vagosympathetic trunk; SNRT – sinoatrial node recovery time; VST – vagosympathetic trunk.

EPP ≤ 0.05.

Electrophysiological parameters of the heart before the destruction of the intracardiac nerve, when stimulating the LVST, have changed: the HR decreased on the average by 16 ± 7 bpm (17.2%), SNRT prolonged by 65 ± 23 ms (9.8%), AV node conductivity decreased by 19 ± 5 bpm (10.5%), AVERP prolonged by 27 ± 13 ms (10.6%), and AERP shortened by 19 ± 11 ms (15.7%).

During the second stage, the destruction of the dorsal zone of the right atrium was performed. The destruction of the dorsal zone of the canine heart right atrium had determined EPH, shown in Table 3.

When stimulating the LVST, have changed in comparison with EPH after local destruction of nerve pathways in the dorsal zone of the right atrium as shown: the HR increased on the average by 6 ± 2 bpm (5.4%), SNRT shortened by 30 ± 13 ms (5%), AV conductivity increased by 14 ± 5 bpm (6.9%), AVERP shortened by 18 ± 7 ms (7.9%), and AERP prolonged by 12 ± 4 ms (8.3%).

While comparing the data of these experiments with EPH before the destruction of epieardial nerve plexuses in the DRA zone (when stimulating parasympathetic trunks), one can see, that the stimulation of the LVST and the RVST after the destruction increases sympathetic impact on the SA node.

The experiments to evaluate EPH after intravenous infusion of atropine sulphate, without the stimulation of VST and with the stimulation of the left and right vagosympathetic trunks, in order to exclude the PNS and to investigate the relation between the nerve plexuses of the dorsal zone of the right atrium and the sympathetic nervous system, were performed during the third stage (Table 3).

While stimulating the LVST, have changed in comparison with EPH after intravenous infusion of atropine sulphate as shown: the HR increased on the average by 16 ± 5 bpm (14.3%), SNRT shortened by 56 ± 19 ms (9.4%), AV conductivity increased by 26 ± 9 bpm (12.7%), AVERP shortened by 27 ± 11 ms (12.1%), and AERP prolonged by 26 ± 8 ms (18.3%).

When stimulating the RVST, have changed: the HR increased on the average by 21 ± 7 bpm (18.75%), SNRT shortened by 62 ± 23 ms (10.4%), AV conductivity increased by 24 ± 10 bpm (11.7%), AVERP shortened by 24 ± 7 ms (10.7%), and AERP prolonged by 28 ± 13 ms (19.7%).

While stimulating vagosympathetic trunks after intravenous infusion of atropine sulphate and comparing the data obtained with EPH after intravenous infusion of atropine sulphate without...
the stimulation of vagosympathetic trunks, one can see that sympathetic impact on SAN function increases and the changes are more evident than in experiments with the ventral and lateral zones of the canine heart right atrium.

The impact of the ventral–lateral zones of the right atrium of canine heart destruction on electrophysiological parameters of the heart

EPH after local destruction of nerve pathways in the ventral and lateral zones, when stimulating LVST and RVST, were similar: the parasympathetic influence for all parameters registered remained the same, but the influence of the sympathetic nervous system was diminished. In order to prove this statement and hoping to achieve complete sympathetic denervation of the SA node we have performed one more group of experiments. During these experiments, nerve pathways were ablated in both zones.

In the fourth group of experiments, baseline electrophysiological parameters of the heart were evaluated during the first stage (Table 4).

Electrophysiological parameters of the heart before the destruction of the intracardiac nerve, when stimulating the LVST, have changed: the HR decreased on the average by 11 ± 5 bpm (11.2%), SNRT prolonged by 52 ± 18 ms (7.5%), AV node conductivity decreased by 25 ± 5 bpm (14.2%), AVERP prolonged by 34 ± 15 ms (13%), and AERP shortened by 14 ± 4 ms (10.9%).

EPH, when stimulating the RVST, have changed: the HR decreased on the average by 17 ± 6 bpm (18.5%), SNRT prolonged by 63 ± 29 ms (9%), AV node conductivity decreased by 17 ± 4 bpm (9.2%), AVERP prolonged by 22 ± 10 ms (8.8%), and AERP shortened by 19 ± 11 ms (15.3%).

During the second stage, the destruction of nerve pathways in the ventral–lateral zones of the right atrium was performed. The destruction of the ventral–lateral zones of the canine heart right atrium had determined EPH, shown in Table 4.

EPH, when stimulating the LVST, have changed in comparison with EPH after local destruction of nerve pathways in the ventral–lateral zones of the right atrium as shown: the HR decreased on the average by 5 ± 2 bpm (5.4%), SNRT prolonged by 30 ± 11 ms (4.1%), AV node conductivity decreased by 9 ± 3 bpm (5.2%), AVERP prolonged by 18 ± 5 ms (6.8%), and AERP shortened by 7 ± 3 ms (5.9%).

EPH, when stimulating the RVST, have changed: the HR decreased on the average by 10 ± 4 bpm (10.9%), SNRT prolonged by 37 ± 14 ms (5.1%), AV node conductivity decreased by 5 ± 2 bpm (2.9%), AVERP prolonged by 14 ± 5 ms (5.3%), and AERP shortened by 9 ± 4 ms (7.6%).

While comparing the data of these experiments with EPH before the destruction of epicardial nerve plexuses in the ventral–lateral zones (when stimulating parasympathetic trunks), one can see, that the stimulation of the LVST and the RVST after the destruction increases parasympathetic impact on the SA node. The changes were similar to those after separate local destruction of nerve pathways in these zones. However, the changes were more evident and this is the sign, that the influence of sympathetic nervous system was diminished markedly.

### Table 4.
Electrophysiological parameters of the heart before and after the destruction of the epicardial nerves entering the right atrium in the ventral–lateral zones

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Heart rate (b/min)</th>
<th>SNRT (ms)</th>
<th>AV node conductivity (b/min)</th>
<th>ERP of the AV node (ms)</th>
<th>ERP of the atrium (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before the destruction:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without stimulation of VST</td>
<td>109 ± 16</td>
<td>638 ± 57</td>
<td>201 ± 15</td>
<td>228 ± 29</td>
<td>143 ± 16</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>98 ± 14</td>
<td>690 ± 89</td>
<td>176 ± 21</td>
<td>262 ± 41</td>
<td>129 ± 15</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>92 ± 11</td>
<td>701 ± 92</td>
<td>184 ± 18</td>
<td>250 ± 49</td>
<td>124 ± 15</td>
</tr>
<tr>
<td>After the destruction:</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>without stimulation of VST</td>
<td>92 ± 12</td>
<td>725 ± 60</td>
<td>174 ± 13</td>
<td>263 ± 26</td>
<td>119 ± 16</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>87 ± 13</td>
<td>755 ± 73</td>
<td>165 ± 22</td>
<td>281 ± 32</td>
<td>112 ± 12</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>82 ± 5</td>
<td>762 ± 64</td>
<td>169 ± 21</td>
<td>277 ± 57</td>
<td>110 ± 11</td>
</tr>
<tr>
<td>After atropine sulphate:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without stimulation of VST</td>
<td>104 ± 14</td>
<td>710 ± 68</td>
<td>187 ± 17</td>
<td>259 ± 28</td>
<td>129 ± 23</td>
</tr>
<tr>
<td>stimulating the LVST</td>
<td>105 ± 12</td>
<td>707 ± 58</td>
<td>194 ± 20</td>
<td>250 ± 31</td>
<td>132 ± 15</td>
</tr>
<tr>
<td>stimulating the RVST</td>
<td>107 ± 10</td>
<td>705 ± 62</td>
<td>191 ± 19</td>
<td>252 ± 29</td>
<td>133 ± 18</td>
</tr>
</tbody>
</table>

AV – atrioventricular; ERP – effective refractory period; LVST – left vagosympathetic trunk; RVST – right vagosympathetic trunk; SNRT – sinoatrial node recovery time; VST – vagosympathetic trunk.

*p ≤ 0.05.*
The experiments to evaluate EPH after intravenous infusion of atropine sulphate, without the stimulation of VST and with the stimulation of the left and right vagosympathetic trunks, in order to exclude the PNS and to investigate the relation between the nerve plexuses of the ventral-lateral zones of the right atrium and the sympathetic nervous system, were performed during the third stage (Table 4).

EPH, when stimulating the LVST, have changed in comparison with EPH after intravenous infusion of atropine sulphate as shown: the HR increased on the average by $1 \pm 2$ bpm (1%), SNRT shortened by $3 \pm 1$ ms (0.4%), AV conductivity increased by $7 \pm 3$ bpm (3.7%), AVERP shortened by $9 \pm 5$ ms (3.5%), and AERP prolonged by $3 \pm 2$ ms (2.3%).

EPH, when stimulating the RVST, have changed: the HR increased on the average by $3 \pm 2$ bpm (2.9%), SNRT shortened by $5 \pm 3$ ms (0.7%), AV conductivity increased by $4 \pm 2$ bpm (2.1%), AVERP shortened by $7 \pm 3$ ms (2.7%), and AERP prolonged by $4 \pm 3$ ms (3.1%).

While stimulating vagosympathetic trunks after intravenous infusion of atropine sulphate and comparing the data obtained with EPH after intravenous infusion of atropine sulphate without the stimulation of vagosympathetic trunks, one can see that the sympathetic impact for all parameters registered remained the same, but the influence of sympathetic nervous system was diminished markedly.

### Discussion

Surgical procedures rather often damage the limited structures of the intracardiac nerves or ganglionic fields and cause diverse cardiac arrhythmias resistant to medicamental treatment [4,5].

In 1975, Kaye performed intracardial parasympathectomy on the dog’s heart [16]. Later, Randall described two parasympathetic ganglionic fields. The ganglia in these fat layers might modulate the function of the SA and AV nodes and contractility of the atria. The postganglionic neurons in the first field innervate the SA node and those ones from the second fat field innervate the AV node [13,14,17–19].

However, the experiments performed by various authors showed different and/or controversial data. Fee et al, after the injection of lidocaine into the first field, obtained a blockade of parasympathetic influence on the AV node [14]. Gatti et al observed only a partial reduction of the parasympathetic influence on the AV node after the destruction of both fat layers [20]. Their data showed that intracardiac ganglia exerted influence on AV nodal function, but the attempts to eliminate these influences on the above-mentioned structures were unsuccessful.

The newest anatomical data have shown that the nerves entering the right atrium are located in the area near the superior right pulmonary vein and the vena cava superior. After entering the endocardium, the nerves form the ventral and dorsal plexuses, and its ganglia are widely scattered around the vena cava superior [12,15].

Although the heart nerves are anatomically examined, it is very hard to explain the origin of the epicardial nerve subplexuses and their influence to the SA function from the point of view of neuromorphological investigations only. That is the reason of detailed electrophysiological studies.

The main markers of the impact of the destruction of intracardial nerve plexuses on the SA node are changes of HR and SA node function recovery time. Electrophysiological data of the SA and AV nodes and the changes are presented as an evidence of destruction of nerve plexuses innervating not only the SA node, but the other zones of the heart, as well.

Our experiments in the ventral and lateral zones of the right atrium have shown, that after local destruction of nerve pathways, when stimulating the LVST and RVST, the parasympathetic influence for all parameters registered remains constant, but the influence of the sympathetic nervous system is diminished.

In experiments with the dorsal zone of the right atrium, the stimulation of the left and right vagosympathetic trunks have shown that after the destruction, sympathetic impact on the SA node increases.

Electrophysiological parameters of the heart after local destruction of nerve pathways in the ventral and lateral zones simultaneously, when stimulating LVST and RVST, were similar to those after separate local destruction of nerve pathways in these zones. However, the changes were more evident and this was the sign, that the influence of sympathetic nervous system was diminished markedly.

Regretfully, as other authors, we failed to denervate the SA node completely. Even after simultaneous destruction of both zones, the influence of sympathetic nervous system was diminished but remained constant. This could mean that sympathetic fibers innervate the SA node via the other zones, also.

These results do not contradict the literary data of the anatomo-morphological investigations concerning these structural and functional relations.
Still, the obtained data prove the possibility of exerting influence on the function of the SA node by performing selective localized surgical denervation of the SA node, which in the future may be successfully employed in clinical practice.

Conclusions

1. The stimulation of the left and right vagosymmetric trunks after the destruction of the ventral zone of the right atrium of the canine heart have shown, that sympathetic impact on the sinoatrial node is diminished.
2. The stimulation of the left vagosymmetric trunk and right vagosymmetric trunk after the destruction of the lateral zone of the right atrium of the canine heart have shown that sympathetic impact on the sinoatrial node is diminished.
3. The stimulation of the left vagosymmetric trunk and right vagosymmetric trunk after the destruction of the dorsal zone of the right atrium of the canine heart have shown, that parasympathetic impact on the sinoatrial node is diminished.
4. The stimulation of vagosymmetric trunk after the destruction of the ventral–lateral zones of canine heart have shown, that sympathetic impact on the sinoatrial node is decreased markedly, but the influence of the sympathetic nervous system is not eliminated.
5. The sinoatrial node may be innervated not only via the ventral and dorsal plexuses, but also via the other zones, as well.
6. While performing surgical interventions and radiofrequency ablations in the zones of the intrinsic heart nerve plexuses, it is necessary to be aware of possible changes in sinoatrial node’s function because of the impairment of these nerve plexuses and, if possible, to avoid surgical manipulations in these zones.

References