Monitoring of laser effects on the conduction system by using an open-irrigated electrode-laser mapping and ablation catheter: laser catheter mapping

Helmut P. Weber1* and Michaela Sagerer-Gerhardt2

1CCEP Center, Section Research Development and Education, Schlesierstrasse 4, Taufkirchen D-82024, Germany; and 2Department of Anesthesiology, Hospital Neuperlach, Teaching Hospital of the LM-University of Munich, Oskar-Maria-Graf-Ring 51, München D-81737, Germany

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Aims
To assess the laser effects on the conduction system in dog hearts by monitoring potential amplitudes (PA) in the focused local electrograms (LEG) recorded via pin electrodes (PEs) from the tip of an open-irrigated electrode–laser mapping and ablation (ELMA) catheter.

Methods and results
A total of 54 mapping guided laser impacts (continuous wave Nd:YAG 1064 nm), at 15 W, irrigation rate 30 mL/min, one per dog, were aimed at the sinus nodal (SN) (n = 20) and atrioventricular (AV) nodal (n = 24) areas, and at the His bundle and fascicles (n = 5, each). Laser effects were assessed by monitoring of PA in the bipolar focused LEGs. Electrophysiological and electropharmacological tests were performed prior to, immediately following, and 3–11 months after the experiments. Lesions were evaluated morphometrically and histopathologically. During laser application PA gradually dwindled. Radiation times limited to 3–5 s were allowed for recovery of PA without affecting functions of the conduction system. Graded laser application modulated SN and AV nodal functions permanently, or caused stable complete AV conduction block with a mapping-dependent escape rhythm and electrical axis deviation after radiation aimed at a fascicle.

Conclusions
Monitoring of PAs recorded in the LEG via PE of the ELMA catheter during laser application is a unique claim of the laser method that enhances the assessment of local electrical activity and ablation efficacy. It allows the assessment of laser effects on the conduction system during ablation. By using the ELMA catheter described, long-term modulation of SN and AV nodal functions are achievable and unwanted complete heart block or fascicular block can be avoided.

Keywords
Open-irrigated laser catheter • Focused intracardiac electrogram • Monitoring of local potential amplitudes • Laser catheter mapping • Laser ablation • Conduction system of the heart

Introduction
Monitoring of focused bipolar intracardiac local electrogram (LEG) recorded via the pin electrode (PE) of the open-irrigated electrode–laser mapping and ablation (ELMA) catheter during laser application aimed at the myocardial walls shows a gradual attenuation of potential amplitude (PA). Dwindling of the PA in the LEG reflects the growth of lesion in the myocardial wall, whereas the abolishment of PA suggests the achievement of a transmural lesion.1 The aim of this study was to investigate the effects of graded mapping guided laser application selectively aimed at various levels of the conduction system in a dog model.

Methods
The study was performed in the CCEP Centre Taufkirchen and in the Central Laser Laboratory and Animal Experimental Laboratory Facilities of the Helmholtz Centre, Neuherberg, Germany. The investigations comply with the principles outlined in the Declaration of Helsinki. Animal experimental studies were conforming to the Directive 86/609/EEC on the protection of animals used for experimental and other scientific purposes, adopted in 1986 by the European Commission.

A total of 54 healthy 15–21 kg beagles of either sex were anaesthetized by intravenous (i.v.) Thiamylal-Na 4%, 0.4 mL/kg and intubated for isoflurane (0.8–1.5%) and with nitrous-oxide anaesthesia. Heart
Monitoring of laser effects on the conduction system

What’s new?

- Focused local electrogram (LEG) recorded via pin electrodes (PEs) mounted near the electrode–laser mapping and ablation (ELMA) catheter tip increases the sensitivity to changes in the electrophysiological characteristics of the tissue subjected to ablation. Monitoring of potential amplitudes (PA) enhances the assessment of local electrical activity and ablation efficacy.
- Laser light is not competitive with the electrical recordings and allows for monitoring of laser effects on the conduction system without noise also during laser application.
- Attenuation and reversibility of PA in the LEG, which is the laser mapping technique, provides a unique useful control of laser effects on the conduction system without the need for additional sophisticated and expensive technology when using the open-irrigated ELMA catheter.

rate, quality of peripheral pulse, and atrial oxygen saturation were monitored throughout the procedure. The animals were catheterized pervenously from the right groin (Seldinger technique). The ELMA catheter (RytmoLas, LasCor GmbH) was inserted via a steerable sheath (e.g., Agilis™ NxT, St Jude Medical) and was manipulated in the dog hearts under X-ray control during continuous saline irrigation and LEG recordings. Left heart access was achieved by using a transseptal laser puncture set.1

Equipment

The ELMA catheter RytmoLas, an 8F radiopaque plastic tube, has an optical fibre fed into its central lumen. The fibre tip is mounted in the central lumen at a given distance from its end hole. The two PEs, 2/4 mm, were mounted symmetrically on the outer side of the catheter tip and were connected to the manifold via cables running along the optical fibre in the lumen of the catheter. Monitoring of bipolar LEG was performed simultaneously with surface lead ECG. As the ELMA catheter is not steerable, Agilis™ NxT steerable introducers were used for manipulation in the heart chambers and for stable positioning of the catheter upon the endocardial area of interest. Laser application was performed without catheter pressure on the endocardium.

‘Catheter irrigation’ was performed by means of a roller pump. The lumen of the catheter was rinsed permanently via an infusion line with heparinized saline 5000 IU/L, 15 mL/min (continuous flow). During laser applications, the flow rate was augmented automatically via the foot switch of the laser to 30 mL/min (‘working flow’).

‘Power source’ was a continuous wave (cw) 1064 nm Nd:YAG laser Medilas fiberom 5060 N, Dornier MedTech, Wessling, provided with a light-guide protection system that can stop the laser automatically in case of optical fibre contact with blood elements or tissue. Light-guide protection system stops the laser automatically prior to thermal damage of the optical fibre tip and prior to the burning of the endomyocardium. Laser radiation was performed at powers of 15 W.

The study protocol

After a 24 h Holter monitoring, electrophysiological and electropharmacological tests were performed, including sinus nodal (SN) recovery times, estimation of Wenckebach point, mean RR-intervals during induced atrial fibrillation, heart rate on metoprolol, and on isoproterenol. Tests were repeated immediately following the laser studies and again after a follow-up of 3–11 months, except eight dogs with laser-induced permanent complete heart block during study. Catheters mapping-guided lesions were placed under fluoroscopic guidance.

In 20 dogs one laser impact per dog was aimed at the SN area, showing the earliest atrial activation in the focused LEG (S-spike). The radiation time was limited to < 5 s (75) in six of the dogs, whereas in 14 dogs the radiation time was 15 s (225 J).

In other 24 dogs, mapping-guided laser impacts were aimed at the central region of Koch’s triangle, where a large atrial and a ventricular, but no His potential was recorded from. In four dogs the radiation was limited to < 5 s, whereas in 16 dogs the radiation was continued until the occurrence of the Wenckebach point. In four dogs, the radiation was continued 5 s beyond that point.

Eventually, in 10 dogs mapping-guided laser impacts were aimed at the His bundle or at a branching segment (n = 5, each). The radiation was limited to 3 s (45 J) in six dogs (n = 3, each), whereas in four dogs (n = 2, each) was applied for 8–10 s (120–150 J).

In all the dogs the long-term effects were assessed by weekly surface lead ECG in the first month, monthly thereafter, and whenever during daily pulse controls heart rate abnormalities were suspected. After the follow-up the chest of the dogs was opened under general anesthesia and hearts were remove for histopathologically evaluations.

Results

Laser effects on sinus nodal and atrioventricular nodal functions

Earliest atrial activation in the SN area (the S-spike) was found 25–30 ms prior to the onset of the P-wave in the surface ECG. Laser application aimed at this area gradually attenuated amplitude potentials in the focused LEG. In the six dogs in which radiation was limited to 4–5 s, PAs were recovered gradually to their initial heights within 18–21 s (mean 20 ± 0.8 s). In the electrophysiological tests, SN functions were not affected, and no lesions were found in the hearts of these animals. In contrast to that after 15 s of radiation in 14 dogs, the amplitudes of the S-spike were attenuated permanently and were split (Figure 1A). Sinus cycle lengths increased from mean of 430 ± 70 to 610 ± 105 ms (P = 0.001). Endocardial sites consistent with these impacts showed circular–oval-shaped clear-cut transmural fibrous scars without signs of mural thrombus or aneurysm formation (Figure 1B).

Mapping-guided laser impacts of 4–5 s (4 dogs) aimed at the area of Koch’s triangle produced a minimal transitory attenuation of PA for 5–8 s without producing a lesion and without influence on the atrioventricular nodal (AVN) functions. In 20 dogs the laser impacts of 10–14 s (mean 11.8 ± 1.7 s) produced a gradual attenuation of local PA, a gradual increase of the atrio–His (AH), and the proximal conduction time whereas the distal, the HV conduction intervals, always remained stable. When laser application was limited to the appearance of the Wenckebach point, PA and AH conduction resumed to their initial values within 11–16.1 min (mean 14.8 ± 3.8 s) (Figure 2). A subendocardial fibrosis was conspicuous in the area of Koch’s triangle consistent with these laser impacts. In four dogs the radiation was continued for 4–5 s beyond the Wenckebach point. The atrial PA were abolished permanently and a chronic complete heart block was produced (Figure 1C). Escape rhythms were 48, 52, 54, and 65 b.p.m., respectively, and QRS complexes were always...
narrow (<100 ms). Circular to oval clear-cut fibrous scars were conspicuous in the area consistent with these radiation sites (Figure 1D).

**Laser effects on the His bundle and fascicles**

Laser impacts limited to 4–5 s aimed at the His bundle or fascicules abolished the conduction but temporarily (Figure 3A) or caused a reversible deviation of the electrical axis (Figure 3B). Normal conduction recurred within 11–17 s (mean 15 ± 3.2 s). In contrast to that, laser application of 8–10 s in four dogs (n = 2, each) induced permanent complete His or fascicular conduction block. In one of the dogs with a His block, QRS complexes were narrow (100 ms) and the escape rhythm ranged between 45 and 50 b.p.m. (Figure 1E, left top). In the second dog, escape rhythm was 35 b.p.m. and QRS complexes were 164 ms (Figure 1E, left bottom). The two dogs with fascicular radiation of 8 s displayed stable, one left and one right, bundle branch block throughout the follow-up. Histological evaluation of the hearts showed fibrous scars interposed between the stumps of the interrupted bundles (Figure 1F).

All the animals survived the tests and the follow-up period of up to 11 months, except the dog with chronic His block, wide QRS complexes, and an escape rhythm of 35 b.p.m. that succumbed suddenly in the sixth week of follow-up.
whereas the volumes of lesions differed very statistically significant criteria, these differences are considered to be statistically significant, AV node is equal to 0.0497 and 0.0174, respectively. By conventional impacts producing modulation and those producing block in the Differences in time and in level of energy delivery between laser experiments and those after a follow-up of 3–11 months (Table 1). Electrophysiology tests performed prior to the studies showed normal function of the conduction system in all of the dogs. The control tests showed substantially modified functions of the SN and the AV node; however, there were no statistical significant differences between the results achieved following immediately the experiments and those after a follow-up of 3–11 months (Table 1). Differences in time and in level of energy delivery between laser impacts producing modulation and those producing block in the AV node is equal to 0.0497 and 0.0174, respectively. By conventional criteria, these differences are considered to be statistically significant, whereas the volumes of lesions differed very statistically significant $P = 0.0011$ (Table 2).

## Discussion

Focused bipolar LEG recordings via the PE of the open-irrigated ELMA as shown in this study cannot be obtained by the routinely used RF mapping and ablation ring-electrode catheters. Focused LEGs improve mapping resolution and provide increased sensitivity to changes in the electrophysiological characteristics of the tissue subjected to ablation. Gradual attenuation of PA in the LEG reflects the gradual spread of heat-induced myocardial coagulation and so allows for a beat-to-beat monitoring of lesion maturation. The changes of PA in the LEG recordings via the PE are not detectable by ring-electrode recordings which exhibit poor ability if any, to detect electrical variations associated with ablation. By using the open-irrigated ELMA catheter, focused LEG recordings via PE were performed routinely from the very beginning of our laser experiments. Pin electrodes positioned at the ELMA catheter tip enhances the assessment of electrical activity and lesion efficacy using electrogram amplitudes. Potential amplitude diminishes gradually as the myocardium becomes electrically inactive, devoid of electrical potentials. Reduction of the LEG amplitudes demonstrates the effectiveness of energy delivery and is also a surrogate for stable positioning of the catheter during the ablation process. Abolishment of PA is associated with the creation of electrically silent tissue. These findings provide evidence for the unique utility of the PE in identifying lesion formation, in providing discrete mapping capability. Improved mapping resolution enables a selective approach to tiny structures of the conduction system such as the His bundle and bundle branches. Successfully titrating ablation to PA diminution allows for online control of laser effects and for decreased ablation time by limiting the amount of energy applied to the targeted structures, e.g. accessory pathways involved in re-entry circuits or isolated firing foci.
The marked differences in the LEG amplitude recordings between PE and the recordings via ring electrodes are likely to be related to the close vicinity of the PE with the myocardial tissue. This limits far-field recordings and improves the operator’s ability to define effective lesion formation. Such discrimination is not possible with the routinely used ring electrodes. In addition to far-field effects, the artefacts during RF delivery render the LEG morphological changes impossible to assess. In contrast to the RF, the PEs of the laser catheter do not deliver energy, and laser light is not competitive with electrical recordings. Therefore, real-time beat-to-beat monitoring of PA is practicable without noise in the LEG and without special filtering exclusively when using the ELMA catheter and substantially contributes to the safety and the efficacy of laser catheter ablation procedures.

The aim of this study was to assess the laser effects on the functions of the conduction system of the heart in a dog model. The relationship between the level of energy, myocardial thickness, and collateral damages and the importance of catheter irrigation and lesion formation was already reported in detail elsewhere.8–10 It has to be emphasized that catheter irrigation is of crucial importance for the open-irrigated ELMA catheter technique and is a major pre-requisite for successful laser application in the cardiovascular system, especially in the intracardiac high-pressure blood environment of the beating heart. It washes away the blood from the optical fibre tip avoiding blood clotting with thrombus formation and it creates a clear path for the laser light to the illuminated area, a major pre-requisite for laser lesion formation.

Also of importance is the fact that cw 1064 nm laser light is converted to heat to coagulate myocardium after penetrating deep intramurally. The blood stream as well as the open-irrigated ELMA catheter itself is not heated up directly from the laser beam or indirectly from the tissue. By the continuous flow of saline at room temperature through its lumen, catheter temperature is kept stable slightly below body temperature during the entire ablation procedure.11

Ought to the low absorption and frequent scattering, the 1064 nm laser photons penetrate deep intramurally before they are absorbed and heat is induced.12 It has been shown that catheter contact force is not a factor in whether a laser lesion is transmural,10 and laser energy settings can be adjusted when ablating tissues of varying thickness, with higher energy applied to thicker tissue and lower energy applied to thinner structures in the heart.8 The endocardial layers are translucent so that laser light passes through it without absorption of photons and without heating.

Stable and permanent laser-induced modifications of SN functions and AVN transmission properties as suggested in this study can be best explained by the here applied catheter technique and the characteristics of the laser lesion.

Probably ought to the larger surfaces and the transmurality of the laser lesions achieved in the core SN regions, a permanent modulation of SN functions were the result. However, SN laser modulation did not progress to sinus arrest in this study. Therefore, SN laser modulation may be a promising therapeutic method for patients with a rare but symptomatic inappropriate sinus tachycardia. Possible laser-induced modifications of ganglionated plexi that may influence SN functions cannot be ruled out. However, there were no intraprocedural vagal reactions observed in the investigated dogs.

Our initial study in five dogs suggested that graded laser catheter applications aimed at the AV nodal regions can modify or block AV

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**Table 1** Modification of SN functions and of AVN transmission properties 3–11 months after laser catheter ablation in 30 dogs

<table>
<thead>
<tr>
<th>SN functions (14 dogs)</th>
<th>AVN transmission (16 dogs)</th>
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</thead>
<tbody>
<tr>
<td>24 h HR ↓ 21.2 ± 7.5%</td>
<td>AH intervals ↑ to 29.0 ± 2.5 ms (38%)</td>
</tr>
<tr>
<td>Maximum HR ↓ 24.0 ± 4.2%</td>
<td>Wenkebach point ↑ 176 ± 15 to 260 ± 10 ms (48%)</td>
</tr>
<tr>
<td>β-Blocker HR ↓ 31.4 ± 3.3%</td>
<td>Mean RR intervals during induced AF ↑ 30%</td>
</tr>
<tr>
<td>HR on isoproterenol ↓ 18.8 ± 5.1%</td>
<td>Isoproterenol infusion did not reverse effects</td>
</tr>
</tbody>
</table>

SNRTs and CSNRTs remained unchanged.

All the values shown above decreased or increased significantly (P > 0.05) and permanently.

HR, heart rate per minute; SNRT, sinus nodal recovery times; ↓, decrease; ↑, increase; AF, atrial fibrillation; CSNRTs, corrected sinus nodal recovery times.

**Table 2** Three to 6-month-old lesions produced by laser applications at 15 W and graded radiation times aimed at various levels of the conduction system in 38 dogs

<table>
<thead>
<tr>
<th>Site of laser application</th>
<th>Radiation times (s)</th>
<th>Lesions (mm)</th>
<th>Diameters</th>
<th>Volumes (mm³)</th>
<th>Level of energy applied (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinus node</td>
<td>15</td>
<td>Transmural</td>
<td>3–7</td>
<td>12–18</td>
<td>252–378</td>
</tr>
<tr>
<td>Modulation (n = 14)</td>
<td></td>
<td></td>
<td>15 ± 0.9</td>
<td></td>
<td>309 ± 107</td>
</tr>
<tr>
<td>AV node</td>
<td>11–16</td>
<td>2–5</td>
<td>3–7</td>
<td>4.3 ± 0.9</td>
<td>501 ± 118</td>
</tr>
<tr>
<td>Modulation (n = 16)</td>
<td>13.1 ± 1.1</td>
<td>6.1–8.2</td>
<td>4.6–8.2</td>
<td>735–2156</td>
<td>225–300</td>
</tr>
<tr>
<td>Block (n = 4)</td>
<td>15–20</td>
<td>7.7 ± 2.1</td>
<td>7.8 ± 2.0</td>
<td>1.140 ± 419</td>
<td>256 ± 40</td>
</tr>
<tr>
<td>Fascicular (n = 2)</td>
<td>8</td>
<td>3–4</td>
<td>3–4</td>
<td>100–190</td>
<td>120</td>
</tr>
<tr>
<td>His block (n = 2)</td>
<td>8–10</td>
<td>2–5</td>
<td>3–4</td>
<td>55–230</td>
<td>120–150</td>
</tr>
</tbody>
</table>
Conclusions

Focused LEG recordings via PE without noise during laser application are a unique claim of the laser method that substantially contributes to the safety and efficacy of the ablation procedure. Reductions of PA recorded during laser application by the PEs are indicators of effective lesion creation and a surrogate of stable catheter tissue contact. Focused LEGs allow for mapping and for targeting of discrete segments of the conduction system. Utilizing the PE recordings, the enhanced electrophysiological discrimination of viable vs. ablated tissues is a useful tool to identify lesions contiguity, close gaps that often cause atrial tachycardia or recurrences after AF ablation. Mapping-guided laser application aimed at the SN region persistently limits maximum heart rate without causing sinus bradyarrhythmia and may be useful in the treatment of patients suffering from inappropriate sinus tachycardia. Mapping-guided graded laser applications aimed at the AV nodal regions may result in long-term modulation of AV conduction without progress to AV block or may help achieve higher escape rhythm with less Pm dependence (lifethreatening condition without intracardiac stimulation) after AV ablation in patients with AF. Pin-electrode laser mapping may help avoid unwanted His or fascicular conduction block.

Acknowledgements

The research was performed in the CCEP Center Taufkirchen, and in the Central Laser Laboratory and the Laboratory Animal Facilities of the Helmholtz Center Munich, Germany. The investigations comply with the principles outlined in the Declaration of Helsinki. Animal experimental studies were conforming to the Directive 86/609/EEC on the protection of animals used for experimental and other scientific purposes, adopted in 1986 by the European Commission.

Conflict of interest: M.S.-G. is CTO, and H.W. is CEO of LasCor GmbH, manufacturer of the open-irrigated ELMA catheter, without any revenue or profit from the company.

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References


Catheter ablation via the brachial artery of ventricular arrhythmia originating from the right coronary cusp

Bing Han*, Shi-jie Li, and Chun-guang Feng

Arrhythmia Service, Division of Cardiology, The Central Hospital of Xuzhou City, 199 South Jiefang Road, Xuzhou 221009, China

*Corresponding author. Tel: +86 516 83985069; Fax: +86 516 83956012. E-mail address: hbing777@hotmail.com

We described a case of a 72-year-old man with frequent premature ventricular contractions (PVC) and recurrent ventricular tachycardia (VT). Multiple anti-arrhythmic medications had failed to relieve symptoms. It was decided to treat the PVC/VT with catheter ablation.

Mapping was first attempted in the right ventricle and ablation failed to eliminate PVC. In view of the possible left-sided origin, a 7F arterial sheath was inserted through the right femoral artery. However, the catheter could not be passed through the right iliac artery which appeared tortuous judged from the shape of the guide wire running through it. The same problem was encountered when using the left femoral artery.

Considering PVC most likely originated from the coronary cusp based on QRS complex morphology, we chose to perform ablation via the right brachial artery. A 7F ablating catheter was smoothly inserted through the right brachial artery. In activation sequence mapping, the earliest activated site was located in the right coronary cusp. A RF application resulted in PVC elimination.

To our knowledge, this is the first report of ablation through the brachial artery of ventricular arrhythmia originating from the right coronary cusp.

The full-length version of this report can be viewed at: http://www.escardio.org/communities/EHRA/publications/ep-case-reports/Documents/Catheter_ablation_via_the_brachial动脉.pdf.