IJC Heart & Vasculature 33 (2021) 100771

Contents lists available at ScienceDirect

IJC Heart & Vasculature

journal homepage: www.journals.elsevier.com/ijc-heart-and-vasculature

Esophageal pressure monitoring for airway management during catheter ablation of atrial fibrillation

Yu-ki Iwasaki [a,*], Yuhi Fujimoto [a], Eiichiro Oka [a], Kanako Ito Hagiwara [a], Kenta Takahashi [a], Ippei Tsuboi [b], Hiroshi Hayashi [a], Kenji Yodogawa [a], Meiso Hayashi [a], Yasushi Miyauchi [c], Wataru Shimizu [a]

[a] The Department of Cardiovascular Medicine, Nippon Medical School, Japan
[b] Department of Cardiovascular Medicine, Nippon Medical School Musashikosugi Hospital, Japan
[c] Department of Cardiovascular Medicine, Nippon Medical School Chiba-Hokusoh Hospital, Japan

ARTICLE INFO

Article history:
Received 26 January 2021
Received in revised form 13 March 2021
Accepted 21 March 2021

Keywords:
Atrial fibrillation
Catheter ablation
Esophageal pressure
Airway management

ABSTRACT

Background: Respiratory management during catheter ablation of atrial fibrillation (AF) is important for the efficacy and safety of the procedure. Obstructive apnea due to an upper airway obstruction might cause serious complications including air embolisms and cardiac tamponade. However, real time monitoring of upper airway obstructions during catheter ablation has not been established. The purpose of the present study was to evaluate esophageal pressure monitoring for respiratory management during catheter ablation of AF.

Methods and Results: Twenty-four consecutive patients (20 men and 4 women; mean age, 61 ± 13 years) with AF who underwent esophageal pressure monitoring during catheter ablation of AF were retrospectively analyzed. The patients were divided into 2 groups. One was the obstructive apnea (OA) group (n = 17), which required airway management tools including nasal airways and/or non-invasive positive airway pressure (NPPV) and the other was the control group (n = 7), which did not require airway management. Esophageal pressure measurements were obtained in all patients, and the OA group exhibited a substantial negative esophageal pressure as compared to the control group (−41.48 ± 19.58 vs. −12.42 ± 5.77 mmHg, p < 0.001). Airway management in the OA group immediately improved the negative esophageal pressure and returned to a normal range (−41.48 ± 19.58 vs. −16 ± 8.1 mmHg, 0 < 0.001) along with a recovery from desaturation.

Conclusions: Esophageal pressure monitoring was a simple and effective method for the evaluation and management of obstructive apnea during AF catheter ablation.

1. Introduction

Atrial fibrillation (AF) is one of the most common arrhythmias, and the prevalence of AF has been increasing for decades [1]. Catheter ablation of AF has been shown to be beneficial in patients not only refractory to pharmacological treatment,[2] but also with heart failure.[3] Recently, the number of catheter ablation procedures for AF has been increasing in Japan. Although, the efficacy and safety of the ablation procedure for AF has been improved by recent advancements in 3-dimensional mapping systems and catheter technologies with contact force and balloon ablation systems,[4] the incidence of complications related to the catheter procedures is not rare even in high-volume centers [5]. Respiratory management for obstructive apnea (OA) during catheter ablation is important to prevent serious complications associated with the procedure including cardiac tamponade and air embolisms. The J-CARAF study revealed that 38.9% of ablation cases were performed with deep sedation, which might cause OA requiring airway management.[6] General anesthesia by an anesthesiologist could establish an optimal respiratory management for catheter ablation, however, the majority of AF catheter ablation cases are performed with moderate or deep conscious sedation.[6] Although a nasal airway and/or non-invasive positive airway pressure ventilation (NPPV) are useful for the management of an upper airway obstruction due to deep conscious sedation,[7,8] insufficient airway management might cause a deep negative intra-thoracic pressure associated with an upper airway obstruction. Therefore, it would be useful if we could measure the real-time intra-thoracic pressure. However, real time monitoring of an upper airway obstruction during catheter ablation has not been established.

* Corresponding author at: The Department of Cardiovascular Medicine, Nippon Medical School, Tokyo, 1-1-5, Sendagi, Bunkyo-ku, Tokyo 1138603, Japan.
E-mail address: iwasaki@nms.ac.jp (Y.-k. Iwasaki).

https://doi.org/10.1016/j.ijcha.2021.100771
2352-9067/

In the present study, we developed a novel esophageal pressure monitoring system in order to evaluate the real-time esophageal pressure indicating the intra-thoracic pressure during catheter ablation of AF.

2. Methods

2.1. Study population

Twenty-four consecutive patients (20 men and 4 women; mean age, 61 ± 13 years) with AF who underwent esophageal pressure monitoring during radiofrequency catheter ablation between April 2015 and September 2015 at Nippon Medical School Hospital were retrospectively analyzed. The patients were divided into 2 groups. One was the OA group, which required airway management tools including nasal airways and/or NPPV and the other one was a control group which did not require airway management. This study was approved by the institutional ethics committee at Nippon Medical School Hospital.

2.2. Esophageal pressure monitoring system

Esophageal pressure monitoring was performed in all patients. The esophageal pressure was measured by a conventional drip infusion line with an internal diameter of 1.0 mm. The esophageal pressure line was parallelly fixed with a 3–0 silk suture to the esophageal temperature probe (SensiTherm, Abbot). A side hole was made at the distal portion of the esophageal pressure line in order to achieve a real time measurement of the esophageal pressure (Fig. 1). An esophageal temperature probe along with the esophageal pressure line was inserted into the esophagus and positioned at the left atrial posterior level. The position of the temperature probe was confirmed by fluoroscopy and normal saline was injected into the esophageal pressure line, which was connected to a conventional pressure transducer, and the zero level was calibrated at atmospheric pressure. The scale for the esophageal pressure was set at a range between +50 and −50 mmHg. The ECG, SpO2, esophageal pressure, and non-invasive blood pressure were recorded on a polygraph system (FCL-2000, Fukuda Denshi).

2.3. Conscious sedation during the ablation procedure

After written informed consent was obtained, radiofrequency catheter ablation of AF was performed. Bispectral index (BIS, A-2000, Nihon Kohden, Tokyo) monitoring was obtained. The intracardiac electrograms and 12-Lead ECG were recorded using an EP Workmate (St. Jude Medical, Minneapolis, MN USA). Deep conscious sedation was established by the intravenous administration of midazolam (10 mg), pentazocine (15 mg), and hydroxyzine (25 mg) and were followed by a continuous infusion of dexmedetomidine (7 μg/kg/hr for 10 min). The dose of dexmedetomidine was adjusted by BIS monitoring ranging from 50 to 60.

2.4. Statistical analysis

The data are expressed as the mean ± standard deviation for continuous variables and as absolute frequencies and percentages for categorical variables. For continuous variables and categorical variables, the differences between the groups were compared with a Student's *t*-test and Fisher's exact test, respectively. P-values less than 0.05 were considered statistically significant. All analyses were performed with GraphPad Prism version 7.0 software (GraphPad Software, Inc., California).

3. Results

3.1. Patients characteristics

The patient characteristics are shown in Table 1. In 24 patients, desaturation developed due to OA, and airway management was performed in 17 patients (OA group), and no desaturation occurred in the remaining 7 patients (control group). Sixteen patients

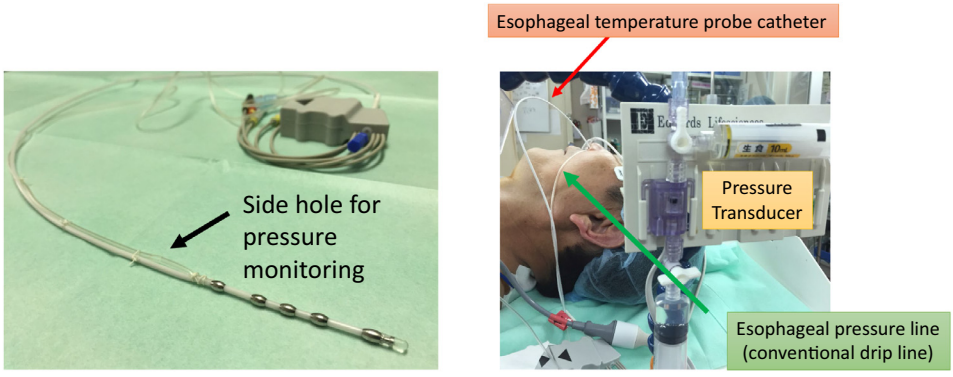

Fig. 1. Esophageal pressure monitoring system combined with the esophageal temperature probe. An esophageal pressure line was connected to a pressure transducer.

Table 1
Baseline characteristics of the study subjects.

		OA group (n = 17)			Control group (n = 7)			p-value
Age	(y/o)	61.2	±	10.7	60.7	±	12.9	0.931
Gender (Male/Female)		14/3			6/1			0.780
Body weight	(kg)	74.7	±	15.0	75.0	±	18.5	0.971
Body mass index	(kg/m^2)	26.9	±	4.8	25.0	±	4.7	0.381
AF type (PAF/non-PAF)		12/5			7/0			0.150
Systolic blood pressure	(mmHg)	116.1	±	13.1	120.7	±	12.4	0.440
Diastolic blood pressure	(mmHg)	62.4	±	13.4	68.7	±	7.8	0.164
Heart rate	(bpm)	73.0	±	16.9	77.7	±	13.1	0.475

received a nasal air way and 5 received NPPV (3 patients used both a nasal airway and NPPV). There were no significant differences in the body weight and BMI between the 2 groups (see Table 2).

3.2. Esophageal pressure during obstructive apnea

The esophageal pressure was successfully measured in all patients with the custom-made esophageal pressure monitoring system. Fig. 2 shows the esophageal pressure changes during deep conscious sedation without any obvious OA. A periodical esophageal pressure curve associated with the respiratory cycle was confirmed and it became negative (≈−15 mmHg) during the inspiratory phase and returned to baseline during the end expiratory phase (≈0mmHg). On the other hand, the patients with OA exhibited dynamic periodical changes of the esophageal pressure with a substantial negative pressure (≈−50 mmHg). The SpO2 was significantly lower in the OA group than control group (98.0 ± 2.1 vs 91.1 ± 4.6 mmHg, p < 0.001). The OA group had a much greater negative esophageal pressure as compared to the control group. The nadir of the esophageal pressure was more negative in the OA group than control group (−41.48 ± 19.58 vs. −12. 42 ± 5.77 mmHg, p < 0.001). A negative esophageal pressure below −30 mmHg preceded the desaturation (SpO2 < 90%) by 52 ± 23 sec.

3.3. Airway management and esophageal pressure

The OA group had a substantial negative esophageal pressure, which was restored to a normal range with airway management such as a nasal airway and/or NPPV.

The nasal airway insertion dramatically improved the airway obstruction resulting in a normalization of a substantial negative esophageal pressure (Fig. 3). The deep negative esophageal pressure significantly improved after the airway management with the nasal airway and/or NPPV in the OA group (−41.48 ± 19.58 vs. −16 ± 8.1 mmHg, 0 < 0.001). The SpO2 significantly increased with the airway management in the OA group (91.3 ± 4.58 vs. 97.7 ± 2. 0 mmHg, 0 < 0.001).

3.4. Complications with esophageal pressure monitoring systems

Total procedure time was not different between the 2 groups (OA group: 189.5 ± 57.0 vs. control group: 162.14 ± 50.2 min, p = 0.26). There were 2 cases of minor nasal bleeding associated with the esophageal catheter insertion in OA group and 1 case in the control group. None of the patients developed any major nasal bleeding requiring otolaryngologic intervention.

4. Discussion

4.1. Esophageal pressure monitoring system

The esophageal pressure recording is the gold standard for respiratory effort measurements in the patients with sleep related respiratory disorders.[9] It has been reported that OA causes repetitive forced respirations against an upper airway obstruction, which generates a substantial negative pressure (−65 mmHg) in the chest cavity.[10] However, the invasive nature of esophageal catheters, which need to be inserted during sleep, is not tolerated by many patients with obstructive sleep apnea in clinical practice. On the other hand, patients undergoing AF catheter ablation with deep sedation usually undergo esophageal temperature monitoring using an esophageal temperature probe. Therefore, an esophageal pressure line along with the temperature probe could be easily placed in the esophagus during catheter ablation in the same manner. We developed a novel esophageal pressure monitoring system,

Table 2
Esophageal pressure and percutaneous oxygen saturation.

		OA group (n = 17)			Control group (n = 7)			p-value
Baseline Eso P	(mmHg)	13.2	±	15.1	−0.4	±	2.8	0.002
Nadir Eso P	(mmHg)	−41.5	±	19.6	−12.4	±	5.8	<0.001
SpO_2	(%)	91.1	±	4.6	98.0	±	2.0	<0.001
Breathing rate	(/min)	14.7	±	3.3	13.9	±	2.4	0.667

Eso P; esophageal pressure, OA; obstructive apnea.

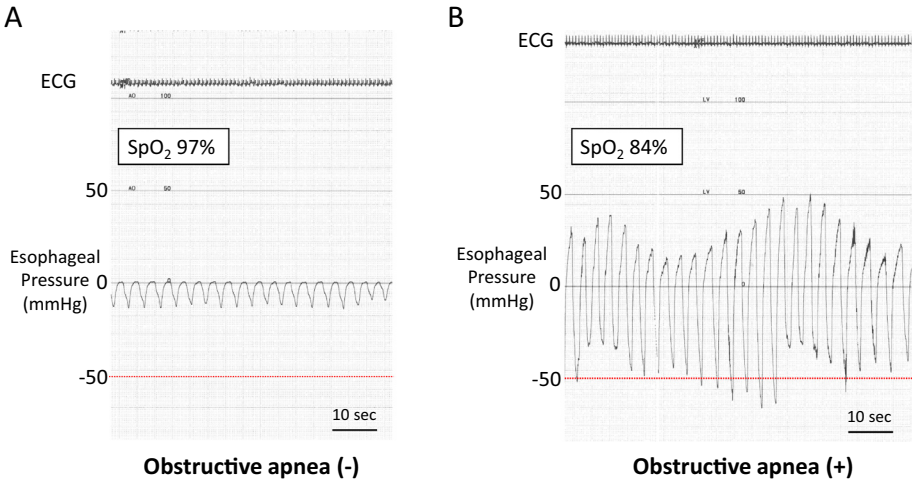

Fig. 2. A: Esophageal pressure curve without obstructive apnea. There are periodical changes in the esophageal pressure associated with the respiratory cycle. The nadir of the esophageal pressure was approximately −10 to −15 mmHg. B: Esophageal pressure curve during obstructive apnea. A substantial deep negative esophageal pressure was recorded, and the nadir of the esophageal pressure was −50 mmHg.

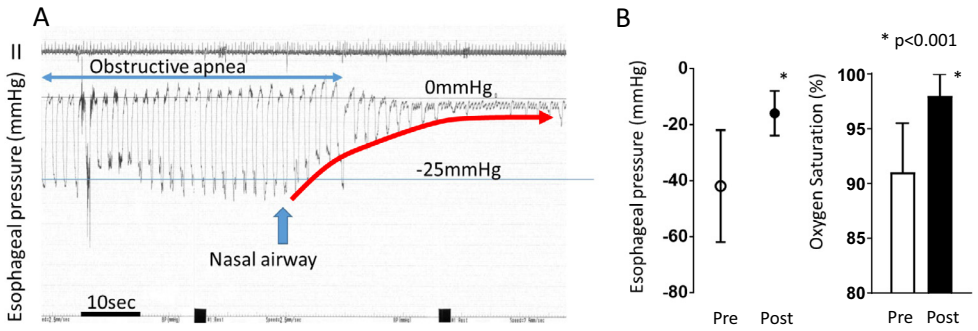

Fig. 3. A: Time course of the effect of the nasal airway during the obstructive apnea. The nasal airway insertion immediately improved the substantial negative esophageal pressure. B: The effect of the airway management on the esophageal pressure and oxygen saturation in the obstructive apnea group. Pre: Before the airway management, Post: After the airway management.

which could measure real-time esophageal pressures during catheter ablation without any additional procedures or complications.

4.2. Obstructive apnea during AF catheter ablation

Obstructive sleep apnea (OSA) is one of the independent risk factors for the development of AF.[11] In addition, the prevalence of OSA in patients with AF is 50%.[12] Anatomical factors including obesity and a small jaw might be associated with the occurrence of OSA.[13] Moreover, deep conscious sedation is often performed for anesthesia and analgesia during catheter ablation of AF. Therefore, the incidence of the occurrence of OA with deep conscious sedation during catheter ablation procedures is inevitably high in patients with AF. We need to focus on the management of OA during AF catheter ablation for a safe and effective procedure.

In the present study, we confirmed that the esophageal pressure could be continuously monitored by a custom-made pressure catheter attached to a conventional esophageal temperature probe during catheter ablation. There were no time consuming or no additional invasive techniques or medical materials needed for the esophageal pressure monitoring. The insertion of the esophageal temperature probe with the pressure monitoring system could be safely achieved during the same procedure as usual.

We reconfirmed that an enormous negative intra-thoracic pressure developed, which reached less than −50mmmHg during OA episodes in AF ablation procedures. The esophageal pressure was measured during OA episodes. The results of a negative esophageal pressure were consistent with the previous basic and clinical investigations.[12,14–16] It has been reported that obstructive sleep apnea generates a deep negative esophageal pressure, which could reach −50 to −60 mmHg. These results implied the importance of airway management during ablation procedures. That is because, an inappropriate airway management could cause a deep negative intra-thoracic pressure, which might lead to serious complications. The dynamic motion of the diaphragm during the OA episode has the potential risk of causing a myocardial perforation especially on the left atrial roof, which could lead to cardiac tamponade, and insufficient radiofrequency energy deliveries at the bottom of the pulmonary veins might cause a reconnection between the pulmonary veins and left atrium. Moreover, a deep negative intra-thoracic pressure might cause an air embolization during catheter and sheath manipulation.[17] In the present study, the airway management using a nasal airway and/or NPPV, significantly improved the deep negative esophageal pressure along with a recovery from a desaturation. Esophageal pressure monitoring could immediately detect the development of OA during the procedure. Early detection of OA would make the airway management earlier. There were no serious complications associated with the esophageal pressure monitoring.

4.3. Application of the esophageal pressure monitoring

The esophageal pressure monitoring system could be utilized without any additional expensive medical equipment or materials. It was able to immediately detect the occurrence of OA before the occurrence of a desaturation. It could be used not only for the clinical use during AF catheter ablation but also for the evaluation of hemodynamic changes during OA. Deep conscious sedation during the ablation procedure mimics clinically occurring OSA syndrome. Esophageal pressure monitoring with hemodynamic measurements could provide a broad pathophysiological evaluation in patients with OA.

4.4. Limitations

There were several limitations to the present study. Firstly, this study was a retrospective and single-center study with a small population. Therefore, the use of a nasal airway and/or NPPV was at the operators' decision. However, the aim of this study was a preliminary study to evaluate the feasibility and safety of esophageal pressure monitoring during catheter ablation of AF by using a custom-made pressure monitoring system. Secondly, there were no capnometer data that would be sensitive to detect apnea. Further randomized with large scale clinical study will be needed to elucidate the effect of esophageal pressure monitor guided airway management in the catheter ablation of AF.

5. Conclusion

Esophageal pressure monitoring was a simple and effective method for the evaluation and management of OA during AF catheter ablation procedures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Mr. John Martin for his linguistic assistance.

The contribution of each author is summarized below:

Yu-ki Iwasaki- Planned and executed the study, performed catheter ablation of AF, analyzed data and wrote 1st draft of the paper.

Yuhi Fujimoto - Performed catheter ablation of AF and corrected the data.

Eiichiro Oka- Performed catheter ablation of AF and corrected the data.

Kanako Ito-Hagiwara- Performed catheter ablation of AF and corrected the data.

Kenta Takahashi - Performed catheter ablation of AF and corrected the data.

Ippei Tsuboi - Performed catheter ablation of AF and corrected the data.

Hiroshi Hayashi- Performed catheter ablation of AF and corrected the data.

Kenji Yodogawa - Performed catheter ablation of AF and corrected the data.

Meiso Hayashi - Performed catheter ablation of AF and corrected the data and reviewed the paper.

Wataru Shimizu- Supervised overall study, reviewed the paper.

There were no grant support in this study.

This manuscript has not been published or presented elsewhere in part or in entirety and is not under consideration by another journal. All authors have read and agree with the final version of the manuscript. The study design was approved by the appropriate ethics review board. We have read and understood your journal's policies, and we believe that neither the manuscript nor the study violates any of these. There are no conflicts of interest to declare.

References

[1] H. Inoue, A. Fujiki, H. Origasa, S. Ogawa, K. Okumura, I. Kubota, et al., Prevalence of atrial fibrillation in the general population of Japan: an analysis based on periodic health examination, Int. J. Cardiol. 137 (2009) 102–107.

[2] H. Calkins, G. Hindricks, R. Cappato, Y.H. Kim, E.B. Saad, L. Aguinaga, et al., 2017 HRS/EHRA/ECAS/APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation: Executive summary, Europace: Eur. Pacing, Arrhythmias, Cardiac Electrophysiol.: J. Working Groups On Cardiac Pacing, Arrhythmias, Cardiac Cellular Electrophysiology of the European Society of Cardiology. 20 (2018) 157–208.

[3] N.F. Marrouche, J. Brachmann, D. Andresen, J. Siebels, L. Boersma, L. Jordaens, et al., Catheter ablation for atrial fibrillation with heart failure, N. Engl. J. Med. 378 (2018) 417–427.

[4] H. Okamatsu, K. Okumura, Strategy and outcome of catheter ablation for persistent atrial fibrillation- impact of progress in the mapping and ablation technologies, Circ. J.: Off. J. Japanese Circ. Soc. 82 (2017) 2–9.

[5] Y. Michowitz, M. Rahkovich, H. Oral, E.S. Zado, R. Tilz, S. John, et al., Effects of sex on the incidence of cardiac tamponade after catheter ablation of atrial fibrillation: results from a worldwide survey in 34 943 atrial fibrillation ablation procedures, Circ. Arrhythmia Electrophysiol. 7 (2014) 274–280.

[6] K. Inoue, Y. Murakawa, A. Nogami, M. Shoda, S. Naito, K. Kumagai, et al., Current status of catheter ablation of atrial fibrillation in Japan: summary of the 4th survey of the Japanese Catheter Ablation Registry of Atrial Fibrillation (J-CARAF), J. Cardiol. (2015).

[7] D. Patel, P. Mohanty, L. Di Biase, M. Shaheen, W.R. Lewis, K. Quan, et al., Safety and efficacy of pulmonary vein antral isolation in patients with obstructive sleep apnea: the impact of continuous positive airway pressure, Circ. Arrhythmia Electrophysiol. 3 (2010) 445–451.

[8] M. Takigawa, A. Takahashi, T. Kuwahara, K. Okubo, E. Nakashima, Y. Watari, et al., Airway support using a pediatric intubation tube in adult patients with atrial fibrillation: A simple and unique method to prevent heart movement during catheter ablation under continuous deep sedation, J Arrhythm. 33 (2017) 262–268.

[9] M. Glos, A. Sabil, K.S. Jelavic, C. Schobel, I. Fietze, T. Penzel, Characterization of respiratory events in obstructive sleep apnea using suprasternal pressure monitoring, J. Clin. Sleep Med. 14 (2018) 359–369.

[10] V.K. Somers, D.P. White, R. Amin, W.T. Abraham, F. Costa, A. Culebras, et al., Sleep apnea and cardiovascular disease: an American Heart Association/ american College Of Cardiology Foundation Scientific Statement from the American Heart Association Council for High Blood Pressure Research Professional Education Committee, Council on Clinical Cardiology, Stroke Council, and Council On Cardiovascular Nursing. In collaboration with the National Heart, Lung, and Blood Institute National Center on Sleep Disorders Research (National Institutes of Health), Circulation 118 (2008) 1080–1111.

[11] A.S. Gami, D.O. Hodge, R.M. Herges, E.J. Olson, J. Nykodym, T. Kara, et al., Obstructive sleep apnea, obesity, and the risk of incident atrial fibrillation, J. Am. Coll. Cardiol. 49 (2007) 565–571.

[12] D. Linz, R.D. McEvoy, M.R. Cowie, V.K. Somers, S. Nattel, P. Levy, et al., Associations of obstructive sleep apnea with atrial fibrillation and continuous positive airway pressure treatment: a review, JAMA cardiology. 3 (2018) 532–540.

[13] M. Kato, T. Adachi, Y. Koshino, V.K. Somers, Obstructive sleep apnea and cardiovascular disease, Circ. J.: Off. J. Japanese Circ. Soc. 73 (2009) 1363–1370.

[14] M. Suzuki, H. Ogawa, S. Okabe, A. Horiuchi, M. Okubo, K. Ikeda, et al., Digital recording and analysis of esophageal pressure for patients with obstructive sleep apnea-hypopnea syndrome, Sleep breathing = Schlaf Atmung. 9 (2005) 64–72.

[15] Y.K. Iwasaki, Y. Shi, B. Benito, M.A. Gillis, K. Mizuno, J.C. Tardif, et al., Determinants of atrial fibrillation in an animal model of obesity and acute obstructive sleep apnea, Heart Rhythm: Off. J. Heart Rhythm Soc. 9 (1409–16) (2012) e1.

[16] Y-k Iwasaki, T. Kato, F. Xiong, Y.-F. Shi, P. Naud, A. Maguy, et al., Atrial fibrillation promotion with long-term repetitive obstructive sleep apnea in a rat model, J. Am. Coll. Cardiol. 64 (2014) 2013–2023.

[17] T. Kuwahara, A. Takahashi, Y. Takahashi, A. Kobori, S. Miyazaki, A. Takei, et al., Clinical characteristics of massive air embolism complicating left atrial ablation of atrial fibrillation: lessons from five cases, Europace: Eur. Pacing, Arrhythmias, Cardiac Electrophysiol.: J. Working Groups On Cardiac Pacing, Arrhythmias, Cardiac Cellular Electrophysiology of the European Society of Cardiology. 14 (2012) 204–208.