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Effects of Electroacupuncture on Minimum Alveolar Concentration of Isoflurane and Cardiovascular System in Isoflurane Anesthetized Dogs

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Abstract

The effects of electroacupuncture (EA) on the minimum alveolar concentration (MAC) and on the cardiovascular system were evaluated with dogs under isoflurane anesthesia. Eight healthy male beagles were randomly assigned to six study groups (five heads/group) with washout intervals of 7 ~ 31 days between experiments for recovery and anesthetic clearance. MAC of isoflurane and cardiovascular parameters were determined after EA at nonacupoint and and at acupoints LI-4, SP-6, ST-36 and TH-8. Electroacupuncture for 30 minutes at LI-4, SP-6, ST-36 and TH-8 acupoints lowered the MAC of isoflurane by 17.5 ±3.1%, 21.3 ±8.0%, 20.5 ±8.2% and 15.6 ±3.1%, respectively ($p < 0.05$). However, electrical stimulation of nonacupoint did not induce a significant change in MAC of isoflurane. In the cardiovascular system, the ST-36 group did not induce any significant change in cardiovascular parameters. In the TH-8 group, the mean and diastolic arterial pressure and the systemic vascular resistance were decreased. In the LI-4 group, cardiac output and cardiac index decreased after EA. These results indicate that EA at LI-4, SP-6 and ST-36 have advantages in isoflurane anesthesia in terms of reducing the dose of anesthetics and minimizing cardiovascular side effects.

Key words : dog, electroacupuncture, isoflurane, minimum alveolar concentration, cardiovascular system

Introduction

Isoflurane was developed in 1965 and approved in the late 1970's in many countries. It has been widely used in veterinary and human practice because of its chemical stability and minimal side effects. However, isoflurane has the known dose-dependent cardiopulmonary side effects, including dose-dependent increase in heart rate, right atrial pressure, expired ventilation, and end-tidal CO_2 tension. On the other hand, isoflurane decreases blood pressure, cardiac output, stroke index, systemic vascular resistance, pH and arterial O_2 tension [14, 17].

Reducing the amount of isoflurane required for general anesthesia would minimize its dose-dependent side effects. Quasha *et al*. [20] reviewed the definition, determination and the factors that affect minimum alveolar concentration (MAC) of inhalation anesthetics. MAC corresponds to the 50% effective dose, or ED_{50}, required anesthetizing 50% of subjects. Therefore, the relative potency and the amount of inhalant anesthetic required can be expressed as MAC. Several physiological factors could affect the MAC. For example, lowering the MAC means reducing the dose of each inhalant anesthetic. Analgesics, such as morphine or fentanyl, reduce the MAC of inhalation anesthetics. However, though morphine reduces MAC, it also has cardiopulmonary side effects [16, 24]. Doherty *et al*. [4] reported that 5-HT antagonist reduces the MAC of halothane in dogs, and Seitz *et al*. [22] reported that adenosine reduced the MAC of halothane MAC in dogs, and reduced mean arterial pressure.

It was found that the MAC of halothane was reduced by electroacupuncture (EA) at the SP-6 acupoint in dogs [27]. Wright and McGrath suggested that additional acupuncture anesthesia could be beneficial for conventional surgical anesthesia by reducing the dose of anesthetics [30]. If the new MAC produced after EA treatment is less than the original MAC, the acupuncture would be implied to produce analgesia or anesthesia [9].

The use of acupuncture therapy in various functional disorders goes back several thousands years. However, the use of acupuncture to induce anesthesia was developed in China in the late 1950's [7]. Over the past two decades, many studies upon acupuncture analgesia have been performed, and there were many suggested mechanisms of acupuncture analgesia, which include trigger point theory, the gate control theory and the modulation of several neurotransmitters [7, 15, 25, 28].

EA at ST-36 and GB-34 induced effective analgesia for an abdominal midline incision with a success rate of 89% [30],

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and Nam and Seo [18] reported upon local and general anesthetic effects of EA at several acupoints located in the head, neck, trunk and extremities, and upon the combined use of EA and sedatives. Kim *et al.* [8] reported that EA at SP-4, SP-6, TH-8 and *Quiang-feng* produced general anesthesia in dogs. Transcutaneous electrical nerve stimulation (TENS) with dens-and-disperse mode of 2/100 Hz at ST-36 reduced opioid analgesic requirements in human patients [2]. In addition, in human patients, many surgical procedures have been performed under acupuncture anesthesia [3, 10, 29].

We considered that if EA produces analgesia, this should be reflected in a reduced dose of anesthetics. Moreover, lowering the dose of anesthetics would minimize the dose-dependent side effects. The effect of EA on reducing the MAC of isoflurane in dogs has not been previously examined. This study was performed to investigate the effects of EA on MAC of isoflurane and on the cardiovascular system in isoflurane anesthetized dogs.

Materials and Methods

Experiment Animals

Eight healthy male beagles (19 month-old, Jungang Lab Animal Co., Seoul, Korea) were used for the study. Their mean body weight was 8.9 kg (7.6 ~ 10.5 kg). Dogs were assigned randomly to six experiment groups (5 heads/group) with washout intervals of 7 ~ 31 days between experiments for the recovery and anesthetic clearance. Feed was withheld for 12 hours before each experiment. The experiment groups were the control, nonacupoint electrically stimulated (NA) and four groups treated with electroacupuncture (EA) at the acupoints, LI-4, SP-6, ST-36 and TH-8 (Fig. 1).

Isoflurane Anesthesia

An open circle anesthetic system (Anesthesia Apparatus FO-20S, Acoma Medical Industry Co., Tokyo, Japan), with a Tec-type vaporizer for isoflurane (Acoma Vaporizer 1 MK-Ⅲ, Acoma Medical Industry Co., Tokyo, Japan), out of circle, was used for this study. Anesthesia was induced with 4% isoflurane (Isoflurane®, Rhodia, Bristol, UK) in oxygen, at a flow rate of 3 *L/min* via a facemask without any preanesthetics. After the induction of anesthesia, an endotracheal tube was inserted and the dog was placed in the right lateral recumbency. General anesthesia was maintained for one hour at least with 2% of isoflurane in oxygen at a flow rate of 100 *ml/kg/min*. Lactated Ringer"s solution was administered intravenously at a rate of 10 *ml/kg/h*. During the experiment the pulmonary arterial temperature was maintained at 38 ± 0.5℃ using a circulating warm water pad and a water blanket.

Electrical Stimulus

For the EA treatment groups, two stainless steel needles(32 gauge, 30 mm long, Haeng Lim Seo Won, Seoul, Korea) were inserted at each acupoint bilaterally. An electrical stimulus was applied at 2 ~ 4 V and 20 Hz for 30 minutes using an electrical stimulator (Pulse Stimulator AM 3000, TEC, Tokyo, Japan).

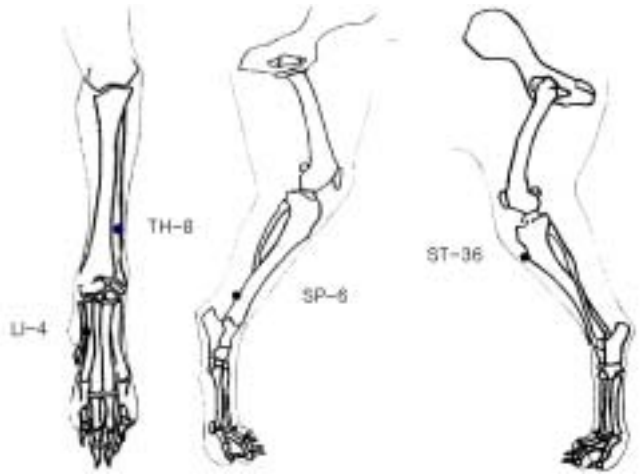

Fig. 1. Acupoints Used for Electroacupuncture
LI-4: between the first and second metacarpal bones, at the level of the head of the first metacarpus. SP-6: on the medial aspect of the hindlimb, caudal to the tibial bone, three-sixteenth the distance from the medial malleolus of the tibia to the stifle joint. ST-36: three-sixteenth the distance from the depression on the ventral margin of the patella to cranial tarsus, about one digit breadth lateral to the tibial crest, in the lateral portion of the cranial tibial muscle. TH-8: interosseous space between ulnar and radius, at the level of one-third the distance from styloid process to olecranon of the ulnar, between the common digital extensor muscle and the origin of abductor pollicis longus muscle.

Minimum Alveolar Concentration (MAC) of Isoflurane

The end-tidal concentration of isoflurane was measured by gas analysis and spirometry module (M-CaiOV, Datex-Ohmeda, Helsinki, Finland) of the anesthetic patient monitoring system (S-3, Datex-Ohmeda, Helsinki, Finland). MAC determinations were made according to the technique described by Eger *et al.* [5]. Briefly, the base of the dog"s tail was shaved, and at least one hour after the induction of anesthesia for stabilization, catheterizations were performed into femoral artery and jugular vein. The end-tidal concentration of isoflurane was lowered to 1.5% after catheterization and this was maintained for 30 minutes at least. Noxious stimulation to determine MAC was performed using a tail-clamping technique with a hemostatic forceps. The tail was clamped with hemostatic forceps until the ratchet caught, and was then shaken continuously for one minute or until a purposeful movement was elicited from the dog. MAC was determined as the concentration midway between the end-tidal concentrations at which the animal would or would not respond to the noxious stimulus. MAC was determined to the closest 0.1% end-tidal isoflurane concentration, which was maintained for at least 15 minutes.

Baseline MAC was determined twice in each group and

the mean value was taken. After EA for 30 minutes, MAC was re-determined (Fig. 2). For the nonacupoint electrical stimulation group, needles were inserted into the nonacupoint at the muscle bellies of left triceps brachii and right quadriceps femoris muscles. For the control group no treatment was applied for the 30-minute electrical stimulation period. The MAC value after EA treatment was compared to the mean baseline MAC value.

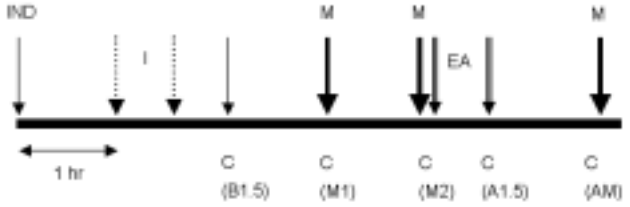

Fig. 2. Experimental protocol. IND: Mask induction. I: Instrumentation to measure the cardiopulmonary parameters. M: Determination of MAC. EA: Electroacupuncture. C: Measuring the cardiopulmonary parameters before determination of 1st MAC (B1.5), after determination of 1st MAC (M1), after determination of 2nd MAC (M2), after electroacupuncture (A1.5) and after determination of post-EA MAC (AM).

Cardiovascular Measurements

Cardiovascular parameters were measured before the 1st MAC was determined (B1.5), and after the determination of the 1st MAC (M1), and the 2nd MAC (M2), and after electroacupuncture (A1.5) and after the determination of the post-EA MAC (AM) (Fig. 2).

Heart rate (HR) and electrocardiogram (ECG) recordings were taken using the anesthetic patient monitoring system. Systolic (SAP), mean (MAP) and diastolic blood pressures (DAP) were measured at the femoral artery. Right atrial pressure (RAP), pulmonary arterial pressure (PAP) and pulmonary arterial wedge pressure (PAWP) were measured through a thermodilution catheter (Swan Ganz, 93-132-5F, Baxter Healthcare Co, Santa Ana, USA). Cardiac output (CO) was determined using the thermodilution technique with an injection of cold saline through the same catheter. Cardiac output was determined in triplicate at least and mean values were used as data. From the above data, the following cardiovascular variables were calculated: cardiac index (CI) = CO/body weight (*ml/min/kg*), stroke index (SI) = CI/HR (*ml/kg*), systemic vascular resistance (SVR) = (MAP - RAP)/CO X 79.9 (*dynes·s/cm*^{5}) and pulmonary vascular resistance (PVR) = (PAP - PCWP)/CO X 79.9 (*dynes·s/cm*^{5}).

To measure the cardiovascular parameters, instrumentation was positioned 60 minutes after the induction of anesthesia. A 20G, 4 cm over the needle catheter (D&B-Cath®, Sin Dong Bang Medical Co., Seoul, Korea) was inserted into the femoral artery and connected to a calibrated pressure transducer (TranStar® Single Monitoring Kit, MX9504, A Furon Company, Hilliard, USA). A 6-F, 10 cm introducer (Percutaneous Sheath Introducer Set, SI-09600, Arrow International Inc., Reading, USA) was placed by percutaneous puncture into left jugular vein, and a 5-F, 75 cm flow-directed thermodilution catheter (Swan Ganz, 93-132-5F) was then advanced through the introducer into the jugular vein. The distal end of the catheter was positioned in the pulmonary artery and the proximal port was positioned in the right atrium. Correct catheter placement was verified by connecting the catheter to pressure transducers and observing the characteristic pressure waveforms on an anesthetic patient monitoring system (S-3, Datex-Ohmeda, Helsinki, Finland).

Statistical Analysis

Statistical analyses of MAC of isoflurane and cardiopulmonary variables were performed using the SPSS 8.0 statistical analysis program.

In this study, experiment animals were used several time with 7 ~ 31 day washout intervals. Therefore, the mean baseline MACs were compared for dogs with different washout periods by one-way ANOVA; $p < 0.05$ was considered significant. To compare the baseline MAC and the post-EA MAC of each group, Wilcoxon's signed rank test was used. For comparison of MAC decrements among groups the Kruskal-Wallis test was used. When a difference was found significant ($p < 0.05$) among groups, the Mann-Whitney U test, which is a nonparametric t-test for independent variables, was also performed ($\alpha = 0.05$). Because of the non-Gaussian distribution of the cardiovascular variables, Friedman's test, which is a nonparametric ANOVA for repeated measures, was used to compare variables (B1.5, M1, M2, A1.5 and AM) within groups. When a difference was found to be significant between variables ($p < 0.05$), multiple comparisons were done using the Wilcoxon's signed rank test. Differences in cardiovascular variables between groups were analyzed using the Kruskal-Wallis test, and when a difference was significant ($p < 0.05$) between groups, the Mann-Whitney U test was used for the multiple comparisons ($\alpha = 0.05$).

Results

Minimum Alveolar Concentration (MAC) of Isoflurane

No significant differences in the variances of the mean baseline minimum alveolar concentrations among dogs with different washout intervals were observed (Table 1). Thirty minutes of electroacupuncture (EA) at the LI-4, SP-6, ST-36 and TH-8 acupoints significantly lowered the MACs of isoflurane ($p < 0.05$). Decrements of MAC (%) in the electroacupuncture groups were significantly different from those in controls or in the nonacupoint electrical stimulation group (Table 2).

Table 1. Analysis of variances of mean baseline minimum alveolar concentration of isoflurane among dogs with different washout period

	Sum of Squares	df[a]	Mean Square	F[b]	p
Between groups	9.894E002	13	7.611E-03	.761(NS[c])	.687
Within groups	.160	16	1.000E-02		
Total	.259	29			

[a]degree of freedom, [b]F ratio, [c]not significant at $F_{.95}$

Table 2. Effect of electroacupuncture on minimum alveolar concentration (MAC) of isoflurane in dogs (n = 5/group)

Group		MAC of Isoflurane		
		Baseline	Post treatment	Decrement(%)
Control		1.31 ± 0.06	1.27 ± 0.08	3.1 ± 4.2
NA[1]		1.21 ± 0.11	1.14 ± 0.16	5.9 ± 3.9
EA[2]	LI-4	1.32 ± 0.12	1.09 ± 0.11*	17.5 ± 3.1[a,b]
	SP-6	1.28 ± 0.13	1.01 ± 0.19*	21.3 ± 8.0[a,b]
	ST-36	1.32 ± 0.09	1.05 ± 0.06*	20.5 ± 8.2[a,b]
	TH-8	1.29 ± 0.07	1.09 ± 0.09*	15.6 ± 3.1[a,b]

Data are expressed as mean ±SD (n = 5). *significantly different from baseline MAC; Wilcoxon's signed rank test ($p < 0.05$), [a]significantly different from control group, [b]significantly different from nonacupoint electrical stimulation group; Mann-Whitney U test ($p < 0.05$), [1]nonacupoint electrical stimulation group, [2]electroacupuncture with 2 ~ 4 V and 20 Hz for 30 minutes

Cardiovascular System

After electroacupuncture treatment at the TH-8 acupoint, mean (MAP) and diastolic arterial pressures (DAP) were decreased ($p < 0.05$), systemic vascular resistance (SVR) was lower than those of the LI-4 and SP-6 groups after post-EA MAC determination (AM) ($p < 0.05$) (Fig. 3, Fig. 5, Table 5). In the LI-4 group, the cardiac output (CO) and the cardiac index (CI) were lowered by electroacupuncture (A1.5) ($p < 0.05$), but no significant differences were observed between groups (Table 9, Fig. 4). No significant differences within or between groups were found in terms of heart rate (HR), systolic arterial pressure (SAP), right atrial pressure (RAP), pulmonary arterial pressure (PAP), pulmonary arterial wedge pressure (PAWP), stroke index (SI) or pulmonary vascular resistance (PVR) (Tables 3, 4, 6, 7, 8, 10 and 11).

In the ST-36 group, no significant differences were observed for any cardiovascular parameter.

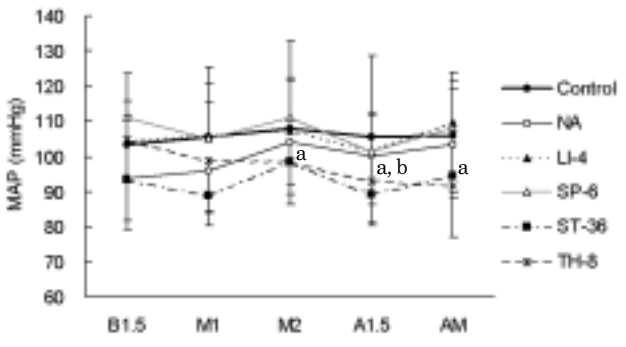

Fig. 3. Effect of electroacupuncture on mean arterial pressure (MAP) in isoflurane anesthetized dogs
Data are expressed as mean ±SD (n = 5). [a]significantly different from B1.5 within group, [b]significantly different from M1 within group; Wilcoxon"s signed rank test ($p < 0.05$)

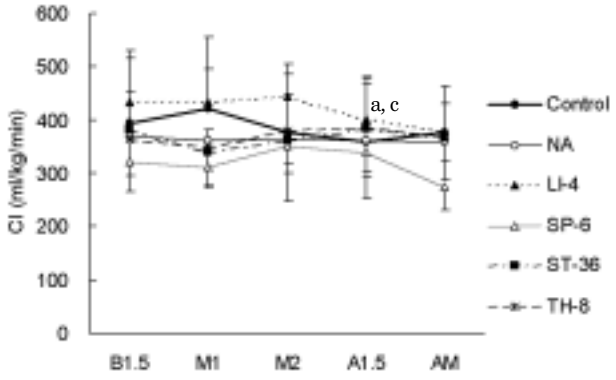

Fig. 4. Effect of electroacupuncture on cardiac index (CI) in isoflurane anesthetized dogs
Data are expressed as mean ± SD (n = 5). [a]significantly different from B1.5 within group, [c]significantly different from M2 within group; Wilcoxon"s signed rank test ($p < 0.05$)

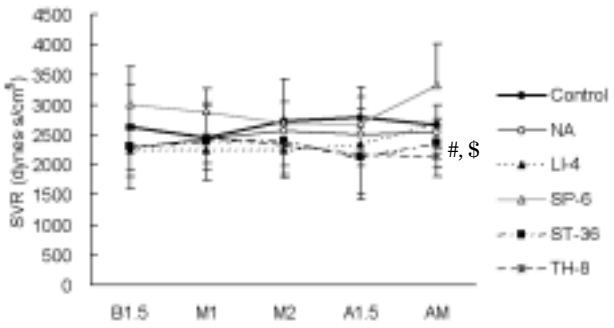

Fig. 5. Effect of electroacupuncture on systemic vascular resistance (SVR) in isoflurane anesthetized dogs
Data are expressed as mean ± SD (n = 5). #significantly different from LI-4 group, $significantly different from SP-6 group; Mann-Whitney U test ($p<0.05$)

Table 3. Effect of electroacupuncture on heart rate (HR) in isoflurane anesthetized dogs

Group		HR(bpm)				
		B1.5[a]	M1[b]	M2[c]	A1.5[d]	AM[e]
Control		170 ± 22	170 ± 26	158 ± 21	158 ± 24	156 ± 20
NA		160 ± 15	153 ± 18	155 ± 24	155 ± 26	147 ± 17
EA	LI-4	170 ± 25	175 ± 16	173 ± 15	173 ± 15	152 ± 17
	SP-6	148 ± 32	151 ± 22	150 ± 22	150 ± 25	160 ± 20
	ST-36	163 ± 25	145 ± 14	162 ± 18	162 ± 10	139 ± 10
	TH-8	150 ± 28	150 ± 11	150 ± 24	150 ± 33	133 ± 19

Data are expressed as mean ± SD (n = 5). [a]before determination of 1st MAC, [b]after determination of 1st MAC, [c]after determination of 2nd MAC, [d]after electroacupuncture, [e]after determination of post-EA MAC

Table 4. Effect of electroacupuncture on systolic arterial pressure (SAP) in isoflurane anesthetized dogs

Group		SAP(mmHg)				
		B1.5	M1	M2	A1.5	AM
Control		152 ± 16	150 ± 19	146 ± 23	143 ± 23	152 ± 22
NA		136 ± 17	137 ± 14	150 ± 15	141 ± 6	148 ± 17
EA	LI-4	147 ± 7	147 ± 13	146 ± 21	144 ± 23	152 ± 17
	SP-6	161 ± 22	155 ± 18	167 ± 17	146 ± 14	160 ± 20
	ST-36	139 ± 17	129 ± 7	141 ± 11	128 ± 8	139 ± 10
	TH-8	150 ± 12	140 ± 15	143 ± 10	138 ± 12	133 ± 19

Data are expressed as mean ± SD.

Table 5. Effect of electroacupuncture on diastolic arterial pressure (DAP) in isoflurane anesthetized dogs

Group		DAP(mmHg)				
		B1.5	M1	M2	A1.5	AM
Control		79 ± 13	83 ± 23	89 ± 27	87 ± 24	83 ± 13
NA		73 ± 15	75 ± 13	81 ± 13	80 ± 19	81 ± 13
EA	LI-4	83 ± 8	85 ± 21	88 ± 18	80 ± 5	88 ± 8
	SP-6	86 ± 9	80 ± 6	84 ± 9	80 ± 11	83 ± 15
	ST-36	71 ± 12	68 ± 9	77 ± 9	70 ± 11	73 ± 7
	TH-8	72 ± 12	78 ± 14	76 ± 14[a]	70 ± 12[a,b]	71 ± 12[b]

Data are expressed as mean ±SD (n = 5). [a]significantly different from B1.5 within group, [b]significantly different from M1 within group; Wilcoxon's signed rank test ($p < 0.05$)

Table 6. Effect of electroacupuncture on right atrial pressure (RAP) in isoflurane anesthetized dogs

Group		RAP(mmHg)				
		B1.5	M1	M2	A1.5	AM
Control		0.2 ± 1.1	0 ± 0.7	0.2 ± 0.8	0 ± 1.0	0 ± 1.0
NA		0.6 ± 0.5	-0.2 ± 1.8	1.4 ± 0.9	0.4 ± 2.3	0.8 ± 1.6
EA	LI-4	-0.2 ± 1.8	0.4 ± 2.8	-0.6 ± 2.8	0.2 ± 2.3	0 ± 2.3
	SP-6	1.2 ± 1.3	1.4 ± 1.3	0.8 ± 1.1	0.4 ± 1.3	1.2 ± 1.3
	ST-36	1.2 ± 1.6	1.2 ± 1.5	1.0 ± 1.2	0.8 ± 1.1	1.0 ± 1.6
	TH-8	1.6 ± 1.5	1.2 ± 1.8	0.8 ± 1.8	2.4 ± 0.5	1.6 ± 1.5

Data are expressed as mean ±SD.

Table 7. Effect of electroacupuncture on pulmonary arterial pressure (PAP) in isoflurane anesthetized dogs

Group		PAP(mmHg)				
		B1.5	M1	M2	A1.5	AM
Control		16.8 ± 5.3	16.8 ± 3.8	15.8 ± 3.0	15.0 ± 3.4	15.4 ± 3.5
NA		15.2 ± 1.5	14.2 ± 1.6	15.0 ± 0	13.8 ± 0.8	15.2 ± 1.1
EA	LI-4	15.6 ± 3.7	16.4 ± 4.2	16.0 ± 3.7	16.0 ± 3.5	15.2 ± 4.1
	SP-6	18.4 ± 4.0	18.4 ± 3.8	17.4 ± 3.5	16.8 ± 2.6	16.8 ± 3.6
	ST-36	16.8 ± 4.8	16.2 ± 3.9	16.8 ± 3.6	16.4 ± 3.2	14.6 ± 2.3
	TH-8	16.8 ± 3.2	16.2 ± 1.8	15.4 ± 1.9	15.8 ± 2.6	15.6 ± 1.3

Data are expressed as mean ±SD.

Table 8. Effect of electroacupuncture on pulmonary arterial wedge pressure (PAWP) in isoflurane anesthetized dogs

Group		PAWP(mmHg)				
		B1.5	M1	M2	A1.5	AM
Control		4.4 ± 2.4	4.2 ± 1.8	3.8 ± 1.3	3.6 ± 1.1	3.4 ± 1.7
NA		5.2 ± 0.4	4.0 ± 1.2	5.2 ± 0.8	4.6 ± 0.9	4.2 ± 0.8
EA	LI-4	4.6 ± 3.2	4.6 ± 2.8	4.8 ± 2.2	4.8 ± 2.8	4.8 ± 1.9
	SP-6	6.2 ± 2.2	5.6 ± 1.8	5.8 ± 2.2	5.8 ± 2.6	5.8 ± 2.7
	ST-36	5.6 ± 0.5	5.4 ± 1.3	5.8 ± 1.3	6.0 ± 1.8	6.0 ± 1.8
	TH-8	6.2 ± 1.9	5.8 ± 1.1	5.8 ± 1.5	6.2 ± 1.1	6.4 ± 1.7

Data are expressed as mean ±SD.

Table 9. Effect of electroacupuncture on cardiac output (CO) in isoflurane anesthetized dogs

Group		CO(L/min)				
		B1.5	M1	M2	A1.5	AM
Control		3.35 ± 1.02	3.58 ± 1.10	3.20 ± 0.89	3.08 ± 0.95	3.23 ± 0.81
NA		3.33 ± 0.78	3.26 ± 0.68	3.27 ± 0.61	3.25 ± 0.64	3.22 ± 0.35
EA	LI-4	3.77 ± 0.65	3.78 ± 0.58	3.86 ± 0.49	3.50 ± 0.63[a,c]	3.30 ± 0.48
	SP-6	3.08 ± 0.68	2.88 ± 0.45	3.41 ± 1.18	3.17 ± 1.02	2.53 ± 0.48
	ST-36	3.38 ± 0.90	3.03 ± 0.57	3.31 ± 0.54	3.43 ± 0.82	3.29 ± 0.78
	TH-8	3.32 ± 0.85	3.17 ± 0.28	3.47 ± 0.82	3.51 ± 0.82	3.33 ± 0.41

Data are expressed as mean ±SD (n = 5). [a]significantly different from B1.5 within group, [c]significantly different from M2 within group; Wilcoxon's signed rank test ($p < 0.05$)

Table 10. Effect of electroacupuncture on stroke index (SI) in isoflurane anesthetized dogs

Group		SI(ml/kg)				
		B1.5	M1	M2	A1.5	AM
Control		2.28 ± 0.57	2.45 ± 0.56	2.38 ± 0.51	2.28 ± 0.66	2.41 ± 0.45
NA		2.30 ± 0.30	2.37 ± 0.32	2.47 ± 0.18	2.35 ± 0.25	2.46 ± 0.25
EA	LI-4	2.53 ± 0.15	2.47 ± 0.21	2.49 ± 0.18	2.31 ± 0.26	2.36 ± 0.30
	SP-6	2.22 ± 0.27	2.09 ± 0.18	2.16 ± 0.42	2.25 ± 0.29	2.23 ± 0.29
	ST-36	2.31 ± 0.38	2.35 ± 0.39	2.37 ± 0.40	2.37 ± 0.43	2.56 ± 0.36
	TH-8	2.44 ± 0.38	2.33 ± 0.13	2.59 ± 0.27	2.58 ± 0.09	2.53 ± 0.24

Data are expressed as mean ±SD.

Table 11. Effect of electroacupuncture on pulmonary vascular resistance (PVR) in isoflurane anesthetized dogs

Group		PVR(dynes s/cm^5)				
		B1.5	M1	M2	A1.5	AM
Control		291 ± 53	282 ± 59	302 ± 44	300 ± 53	296 ± 46
NA		244 ± 24	258 ± 53	243 ± 28	230 ± 22	275 ± 24
EA	LI-4	231 ± 30	248 ± 37	230 ± 38	251 ± 31	248 ± 60
	SP-6	323 ± 95	350 ± 100	300 ± 120	287 ± 104	326 ± 44
	ST-36	258 ± 41	283 ± 75	236 ± 39	310 ± 161	255 ± 07
	TH-8	257 ± 40	263 ± 34	228 ± 45	223 ± 24	224 ± 53

Data are expressed as mean ±SD.

Discussion

Minimum alveolar concentration (MAC) has units of percentage per atmosphere, and therefore, is an alveolar anesthetic partial pressure. MAC should represent the anesthetic partial pressure at the site of action, the brain. An end-tidal anesthetic concentration is held at a constant level for at least 15 minutes in an attempt to reach equilibrium between the alveolar gas (end-tidal), the arterial blood and brain. The determination of MAC has three basic components: the applied noxious stimulus, a defined response and the measurement of end-tidal anesthetic concentration [20]. In the present study, the mean baseline isoflurane MACs of the six groups were 1.29 ±0.09. This result is similar to that of Steffey (1.28, 1.30 or 1.39) [23].

A number of studies have been performed to determine whether the MAC may be affected by certain conditions, such as the duration of anesthesia, sex, age, $PaCO_2$, PaO_2, pH, blood pressure, body temperature, sedatives, or neurotransmitters [5, 20]. In the present study, most of the conditions that might affect the MAC were controlled.

We found that electroacupuncture (EA) at each acupoint lowered the MAC of isoflurane by about 20% in dogs, but that the decrements in MAC values of EA groups were not significantly different from each other. This result is similar to that of a report, which described the effect of EA at SP-6

during halothane anesthesia in dogs [27]. MAC corresponds to the ED_{50}. The dose that corresponds to ED_{95}, in a human study, was found to be 20 ~ 40% greater than MAC [23]. A 20% reduction of MAC could imply that anesthesia might be produced in 95% of patients receiving the original MAC (ED_{50}) of the anesthetic.

EA reduced the MAC of halothane in dogs [27]. Tay *et al.* [26] investigated the mechanism of EA in terms of reducing the MAC of halothane, and found that a MAC decreased by high frequency (200 Hz) EA was not reversed by naloxone,an endorphin antagonist. However, the analgesic effect of high frequency EA was partially blocked by serotonin synthesis inhibitor [1]. In the present study, EA was performed at LI-4, SP-6, ST-36 and TH-8 at intermediate frequency (20 Hz), and was found to lower the MAC of isoflurane in dogs. Fei *et al.* [6] reported differences in the production of endorphins following EA at different frequencies. Methionine enkephalin concentrations increased after EA at low (2 Hz) and intermediate (15 Hz) frequencies. After EA at high frequency dynorphin levels increased but enkephalin levels were unaltered. Enkephalin is released from periaqueductal gray (PAG) and activates the raphe descending inhibitory system, which blocks spinal cord pain transmission by releasing monoamines, 5-HT and norepinephrine (NE), thereby causes analgesia [9].

Philbin and Lowenstein reported that the cardiovascular changes observed after isoflurane anesthesia are caused by the beta-adrenergic stimulation [19]. In the present study, mean and diastolic arterial pressure and systemic vascular resistance were decreased in the TH-8 group. Decrease in blood pressure might have been caused by the change in SVR [21]. From these results, EA at TH-8 might be limited in terms of its use with isoflurane anesthesia in dogs, although a MAC lowering effect was observed.

In the LI-4 group, the cardiac output and cardiac index decreased after EA. Scheeren *et al.* [21] reported that cardiac output was reduced and that this was followed by a decreased oxygen demand after isoflurane anesthesia. However, arterial pressure was maintained due to an increased SVR. Lin *et al.* [12] reported that EA at 2 and 20 Hz for 10 minutes at the LI-4 acupoint in rats elevated the blood pressure and found that these were blocked by regitine injection, which shows that EA at LI-4 selectively activates the sympathetic nervous system. In the present study, EA at ST-36 did not produce significant changes in the cardiovascular system. However, there are some reports that EA at ST-36 lowers blood pressure in dogs with different mechanisms [11, 13]. Li *et al.* [13] reported that inhibiting the sympathetic vascular tone by EA at ST-36 lowered blood pressure without changing the heart rate, whereas Lee *et al.* [11] reported that the major role of decreasing the blood pressure was decreased cardiac output, caused by decreased stroke volume mediated by increased parasympathetic input. Further studies should be undertaken to clarify the effect of EA at ST-36.

In the present study, the effects of 30 minutes of EA treatment were observed at each acupoint on MAC and on the cardiopulmonary system under isoflurane anesthesia in dogs. However, it should be noted that many investigators have used two or more acupoints simultaneously for acupuncture anesthesia [8, 9, 18, 30]. Further studies should be undertaken upon the effects of EA at multiple acupoints on the MAC of isoflurane.

Summarizing, EA at LI-4, SP-6 and ST-36 offer an advantage in isoflurane anesthesia by reducing isoflurane requirements and minimizing the associated cardiopulmonary side effects. However, EA at TH-8 might be limited in combination with isoflurane anesthesia despite the MAC lowering effect.

The present study is limited in terms of its ability to predict changes in the cardiovascular system at higher MACs in combination with EA, i.e., at levels sufficient for surgical anesthesia. Studies on the effects of electroacupuncture on cardiovascular system at the higher MACs should be performed.

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