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Increases in Hemodynamic Variables and Catecholamine Levels after Rapid Increase in Isoflurane Concentration

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Background: **Ventilation of the lungs with isoflurane in nitrous oxide and oxygen has been shown to increase the plasma concentration of norepinephrine. Whether this increase is related to the tachycardia and increased arterial blood pressures, seen following a sudden increase in the concentration of isoflurane, was tested in humans.**

Methods: **Twenty-two healthy patients in whom the trachea was intubated were given 15 min of stable isoflurane-O_2-air anesthesia [end-tidal concentration of isoflurane (ET_{Iso}) of 1.3%] (baseline). Patients were then randomly allocated to one of two groups. For 13 "Iso_{High}" patients, the inspired concentration of isoflurane was increased abruptly. In those patients, the ET_{Iso} was kept at 2.6% for 10 min, *i.e.*, until the end of the study, after which the depth of anesthesia was reduced. For nine "Iso_{Low}" control patients, the ET_{Iso} level of 1.3% was continued until the end of the study. Heart rate, arterial pressures, catecholamine levels, and end-tidal concentration of CO_2 were recorded at baseline and at 1, 1.5, 2, 4, 6, and 10 min after increase in isoflurane.**

Results: **Iso_{High} patients showed significant increases in heart rate (40%, from 84.6 to 118.1 beats/min), systolic arterial pressure (SAP, 23%, from 96.4 to 118.3 mmHg), and diastolic arterial pressure (DAP, 30%, from 53.9 to 70.0 mmHg); all three variables peaked at 2 min. Significant increases occurred also in norepinephrine levels (80%, from 0.342 to 0.615 ng/ml) and in end-tidal concentration of CO_2 (from 4.22% to 4.43%), both of which peaked at 4 min. Epinephrine levels did not increase significantly, although significant differences were seen between Iso_{High} and Iso_{Low} patients during the trial. Iso_{Low} patients had no changes in these variables.**

Conclusions: **A sudden increase in isoflurane concentration is associated with a transient but clinically significant increase in heart rate, arterial pressures, and norepinephrine concentration. (Key words: Anesthetics, volatile: isoflurane. Heart: tachycardia. Sympathetic nervous system: catecholamines; epinephrine; norepinephrine.)**

ISOFLURANE is known to increase heart rate (HR),[1] causing significant tachycardia during induction of anesthesia given by face mask to children.[2] After induction with thiopental, and then ventilation with isoflurane, nitrous oxide, and oxygen by mask, the plasma concentration of norepinephrine increases in adults.[3] Plasma levels of catecholamines are increased during isoflurane-induced controlled hypotension, when opioid analgesics are not used.[4] With opioids, stable isoflurane anesthesia used for controlled hypotension does not increase plasma catecholamines.[5]

In our experience, when the isoflurane concentration is increased rapidly in adults, tachycardia and an increase in arterial pressures often ensue. This phenomenon may be associated with catecholamine release. Therefore, we studied the effect of an increase in isoflurane concentration on hemodynamic variables and catecholamine levels in healthy patients. Patients receiving a constant level of isoflurane served as controls.

Patients and Methods

Twenty-two ASA physical status 1 patients undergoing elective minor surgery participated in the study (table 1). The Ethics Committee of the Fourth Department of Surgery approved the study protocol, and each patient provided written informed consent.

Anesthesia

Oxazepam, 15–30 mg orally, was given the night before surgery, and diazepam, 0.2 mg/kg orally, 90 min

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Table 1. Patient Characteristics

Group	N	Sex (M/F)	Age* (yr)	Weight* (kg)	Height* (cm)
Iso_{High}	13	5/8	31 ± 9	68 ± 15	170 ± 13
Iso_{Low}	9	4/5	30 ± 8	68 ± 15	173 ± 8

* Values are mean ± SD.

before anesthesia. In the operating room, a peripheral intravenous catheter was inserted into a cubital vein. A radial artery was cannulated for continuous monitoring of arterial pressures (Cardiocap Ultima®, Datex, Finland). A basilic vein was cannulated, and a 70-cm catheter was introduced into the right ventricle of the heart (location verified by pressure waveform, Cardiocap Ultima®). We applied local anesthetic cream (EMLA®, Astra, Sweden) to all puncture sites 90 min before cannulations. Patients rested for 20 min after cannulations. Continuous monitoring of lead CB_5 of the electrocardiogram was started. The electrocardiogram was printed out throughout the study period, and hemoglobin oxygen saturation (Sp_{O_2}) by pulse oximetry was recorded.

We administered 2.5 mg/kg propofol for induction of general anesthesia and 0.1 mg/kg vecuronium to provide muscle relaxation. No anticholinergic drug was given. After tracheal intubation, the lungs were ventilated mechanically with a mixture of oxygen and air at a fractional inspired concentration of oxygen of 0.35. We used a semi-open circuit system (Servo® 900 B ventilator, Siemens Elema, Sweden) at a fresh gas flow of 10L/min. Maintenance of anesthesia consisted of administration of isoflurane sufficient to produce an end-tidal concentration of isoflurane (ET_{Iso}) of 1.3% and mild hypocapnia end-tidal concentration of carbon dioxide (ET_{CO_2}) of 4.2%, Cardiocap Ultima®]. For each patient, the gas monitor was calibrated with a known concentration of CO_2 (5.0 vol%) and enflurane (3.0 vol%; Quick Cal™ ®, Datex, Finland). After stable isoflurane anesthesia for 15 min (baseline), patients were allocated randomly to one of two groups.

For 13 "Iso_{High}" patients, we increased the inspired concentration of isoflurane to 5%, the goal being to produce an ET_{Iso} of 2.6%. The end-tidal level of 2.6% was maintained until the end of the study by adjusting the vaporizer setting, when necessary. Heart rate, SAP and DAP, and ET_{CO_2} were recorded at baseline and at 1, 1.5, 2, 4, 6, and 10 min after increasing the concentration of isoflurane. After 10 min, depth of anesthesia was lightened. For the other nine patients (the "Iso_{Low}" group, controls), ET_{Iso} was kept at 1.3%, and the same variables were recorded at parallel time. The study was completed before surgery. For determination of catecholamine levels, mixed venous blood samples were drawn from the right ventricle of the heart at these same time points and were placed in prechilled tubes containing ethylenediaminetetraacetic acid (EDTA). The samples were immersed immediately in ice, centrifuged at 0° C, and stored at −70° C.

Catecholamine Assay

Plasma concentrations of norepinephrine and epinephrine were determined in duplicates by high-pressure liquid chromatography using electrochemical detection (ESA Coulochem 5100A, Bedford, MA). The method is a modification from Seppälä *et al.*[6] Catecholamines were extracted with activated aluminum (Merck, Darmstadt, Germany), and dihydroxybenzamine was used as an internal standard. The aqueous mobile phase contained 0.03 mol/l of monochloroacetic acid, 0.03 mol/L of Na_3PO_4, 120 mg/L of octanylsulphonic acid, and 25 mg/L of Na-EDTA (pH 2.55, adjusted with phosphoric acid). A reversed-phase Zorbax ODS C_{18} column (Rockland Tech., Newport, DE) was used. Detection limits for norepinephrine and epinephrine were 0.03 and 0.015 ng/ml, respectively. The method has intra-assay coefficients of variation of approximately 4% for norepinephrine and 10% for epinephrine in the physiologic concentration ranges.

Statistical Analyses

Data were analyzed using Wilcoxon matched-pairs, signed-rank test to compare differences within groups, and the Mann-Whitney-U test to compare differences between groups. Regression analysis was drawn for the relationship between the changes in catecholamine concentrations and hemodynamic parameters. Data are presented as means ± SD. A P value less than .05 was considered statistically significant.

Results

The study groups were comparable with regard to sex, age, weight, and height (table 1). By 2 min after abrupt increase in isoflurane, ET_{Iso} had increased to 2.5 ± 0.16% in Iso_{High} patients.

Figures 1–3 show that hemodynamic variables increased significantly in Iso_{High} patients, peak values occurring at 2 min: compared with baseline, HR increased 40%; SAP, 23%; and DAP, 30%, on average. (For one Iso_{High} patient, HR increased from 87 to 160 beats/min

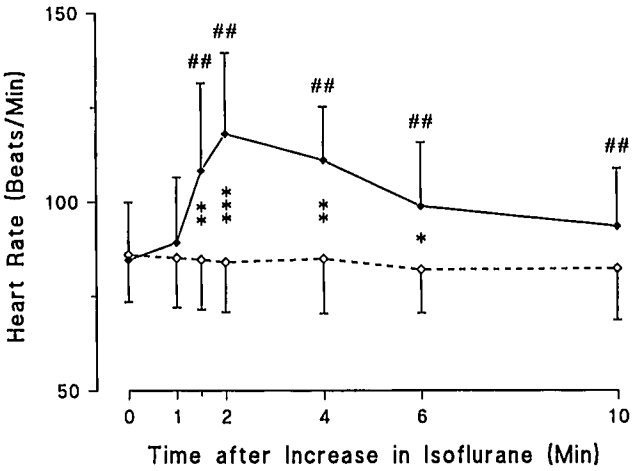

Fig. 1. Heart rate at six time points for 22 patients given one of two levels of isoflurane. Both groups first had 15 min of stable isoflurane anesthesia end-tidal concentration (ET_{Iso}) of 1.3%]; the end of this period is represented by 0 on the time scale (baseline). Nine control patients (the Iso_{Low} group, ◇---◇) continued receiving this constant level of isoflurane for 10 min more, *i.e.*, until the end of the study. Thirteen other patients (the Iso_{High} group, ♦—♦) had an abrupt increase in the inspired concentration of isoflurane, the goal being to produce an ET_{Iso} of 2.6%. Ten minutes later, anesthesia was lightened. Values are means ± SD. Differences between groups were significant at the following *P* levels: <.05,* <.01, and <.001,*** as determined by the Mann-Whitney U test. Differences within the Iso_{High} group from baseline were significant at *P* < .01,## as determined by Wilcoxon matched-pairs signed-rank test.**

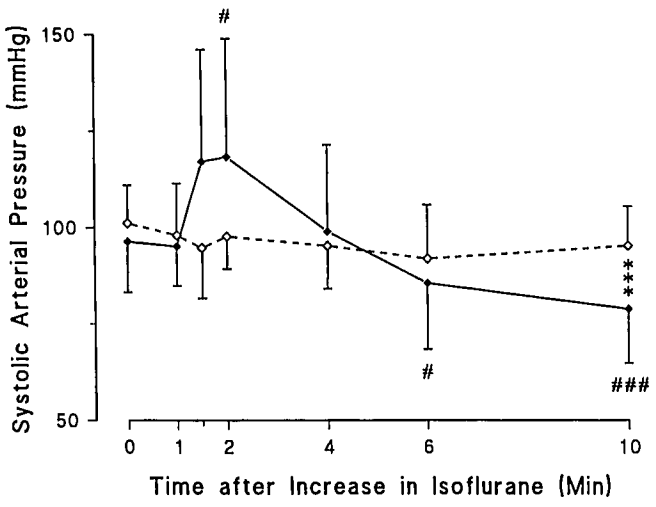

Fig. 2. Systolic arterial pressure for Iso_{High} and Iso_{Low} patients (see legend for fig. 1). Differences between groups were significant at *P* < .001.* Differences within the Iso_{High} group from baseline were significant at the following *P* levels: <.05# and <.001.###**

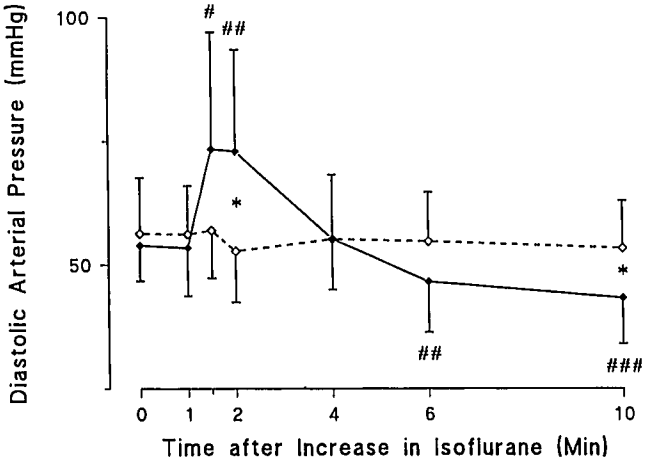

Fig. 3. Diastolic arterial pressure for Iso_{High} and Iso_{Low} patients (see legend for fig. 1). Differences between groups were significant at *P* < .05.* Differences within the Iso_{High} group from baseline were significant at the following *P* levels: <.05,# <.01,## and <.001.###

and arterial pressures from 124/64 to 171/105 mmHg.) Iso_{Low} patients had no change in hemodynamic variables (figs. 1–3). Except for the sinus tachycardia in Iso_{High} patients, no cardiac arrhythmias were discernible in any patient.

Changes in catecholamine levels are shown in figures 4 and 5. For Iso_{High} patients, epinephrine levels were highest at the 2-min recording, but the change from baseline was not statistically significant. The plasma epinephrine concentrations did correlate, however,

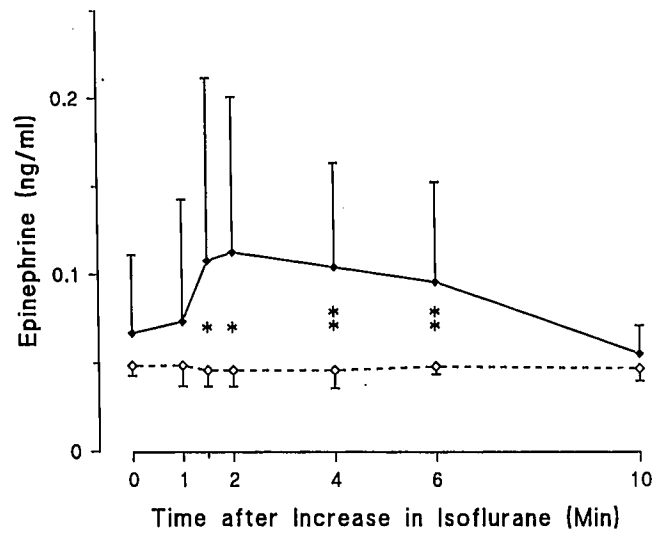

Fig. 4. Plasma epinephrine levels for Iso_{High} and Iso_{Low} patients (see legend for fig. 1). Differences between groups were significant at the following *P* levels: <.05* and <.01.**

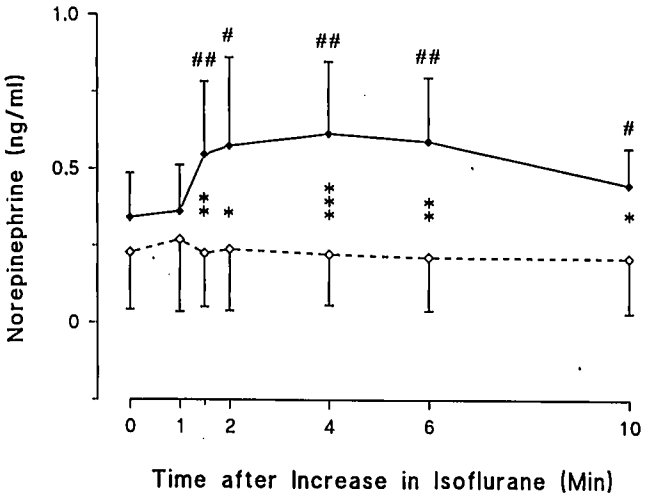

Fig. 5. Plasma norepinephrine levels for Iso_{High} and Iso_{Low} patients (see legend for fig. 1). Differences between groups were significant at the following *P* levels: <.05,* <.01, and <.001.*** Differences within the Iso_{High} group from baseline were significant at the following *P* levels: <.05# and <.01.##**

with the increase in HR (r = 0.6909, $P < .05$; table 2). Iso_{Low} patients had no change in epinephrine levels. The difference between mean values of epinephrine in the two groups was significant in data points from 1.5 to 6 min. In Iso_{High} patients, norepinephrine levels were highest at the 4-min recording, and the increase (80%) was significant ($P < .01$). This increase correlated well with changes in arterial pressures (table 2). In Iso_{Low} patients, the plasma norepinephrine levels remained stable, and the difference between the two groups was significant in data points from 1.5 to 10 min.

Table 3 shows ET_{CO_2} and Sp_{O_2} during the trial. For Iso_{High} patients, ET_{CO_2} increased from 4.22 ± 0.51% to its maximum, 4.43 ± 0.58% ($P < .01$), at 4 min and decreased to 4.27 ± 0.46% at 10 min. Increases in ET_{CO_2} were associated with increases in plasma concentrations of epinephrine (r = 0.5596, $P < .05$). For Iso_{Low} patients, ET_{CO_2} varied from 4.13% to 4.24%. Sp_{O_2} remained above 94% for every patient throughout the study.

Discussion

The present study shows that when depth of isoflurane anesthesia is increased abruptly, HR, arterial pressures, and plasma concentrations of norepinephrine also increase. These changes did not occur in control patients given a stable concentration of isoflurane.

Isoflurane anesthesia is associated with marked vasodilatation,[7,8] which, under normal conditions, is compensated for by tachycardia. There are several explanations regarding the cause of tachycardia. Some believe that the baroreflex function is almost normal during isoflurane anesthesia.[9] At the least, baroreflex function is depressed during isoflurane anesthesia,[10] but less so than during enflurane or halothane anesthesia.[11] In this study, baroreflex activation would not seem likely since arterial blood pressure also was increased. Another possible explanation for tachycardia is beta-sympathomimetic activation: because isoflurane depresses parasympathetic activity to a greater extent than sympathetic activity, sympathetic function remains more intact and causes tachycardia.[12]

The mechanism of sympathoadrenal activation in our study is not clear. Isoflurane is an irritating vapor,[13] producing laryngospasm and breath-holding in pediatric patients during induction of anesthesia by face mask.[14] In a recent study by Nishino *et al.*,[15] nasal insufflation of 5% enflurane, isoflurane, or halothane were associated with prolongation of expiratory time of spontaneous ventilation, and an increase in laryngeal wall tension. Topical lidocaine applied to the nasal mucosa abolished these airway reflexes. Coleridge *et al.*[16] have shown that high concentrations of halothane, ether, chloroform, or trichloroethylene produce an immediate excitation of pulmonary stretch receptors, followed by a marked depression of receptor activity. Unfortunately, they did not report the changes in hemodynamics. In the present study, the receptors of upper airways were passed using tracheal intubation. Lungs, however, are rich in sensory afferent nerve endings, some of which may be the source of sympathoadrenal reflex responses presented here.

The results obtained in the present study are in accordance with our earlier findings,[3] *i.e.*, that ventilation by mask with isoflurane in nitrous oxide and oxygen increased the plasma concentration of norepinephrine.

Table 2. Correlations between Catecholamine Plasma Concentrations and Hemodynamic Parameters from Baseline to 2 min in Patients in Whom the Isoflurane Concentration Was Increased Abruptly

	Correlation (*r*)	*P*
Epinephrine *vs.* HR	0.6909	<.05
Norepinephrine *vs.* SAP	0.8273	<.01
Norepinephrine *vs.* DAP	0.8412	<.001

HR = heart rate; SAP = systolic arterial pressures; DAP = diastolic arterial pressures.

Table 3. ET_{CO_2} and Hemoglobin Oxygen Saturation for Iso_{High} and Iso_{Low} Patients*

		Time after Abrupt Increase in Concentration of Isoflurane (min)					
	Baseline	1	1.5	2	4	6	10
ET_{CO_2} (%)							
Iso_{High}	4.22 ± 0.51	4.25 ± 0.50	4.26 ± 0.53	4.32 ± 0.54†	4.43 ± 0.58‡	4.40 ± 0.53†	4.27 ± 0.46
Iso_{Low}	4.24 ± 0.34	4.2 ± 0.33	4.21 ± 0.31	4.23 ± 0.36	4.19 ± 0.36	4.18 ± 0.36	4.13 ± 0.33
Sp_{O_2} (%)							
Iso_{High}	98 ± 1.0	98.3 ± 0.9	98.5 ± 0.7	98.3 ± 0.8	98.3 ± 0.8	97.9 ± 1.2	97.9 ± 1.5
Iso_{Low}	97.4 ± 0.9	97.4 ± 0.9	97.3 ± 1.0	97.2 ± 1.1	97.3 ± 1.0	97.4 ± 0.9	97.4 ± 0.9

Values are mean ± SD.

ET_{CO_2} = end-tidal concentration of carbon dioxide; Sp_{O_2} = hemoglobin oxygen saturation.

* Twenty-two surgical patients were given 15 min of stable isoflurane anesthesia [end-tidal concentration of isoflurane (ET_{Iso}) of 1.3%]; the end of this period is baseline. Then, for nine of these patients (the control Iso_{Low} group), isoflurane was continued at this level for 10 more min. The other 13 patients (the Iso_{High} group) were given an abrupt increase in isoflurane, the goal being to produce an ET_{Iso} of 2.6%. Ten minutes later, isoflurane was decreased.

† $P < .05$ *versus* baseline (as determined by Wilcoxon's test).

‡ $P < .01$ *versus* baseline (as determined by Wilcoxon's test).

Nitrous oxide has been shown to augment sympathetic outflow,[17] and nitrous oxide also decreases removal of norepinephrine from the pulmonary circulation.[18] Our previous results may be influenced at least partly by nitrous oxide. In the present study, however, nitrous oxide was not used. These results are also similar to those from a recent paper in which HR and arterial blood pressure increased in patients breathing high inspired concentrations of desflurane.[19]

The method used here was unusual and specific to this particular study. The responses seen in these patients may not be the same in patients who have received opioids,[5] nitrous oxide,[17,18] or other drugs. We used a semi-open circuit anesthesia system to evaluate the phenomenon. The concentration of isoflurane would have changed more slowly with a semi-closed system (low fresh gas flow), and the sympathoadrenal response presented here might have been smaller. Also, to avoid the increases in plasma levels of catecholamines caused by hypercarbia,[20] the lungs of our patients were hyperventilated slightly. ET_{CO_2} increased in Iso_{High} patients (maximum value at 4 min), likely reflecting the increase in cardiac output,[21] in turn associated with the catecholamine release.[22] No patient became hypercarbic or hypoxic during the study.

The lungs selectively take up catecholamines, especially norepinephrine, to a significant extent.[23,24] Derbyshire *et al.*[25] observed higher concentrations of catecholamines in central venous blood than in arterial or peripheral venous blood. Therefore, to determine the level of these substances in plasma, we took samples of mixed venous blood from the right ventricle of the heart.

In conclusion, rapid increase in the inspired concentration of isoflurane causes sympathoadrenal activation and an associated hemodynamic response. This sequence could be misinterpreted by a clinician who expects deepening of anesthesia but sees, instead, an increase in HR, arterial pressures, and ET_{CO_2}. We believe that activation of sympathoadrenal system may be caused by the irritating effect of isoflurane on the airways. Also, an unknown autonomic control mechanism may be involved.

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