

**Effect of charcoal filter on recovery  
from inhalation anesthesia  
in a semiclosed rebreathing circuit**

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**Effect of charcoal filter on recovery  
from inhalation anesthesia  
in a semiclosed rebreathing circuit**

**Directed by Professor Wyun Kon Park**

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degree of Master of Medical Science**

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## **Abstract**

### **Effect of charcoal filter on recovery from inhalation anesthesia in a semiclosed rebreathing circuit**

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Activated charcoal has the ability to adsorb a wide variety of substances. This property can be used to prevent the gastrointestinal absorption of various drugs and toxins and to facilitate their elimination, even after systemic absorption. In many previous studies, charcoal has also been shown to adsorb halothane or isoflurane efficiently and thus hasten anesthetic recovery. Recently, sevoflurane and desflurane have been used more frequently because they have a lower solubility than do halothane or isoflurane. In the present study, we evaluated the efficiency of charcoal filters in eliminating sevoflurane and desflurane during recovery from inhalation anesthesia in a semiclosed circuit. Bispectral index (BIS) values were monitored to evaluate the patients' hypnotic states over the duration of this study.

After obtaining informed consent, sixty healthy patients were randomly assigned to one of four groups: the sevoflurane control (without charcoal filter) group, the sevoflurane with charcoal filter group, the desflurane control group, or the desflurane with charcoal filter group. Anesthesia was induced with 2  $\mu\text{g}/\text{kg}$  of fentanyl, 5  $\text{mg}/\text{kg}$  of thiopental sodium, and 0.6  $\text{mg}/\text{kg}$  of rocuronium. During maintenance of anesthesia, ventilation was controlled to maintain normocapnia, and BIS values were adjusted between 40 and 50. At the end of

surgery, a charcoal filter was attached to the expiratory limb of the breathing circuit of charcoal filter group subjects. After inhaled anesthetics were discontinued, ventilation was controlled with the same minute volume as the intra-operative period and at a fresh gas flow rate of 5 L/min with 100% O<sub>2</sub>. From this time, BIS, inspiratory, and end-tidal anesthetic concentrations were recorded every 30 seconds. The times from discontinuing the anesthetic to obeying commands, such as eye opening, and to extubation were recorded.

For the sevoflurane group, use of a charcoal filter resulted in more rapid eye opening ( $11.1 \pm 3.8$  vs.  $14.8 \pm 3.0$  min) and shorter extubation time ( $11.9 \pm 3.9$  vs.  $15.3 \pm 3.2$  min) compared with those of the control group. For the desflurane group, eye opening ( $6.2 \pm 1.4$  vs.  $10.3 \pm 1.7$  min) and extubation ( $6.7 \pm 1.4$  vs.  $10.5 \pm 1.1$  min) also occurred more rapidly in the charcoal filter group than in the control group. There were no differences in BIS values at the time of eye opening between the control and charcoal filter groups for both inhaled anesthetics. The exponential time constant ( $\tau$ ) of alveolar anesthetic concentration in the charcoal filter group was significantly shorter than that in the control group for both sevoflurane ( $1.7 \pm 0.5$  vs.  $2.5 \pm 1.1$  min) and desflurane ( $1.4 \pm 0.3$  vs.  $2.0 \pm 0.3$  min).

A charcoal filter attached to the expiratory limb of the semiclosed rebreathing circuit during recovery from inhalation anesthesia (sevoflurane or desflurane) adsorbed exhaled anesthetics and reduced the reuptake of these substances, which resulted ultimately in a shortened emergence time.

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Keywords: charcoal, recovery, bispectral index (BIS), sevoflurane, desflurane

# **Effect of charcoal filter on recovery from inhalation anesthesia in a semiclosed rebreathing circuit**

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## **I . INTRODUCTION**

Activated charcoal has the ability to adsorb a wide variety of substances. This property can be used to prevent the gastrointestinal absorption of various drugs and toxins and to facilitate their elimination, even after systemic absorption.<sup>1</sup> Activated charcoal has also been used since World War I as a means of adsorbing toxic gases from the inspired atmosphere.<sup>2</sup>

Most inhaled anesthetics used now are chlorofluoro-(HCFCs) or fluoro-(HFCs) derivatives used in a circle system. A portion of anesthetics exhaled from a patient is re-breathed by the patient and the remainder is eliminated from the breathing circuit through a scavenging system. Surplus anesthetics can contaminate operating rooms and the atmosphere, causing environmental pollution issues such as the greenhouse effect and destruction of the ozone layer.<sup>3</sup> The role of inhaled anesthetics in environmental pollution can be reduced by use of a low-flow system or by incorporating charcoal filters into the scavenging system. These steps can reduce the quantity of inhaled anesthetics consumed and the amount of anesthetic effluence released into the air.<sup>4</sup>

On the other hand, rebreathing inhaled anesthetics during recovery disturbs rapid decrease of alveolar anesthetic concentration and patient emergence. This

rebreathing of inhaled anesthetics can be reduced by use of a high-flow system that can reduce re-circulation of anesthetics itself or by use of a charcoal filter attached within the circuit. Actually, it has been reported that charcoal may adsorb halothane or isoflurane efficiently,<sup>2,5-9</sup> hasten anesthetic recovery without adverse effects on the humidity or resistance of the circuit, make it easy to control the depth of anesthesia, and eliminate unintended inhaled anesthetic overdoses.<sup>10-14</sup>

Higher concentrations of sevoflurane given over longer periods of time to a patient can trigger compound A production. Compound A produced by the degradation of sevoflurane may increase the risk of renal injury.<sup>15,16</sup> In this case, it is reported that a charcoal filter can adsorb not only sevoflurane, but also compound A effectively.<sup>17</sup>

The use of charcoal can reduce air pollution and body intoxication by inhaled anesthetics as well as hasten recovery from anesthesia. However, few clinical studies have reported on the adsorptive effect of charcoal with sevoflurane or desflurane, which have lower solubility and have been widely used recently. Recovery time from inhaled anesthetics differs based on the characteristics of the anesthetic and the inhaled dosage. Sevoflurane and desflurane show the shortest elimination time of about ten minutes at recovery.<sup>18,19</sup> This is comparable to the recovery time for propofol, an anesthetic used often for out-patient anesthesia.<sup>20</sup> Charcoal use is expected to significantly shorten the recovery time of these anesthetics. Rapid recovery from anesthesia is particularly important in ambulatory situations. Rapid recovery also has economic benefits due to faster discharge from recovery rooms and shorter hospitalization times. It is also important in spinal or intra-cranial neurosurgery because an immediate post-op evaluation of neural function is necessary. Rapid and complete elimination of inhaled anesthetics from an anesthetized patient is also inevitably necessary in cases of malignant hyperthermia.<sup>13,14</sup>

Most previous studies on charcoal filters analyzed the elimination of inhaled

anesthetic itself, but the bispectral index (BIS) (A-2000BIS™ monitor, Aspect Medical System, USA) was used in the present study to objectively evaluate patients' hypnotic states at emergence. Bispectral index monitoring utilizes a well-validated algorithm to analyze patient EEG patterns and translate them into a value reflecting the patient's hypnotic state. Specifically, the BIS has been useful as a pharmacodynamic measure of the level of patient responsiveness (i.e., response to verbal commands).<sup>21</sup> Many reports evaluated anesthetic depth with BIS monitoring, but studies evaluating the impact of charcoal on anesthetic recovery with BIS monitoring objectively and scientifically are few.

The purpose of this study was to evaluate the efficiency of charcoal filters on the elimination of sevoflurane and desflurane when recovering from inhalation anesthesia. Ultimately, the effects were determined using a recovery index that included eye opening and extubation times as monitored by BIS.

## II. MATERIALS AND METHODS

### 1. *IN VITRO* STUDY

In an *in vitro* pre-test, the effects of a charcoal filter, volumes of 100 ml (pallet type, diameter 4×(5-8) mm; Shinki chemical, Seoul, Korea) on resistance to gas flow and on the adsorption of inhalation anesthetics were studied separately in a semiclosed circle system connected to an artificial lung. An artificial lung (5 liters) was connected to the breathing circuit of an anesthetic machine, and a charcoal filter was added to the expiratory limb of the circuit. Pressure gauges were located on both sides of a charcoal filter and the artificial lung was ventilated with 100% O<sub>2</sub> at a fresh gas flow of 5 L/min. Pressure was measured at the front and the rear of the charcoal filter.

To test the adsorptive capacity of the charcoal filter, the artificial lung was mechanically ventilated with 100% O<sub>2</sub> at a fresh gas flow of 5 L/min and a minute volume of 6 L/min. Prior to the study, the accuracy of the vaporizer was determined at incremental 1 vol% settings to be within  $\pm 5\%$  of the dial setting for sevoflurane. Sevoflurane was administered at a vaporizer dial setting of 1 vol% for three minutes and the dial setting was then raised to 2 vol% and 4 vol% every three minutes. The end-tidal sevoflurane concentration was recorded every 30 seconds with and without the charcoal filter using the Draeger Infinity Delta Monitor (Draeger Medical AG&CO, Luebeck, Germany).

### 2. CLINICAL STUDY

Institutional Review Board (IRB) approval of Yonsei University College of Medicine for the study and informed consent were obtained. Sixty healthy

patients (ASA physical status I or II) who were 20-70 years of age and undergoing elective surgery under inhalation anesthesia with tracheal intubation were enrolled. Patients were randomly assigned via a computer-generated random numbers table to one of four groups: the sevoflurane control (without charcoal filter) group, the sevoflurane with charcoal filter group, the desflurane control group, or the desflurane with charcoal filter group. Sevoflurane was administered via a Draeger Vapor 2000 vaporizer (Draeger Medical AG&CO, Luebeck, Germany), and desflurane was administered via a Draeger D-Vapor vaporizer (Draeger Medical AG&CO, Luebeck, Germany).

Anesthesia was induced with 2 µg/kg of fentanyl, 5 mg/kg of thiopental sodium, and 0.6 mg/kg of rocuronium. While under anesthesia, all patients received O<sub>2</sub> (1 L/min) and air (1 L/min), and ventilation was controlled to maintain normocapnia using a semiclosed circle system. BIS monitors were applied and values were adjusted between 40 and 50 intra-operatively with the use of either sevoflurane or desflurane. The end-tidal CO<sub>2</sub> tension and anesthetic concentrations were measured using the Draeger Infinity Delta Monitor (Draeger Medical AG&CO, Luebeck, Germany).

Upon completion of surgery, the end-tidal concentration of each anesthetic was maintained at 1 minimum alveolar anesthetic concentration (MAC) and the residual neuromuscular block was reversed with glycopyrrolate and neostigmine. A charcoal filter was attached in the expiratory limb of the breathing circuit for patients in the charcoal filter group. After inhaled anesthetics were discontinued, ventilation was controlled with the same minute volume as the intra-operative period and with 100% O<sub>2</sub> at a fresh gas flow of 5 L/min until extubation. Following this, BIS, inspiratory, and end-tidal anesthetic concentrations were recorded every 30 seconds. Vital signs were recorded every five minutes. Time from the discontinuation of anesthetic to responsiveness to commands, such as eye opening, (assessed at 30-s intervals) and time from discontinuation of anesthetic to extubation were recorded.

Data for anesthetic were summarized as the rate of decay of the alveolar concentration ( $F_A$ ) during elimination of anesthetic relative to the last alveolar concentration during administration of anesthetic ( $F_{A0}$ ) (i.e.,  $F_A/F_{A0}$ ). Using a least-squares fit for the data from  $F_A/F_{A0}$ , we derived a plot equation for exponential decay ( $F_A/F_{A0} = y_0 + \text{constant} \cdot e^{\text{Exponent} \cdot \text{Minutes}}$ ) and calculated the exponential time constant ( $\tau$ ),  $\tau = -1/\text{Exponent}$ ). Analysis was performed using SigmaStat version 2.03 (Systat Software Inc., California, USA). Demographic data, recovery index and exponential time constant ( $\tau$ ) were represented as the mean and standard deviation (SD) and compared using the unpaired Student's t-test. P values  $< 0.05$  were considered to be significant. A priori power analysis based on previously published data suggested that a minimum sample size of ten patients per group would be required to detect a three minute difference in means (SD: 2 min) for eye opening time among the anesthetic groups with a power of 90% at the  $P < 0.05$  level of significance.

### III. RESULTS

The in vitro pretest using an artificial lung demonstrated no difference in airway pressures between the proximal and distal ends of a charcoal filter when the artificial lung was ventilated with 100% O<sub>2</sub> at a fresh gas flow of 5 L/min and a minute volume of 6 L/min. End-tidal sevoflurane concentration with the charcoal filter increased more slowly than concentrations without the charcoal filter (Fig. 1).

There were no significant differences between the control and the charcoal filter group with respect to patient demographics, duration of anesthesia, and BIS at eye opening for each inhaled anesthetic (Table 1,2). The mean duration of anesthesia in all patients was  $152 \pm 76$  (30-330) min.

Elimination of anesthetic ( $F_A/F_{A0}$  ratio) was more rapid (Fig. 2,3) in charcoal filter groups than in control groups for both anesthetics. A least-squares exponential fit to the data for the  $F_A/F_{A0}$  ratio at various points following anesthesia was demonstrated.

Table 3 and 4 show the amount of time until eye opening and the amount of time until tracheal extubation, with and without the charcoal filter for each anesthetic. For the sevoflurane group, use of a charcoal filter resulted in more rapid eye opening ( $11.1 \pm 3.8$  vs.  $14.8 \pm 3.0$  min) and shorter time to extubation ( $11.9 \pm 3.9$  vs.  $15.3 \pm 3.2$  min) when compared with the control group. For the desflurane group, eye opening ( $6.2 \pm 1.4$  vs.  $10.3 \pm 1.7$  min) and extubation ( $6.7 \pm 1.4$  vs.  $10.5 \pm 1.1$  min) occurred earlier in the charcoal filter group than in the control group. The exponential time constant ( $\tau$ ) of the alveolar anesthetic concentration for the charcoal filter group was significantly shorter than the control group in both sevoflurane ( $1.7 \pm 0.5$  vs.  $2.5 \pm 1.1$  min) and desflurane ( $1.4 \pm 0.3$  vs.  $2.0 \pm 0.3$  min).

### Adsorptive capacity of charcoal filter *in vitro* pretest

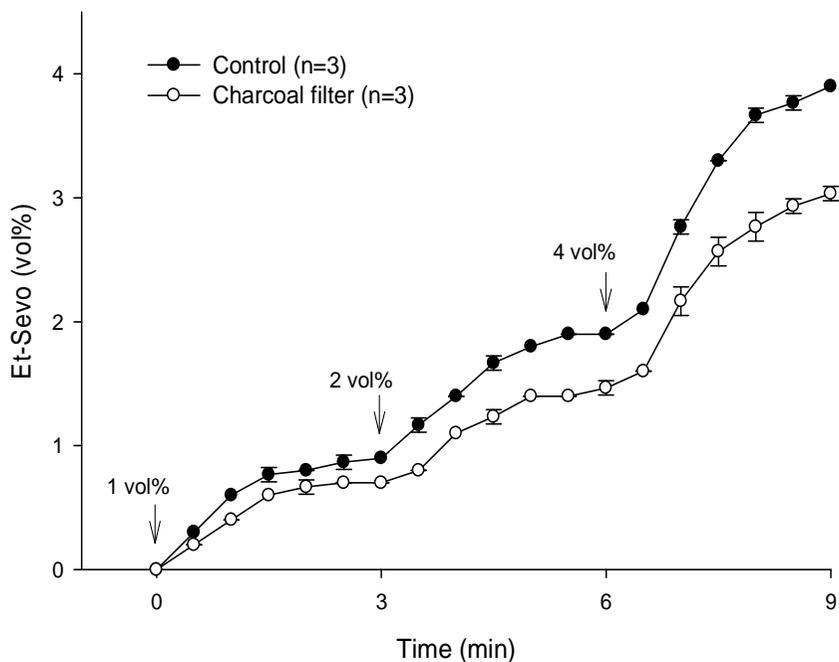


Figure 1. Effect of charcoal filter on end-tidal sevoflurane concentration (Et-Sevo) for *in vitro* pretest. Artificial lung (5 liter) was connected to a semiclosed breathing circuit and mechanically ventilated with 100% O<sub>2</sub> at a fresh gas flow of 5 L/min and a minute volume of 6 L/min. Sevoflurane was administered at a vaporizer dial setting of 1 vol% for three minutes. Dial setting was then raised to 2 vol% and 4 vol% every three minutes. End-tidal sevoflurane concentration with the charcoal filter increased more slowly than concentration without the charcoal filter.

## Sevoflurane

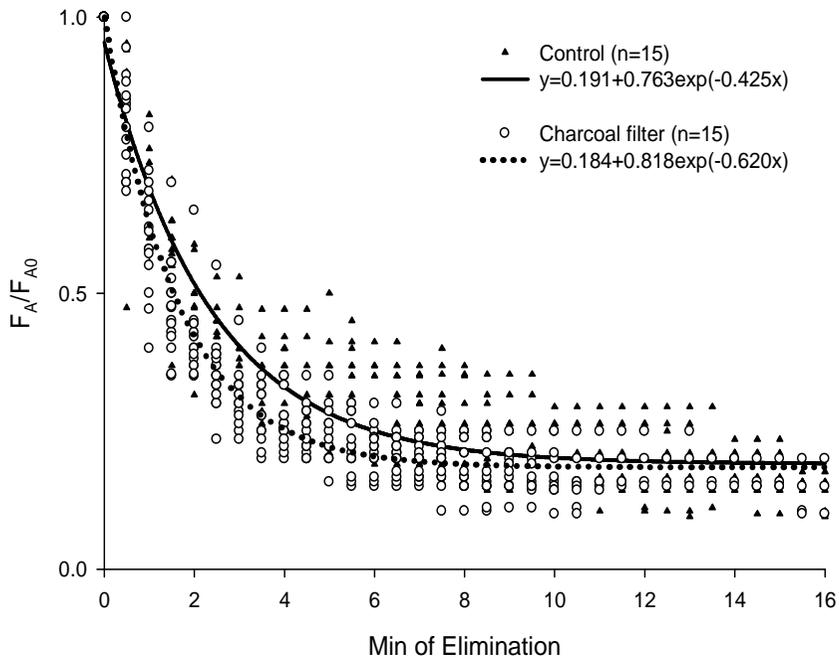


Figure 2.  $F_A/F_{A0}$  declined exponentially after anesthesia with sevoflurane. A plot equation for exponential decay was derived using the least-squares fit for data from  $F_A/F_{A0}$  ( $r^2$ : control, 0.885; charcoal filter, 0.933). The exponential time constant ( $\tau$ ) of the alveolar anesthetic concentration for the charcoal filter group was significantly shorter than the control group ( $1.7 \pm 0.5$  vs.  $2.5 \pm 1.1$  min) ( $P < 0.01$ ).  $F_A/F_{A0}$  refers to the decay rate of alveolar concentration ( $F_A$ ) during elimination of the anesthetic relative to the last alveolar concentration during administration of the anesthetic ( $F_{A0}$ ). exp, exponent.

## Desflurane

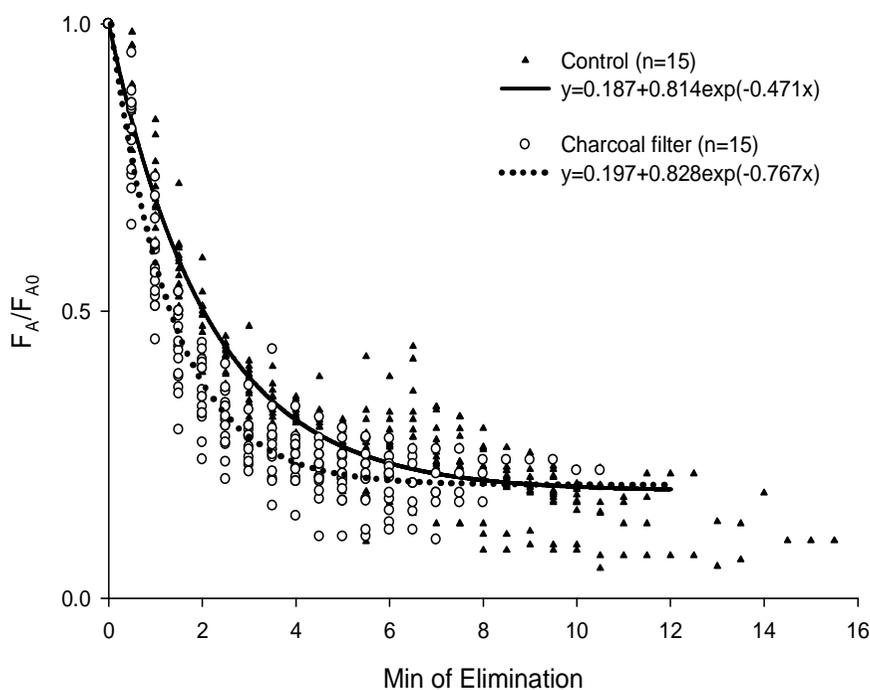


Figure 3.  $F_A/F_{A0}$  declined exponentially after anesthesia with desflurane. A plot equation for exponential decay was derived using the least-squares fit for data from  $F_A/F_{A0}$  ( $r^2$ : control, 0.937; charcoal filter, 0.948). The exponential time constant ( $\tau$ ) of the alveolar anesthetic concentration for the charcoal filter group was significantly shorter than the control group ( $1.4 \pm 0.3$  vs.  $2.0 \pm 0.3$  min) ( $P < 0.01$ ).  $F_A/F_{A0}$  refers to the decay rate of alveolar concentration ( $F_A$ ) during elimination of the anesthetic relative to the last alveolar concentration during administration of the anesthetic ( $F_{A0}$ ). exp, exponent.

Table 1. Patient demographic characteristics and BIS at eye opening for the sevoflurane group

	Control group ( n = 15 )	Charcoal filter group ( n = 15 )
Age (yr)	49 ± 12	44 ± 11
Height (cm)	161 ± 9	164 ± 11
Weight (kg)	65 ± 11	66 ± 10
BMI (kg/m <sup>2</sup> )	24.7 ± 2.8	24.4 ± 3.1
Duration of anesthesia (min)	146 ± 72	154 ± 77
BIS at eye opening	90 ± 7	86 ± 9

Data are mean ± SD. BMI, body mass index; BIS, bispectral index.

Table 2. Patient demographic characteristics and BIS at eye opening for the desflurane group

	Control group ( n = 15 )	Charcoal filter group ( n = 15 )
Age (yr)	40 ± 16	44 ± 11
Height (cm)	165 ± 6	163 ± 10
Weight (kg)	62 ± 8	61 ± 9
BMI (kg/m <sup>2</sup> )	22.7 ± 2.2	23.1 ± 2.4
Duration of anesthesia (min)	161 ± 84	148 ± 78
BIS at eye opening	89 ± 6	90 ± 4

Data are mean ± SD. BMI, body mass index; BIS, bispectral index.

Table 3. Patient emergence and exponential time constant ( $\tau$ ) for anesthetic following discontinuation of sevoflurane

	Control group ( n = 15 )	Charcoal filter group ( n = 15 )
Eye opening (min)	14.8 $\pm$ 3	11.1 $\pm$ 3.8*
Extubation (min)	15.3 $\pm$ 3.2	11.9 $\pm$ 3.9 <sup>†</sup>
Exponential time constant ( $\tau$ ) (min)	2.5 $\pm$ 1.1	1.7 $\pm$ 0.5*

Data are mean  $\pm$  SD. Exponential time constant ( $\tau$ ) is the time it takes alveolar anesthetic concentration decrease to reach about 36.8% of the initial alveolar emergence concentration. \*  $P < 0.01$ , <sup>†</sup>  $P < 0.05$  vs. control group.

Table 4. Patient emergence and exponential time constant ( $\tau$ ) for anesthetic following discontinuation of desflurane

	Control group ( n = 15 )	Charcoal filter group ( n = 15 )
Eye opening (min)	10.3 $\pm$ 1.7	6.2 $\pm$ 1.4*
Extubation (min)	10.5 $\pm$ 1.1	6.7 $\pm$ 1.4*
Exponential time constant ( $\tau$ ) (min)	2.0 $\pm$ 0.3	1.4 $\pm$ 0.3*

Data are mean  $\pm$  SD. Exponential time constant ( $\tau$ ) is the time it takes alveolar anesthetic concentration decrease to reach about 36.8% of the initial alveolar emergence concentration. \*  $P < 0.01$  vs. control group.

#### IV. DISCUSSION

For inhaled anesthetics, two elements determine recovery. First of these elements is the effect site concentration of the anesthetic that permits awareness, or MAC-awake. The second element determining recovery is the clearance of anesthetic from the effect site. Clearance of anesthetic is accomplished through blood circulation and alveolar ventilation. Several factors influence clearance including solubility of the anesthetic, duration of anesthesia, cardiac output, and alveolar minute ventilation.<sup>22</sup> If the solubility of an anesthetic is very low, most of the anesthetic will be cleared via ventilation and consequently will not recirculate and not delay recovery. A longer period of anesthesia will cause more anesthetic to accumulate in muscle and fat, so that an increase in the duration of anesthesia will result in increased recovery time from the anesthesia.<sup>23</sup> An increase in ventilation can facilitate a decrease in the alveolar concentration of an inhaled anesthetic but it can induce hypocapnia, which is a significant limitation. A final consideration is the existence of rebreathing and the rate of fresh gas flow during emergence. To prevent rebreathing in a semiclosed rebreathing circuit, a high rate of fresh gas flow is necessary.

In a semiclosed or closed breathing circuit, it has been shown that the adsorption of inhaled anesthetics (halothane<sup>2,4,6-8,11</sup> or isoflurane<sup>9,11,12,24</sup>) with a charcoal filter may prevent rebreathing of anesthetics, promote elimination of anesthetic, and shorten the emergence time. The enormous adsorptive capacity of charcoal with regard to volatile anesthetic agents<sup>25-27</sup> as well as charcoal's low resistance to gas flow<sup>26</sup> have been studied. Baumgarten<sup>5</sup> reported that a small dose of charcoal (30-45 ml) could adsorb no less than 1500 ml of inhaled anesthetics and Alexander et al.<sup>2</sup> reported that charcoal filters with a density of 0.35-0.54 g/cm<sup>3</sup> had a resistance of only 0.01-0.06 cm H<sub>2</sub>O/L · min to a gas flow of O<sub>2</sub> 5 L/min. Factors affecting the duration of adsorption by a given amount of charcoal include particle size, the evenness of packing, humidity, and

the flow rate of gas passing through the charcoal. As particle size increases and packing becomes more uneven, the duration of effective adsorption shortens. Excess humidity also reduces the duration of adsorption. On the other hand, complete drying of activated charcoal impairs its efficiency.<sup>7</sup> Capon<sup>28</sup> has shown that charcoal can be regenerated by autoclaving.

In the present study, a charcoal filter efficiently eliminated sevoflurane and desflurane from the breathing circuit and significantly shortened the emergence time. There were no significant differences in the duration of anesthesia and BMI that could differentiate recovery time from inhalation anesthesia between control and charcoal filter groups. Alveolar minute ventilation was controlled to maintain normocapnia until extubation, and the fresh gas flow rate (5 L/min) was equal for all groups. As a result, our conclusion was that significant differences in the amount of time until eye opening, the amount of time until extubation, and the exponential time constants ( $\tau$ ) for alveolar anesthetic concentration between the control and the charcoal filter group were a result of charcoal's adsorptive effects.

In this study, BIS values were adjusted between 40 and 50 intra-operatively. Following surgery, alveolar anesthetic concentration was maintained at 1 MAC. Concurrently, the mean BIS in all patients was  $38 \pm 7$ . BIS at eye opening was not statistically different between the sevoflurane control ( $90 \pm 7$ ) and sevoflurane charcoal filter groups ( $86 \pm 9$ ), or the desflurane control ( $89 \pm 6$ ) and desflurane charcoal filter groups ( $90 \pm 4$ ).

Using the plot equation from Figures 2 and 3, we calculated an  $F_A/F_{A0}$  when responsiveness to the eye-opening command occurred in each group: sevoflurane control group, 0.19; sevoflurane charcoal filter group, 0.18; desflurane control group, 0.19; and desflurane charcoal filter group, 0.20. In the present study, the value of  $F_{A0}$  was 1 MAC. As a result, these findings suggest that responsiveness to the eye-opening command occurred when the value of  $F_A$

was 0.18-0.20 MAC for each group. It is known that response to a command occurs when the cerebral partial pressure of the anesthetic equals 0.33 MAC (MAC-awake).<sup>29,30</sup> A difference was suggested between end-tidal ( $F_A$ ) and cerebral anesthetic partial pressures (MAC-awake) when the patient awoke because cerebral partial pressure lagged alveolar partial pressure.<sup>31</sup> A lower end-tidal partial pressure than predicted may be due to the fact that cerebral gray matter receives anesthetic stored in white matter via inter-tissue diffusion.<sup>32</sup>

A charcoal filter is expected to have the capability to efficiently adsorb inhaled anesthetics of higher concentration than in the present study. The use of charcoal filters may be considered following surgeries in which a high concentration of the inhaled anesthetic is maintained, or when a high concentration of inhaled anesthetic is administered unintentionally.

Fast emergence and recovery from anesthesia has not only cost-reductive effects but also is useful in neurosurgery when early evaluation of neural function is necessary, as well as in cases of malignant hyperthermia in which rapid and complete elimination of inhaled anesthetics from an anesthetized patient is crucial.<sup>13,14</sup> Adsorption of halogenated anesthetics by charcoal can reduce atmospheric pollution by reducing the amount of inhaled anesthetics released through the scavenging system<sup>3,4</sup> and may limit the production of compound A by reducing the inflow of inhaled anesthetics into a CO<sub>2</sub> absorber.<sup>17</sup>

A charcoal filter has several limitations. The prevention of rebreathing in a semiclosed circuit is possible simply by use of the high flow system. Insertion of a charcoal filter into a breathing circuit is somewhat troublesome. Nevertheless, Sakata et al.<sup>33</sup> recently reported that the emergence time could be shortened significantly by using hypercapnic hyperventilation with a rebreathing device in which activated charcoal had been inserted. This report suggests that a charcoal filter may continue to be considered a valuable device in the future. Future studies may be warranted to define the formula for efficient

charcoal filter adsorption of anesthetic in low minute volumes or low flow rates.

## **V. CONCLUSION**

Emergence time from inhalation anesthesia was shortened when a charcoal filter was used as long as minute volume was controlled to maintain normocapnia and 100% O<sub>2</sub> was supplied at a flow rate of 5 L/min. The charcoal filter could efficiently adsorb and eliminate sevoflurane and desflurane from the lungs and the breathing circuit. A charcoal filter is likely to be useful when rapid emergence and recovery from inhalation anesthesia is necessary.

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## Abstract (in Korean)

### 반폐쇄식 순환형 호흡회로를 이용한 흡입마취시 활성탄소 여과기가 마취로부터의 회복에 미치는 영향

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장 동 진

활성탄소는 다양한 종류의 물질들을 흡착할 수 있는 특성이 있어 예전부터 약물이나 독성 물질 중독 시에 경구적으로 투여함으로써 위장관에서의 흡수를 막아주고 체내로부터의 제거를 촉진시켜 전신 독성의 예방이나 치료에 사용되어 왔다. 마취에 있어서도 활성탄소는 흡입마취제를 효과적으로 흡착시킨다는 연구 결과가 보고되어 있다. 그러나, sevoflurane과 desflurane은 낮은 혈액/가스분배계수를 가지고 있어 현재 널리 쓰이고 있는 흡입마취제이지만, 이에 대한 활성탄소의 흡착효과에 대한 연구결과는 아직 보고된 바가 없다.

본 연구에서는 기도삽관 하에 흡입마취제 (sevoflurane, desflurane)를 이용하여 전신마취를 시행한 성인 남녀 60 명을 대상으로, 마취기계의 호기 회로에 활성탄소 여과기를 부착하는 것이 이 두 흡입마취제를 이용한 마취로부터의 회복 시 각성 속도에 어떤 영향을 미치는지에 대하여 각각 알아보고자 하였다. 또한 BIS를 이용하여 마취 중과 회복 시에 마취심도의 평가를 객관적으로 하고자 하였다. 활성탄소 여과기를 사용한 군을 실험군으로 하고 사용하지 않은 군을

대조군으로 하였으며, 회복기간에는 환자의 생체 징후와 BIS의 변화, 그리고 호기 및 흡기 내의 마취가스 농도의 변화를 기록하였고, 궁극적으로 환자의 각성까지 걸리는 시간과 발관 시간, 술 후 각성 상태 등을 평가 비교하였다.

흡입마취제의 투여를 중단한 후 sevoflurane 실험군이 sevoflurane 대조군보다 구두 명령에 반응하여 눈을 뜨는 시간이 유의하게 빨랐으며 ( $11.1 \pm 3.8$  vs.  $14.8 \pm 3.0$  min), 발관시간도 실험군에서 유의하게 빨랐다 ( $11.9 \pm 3.9$  vs.  $15.3 \pm 3.2$  min). 이는 desflurane에서도 마찬가지로, 실험군에서 눈을 뜨기까지 걸린 시간 ( $6.2 \pm 1.4$  vs.  $10.3 \pm 1.7$  min)과 발관까지 걸린 시간 ( $6.7 \pm 1.4$  vs.  $10.5 \pm 1.1$  min)이 대조군에서보다 모두 유의하게 짧았다. 각 흡입마취제에서 대조군과 실험군 사이에 각성 시 BIS의 차이는 없었다. 회복시 폐포내 흡입마취제 농도의 시간상수( $\tau$ )는 sevoflurane 실험군의 시간상수 ( $1.7 \pm 0.5$  min)가 sevoflurane 대조군의 시간상수 ( $2.5 \pm 1.1$  min)보다 유의하게 짧았으며, desflurane 실험군의 시간상수 ( $1.4 \pm 0.3$  min) 또한 desflurane 대조군의 시간상수 ( $2.0 \pm 0.3$  min)보다 유의하게 짧았다.

Sevoflurane과 desflurane에 대한 본 연구에서, 활성탄소 여과기의 사용이 흡입마취제를 호흡회로에서 효과적으로 제거할 수 있게 하고 환자의 각성시간을 유의하게 단축시킨다는 결론을 얻었다.

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핵심되는 말 : 활성탄소, 회복, bispectral index(BIS), sevoflurane, desflurane