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Transcutaneous electrical acupoint-stimulation potentiates the anesthetic effect of enflurane in humans

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Abstract: The effect of transcutaneous electrical acupoint stimulation (TEAS) on enflurane anesthesia and hemodynamic changes during craniotomy was studied. Eighty neurosurgical patients were randomly divided into two groups. Anesthesia was induced with fentanyl, droperidol, thiopental, and suxamethonium by intubation. In group A, anesthesia was maintained with enflurane ($n = 40$), and in group B was supplemented by TEAS with Han's acupoint nerve stimulator (HANS) to Hegu, Yuyao, and Fengchi points on the operated side ($n = 40$). The results showed that the ratio between expired concentration and minimum alveolar concentration of enflurane during operation in group B was 37.8%–47% lower than that in group A, and that the hemodynamics were more stable during operation. The results also demonstrated that the patients in Group B recovered faster after operation. It was concluded that TEAS with HANS significantly potentiated the anesthetic effect of enflurane.

Key words: Enflurane, Acupoint, Electrical stimulation, Anesthesia, Craniotomy

Introduction

Acupuncture stimulation may activate the body's pain modulatory system by increasing the release of endogenous opioids [1]. Acupuncture anesthesia for craniotomy has been used for more than 20 years in China. Standard procedures, including the selection of suitable acupuncture points, optimal stimulation parameters, and prediction of anesthetic effect have been studied for neurosurgeries in the frontal, temporal, parietal, and occipital regions and in the posterior cranial fossa [2]. Although this method has many advantages, including safety, simplicity, minor disturbances of homeostasis with the patient being conscious and cooperative during surgery, the analgesic effect of acupuncture is not potent enough to render the patient completely free from pain. Therefore, it might be desirable to combine acupuncture with conventional analgesics or anesthetics to achieve the optimal level of anethesia. In this study, therefore, we observed the effect of transcutaneous electrical acupoint stimulation (TEAS) on enflurane anesthesia and hemodynamic changes during craniotomy.

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Patients and Methods

Patients

Eighty patients, ASA class I or II who were free of cardiovascular and respiratory diseases and scheduled for neurosurgery (mainly resections of brain tumor or cerebral vascular malformation) were studied. The patients were randomly divided into two groups. The characteristics of the patients in each group are shown in Table 1.

Anesthesia

All patients were premedicated with sodium phenobarbital 0.2 g and atropine 0.5 mg i.m. 1 h before anesthesia. Anesthesia was induced with fentanyl 5–6 μg/kg, droperidol 5 mg, and thiopental 6 mg/kg i.v. Tracheal intubation was facilitated with suxamethonium 1.5–2 mg/kg. Anesthesia was maintained with enflurane mixed with oxygen in group A. The patients in group B were stimulated with Han's acupoint nerve stimulator (HANS) through two pairs of skin electrodes (ECG electrodes) placed on Hegu (on thenar muscles), Yuyao (middle of eyebrow) and Fengchi (back of neck) points on the operated side, using a dense-and-disperse frequency of 2/100 Hz and an intensity of 9–12 mA, com-

Table 1. Characteristics of patients

	Group A	Group B
Number	40	40
Male:Female	26 : 14	25 : 15
Age (years)	37.6 ± 1.4	40.4 ± 1.4
Height (cm)	167.0 ± 1.1	165.9 ± 1.1
Weight (kg)	64.0 ± 1.5	62.5 ± 1.5
Diseases		
Glioma	18	19
Meningioma	13	14
AVM	9	7
Sites of craniotomy		
Frontal	18	19
Temporal	11	12
Occipital	11	9

Data are mean ± SEM.
AVM, arteriovenous malformation.

bined with enflurane inhalation. The scalp on the operated side was infiltrated with normal saline 200 ml and adrenaline 0.2 mg. The patients were ventilated with IPPV to maintain an end-tidal CO_2 of 3.5%–5.5%. Vecuronium 4–8 mg i.v. was given during the operations.

Observed parameters

The inhaled and expired concentrations of enflurane (Fi-enf and Fex-enf), Fio_2, $Petco_2$, tidal volume (TV), minute volume (MV), respiratory frequency (RR), and the ratio between expired concentration and standard minimum alveolar concentration (Ce/MAC) were monitored with a Capnomac Ultima (Datex, Helsinki, Finland). The hemodynamic parameters were measured with impedance cardiography (HB-3COG, Shijiazhuang, China). The stroke volume was calculated from Kubicek's equation. Cardiac index (CI), stroke index (SI), heart rate (HR), mean arterial pressure (MAP), total peripheral resistance (TPR), and Heather's index (HI) were calculated by standard formulae [3]. After operation, the recovery time of spontaneous breath (the time between stop of ventilator and recovery of spontaneous breath), awakening time (the time between the end of operation and response to verbal commands), spontaneous TV and MV, and the incidence of shivering, restlessness, and hypertension were observed.

Observed steps

All of the above parameters were measured and recorded before the induction of anesthesia, before the incision, after the incision of the scalp, during drilling the hole in the cranium, after opening the dura mater of brain, during the manipulation of the tumor, and during closing the dura mater and hypodermis, respectively.

Statistical analysis

Both one-way and two-way analyses of variance were used to compare the parameters between and within the two groups, respectively. Non-parametric data were compared with the chi-square test. A difference was considered statistically significant if the P value was less than 0.05.

Results

The age, height, body weight, sex ratio, hemodynamic parameters before anesthesia, and duration of anesthesia were not significantly different between the two groups. The changes in enflurane concentrations (in-

Table 2. Changes of enflurane concentrations during operation

	Before incision	After incision	During drilling hole	During opening of dura mater	During removal of tumor	During closing of dura mater	During closing of hypodermis
Inhaled concentration (%)							
Group A	3.86 ± 0.10	4.01 ± 1.02	3.65 ± 0.10	2.89 ± 0.09	2.49 ± 0.09	2.63 ± 0.09	2.81 ± 0.12
Group B	2.07 ± 0.07*	2.21 ± 0.08*	2.12 ± 0.06*	1.66 ± 0.05*	1.34 ± 0.05*	1.44 ± 0.05*	1.74 ± 0.06*
Expired concentration (%)							
Group A	2.36 ± 0.05	2.48 ± 0.06	2.50 ± 0.06	2.23 ± 0.08	2.01 ± 0.07	2.07 ± 0.07	2.20 ± 0.07
Group B	1.25 ± 0.04*	1.34 ± 0.04*	1.35 ± 0.05*	1.23 ± 0.03*	1.08 ± 0.04*	1.13 ± 0.05*	1.37 ± 0.05*
Ce/MAC[a]							
Group A	1.40	1.48	1.49	1.33	1.20	1.23	1.31
Group B	0.74	0.80	0.80	0.73	0.64	0.67	0.82

Values are mean ± SEM.
* $P < 0.001$ vs. group A.
[a] Standard MAC of enflurane: 1.68%.
Ce, expired concentration; MAC, minimum alveolar concentration.

Table 3. The changes of hemodynamics during operation (%)

	Before incision	After incision	During drilling hole	During opening of dura mater	During removal of tumor	During closing of dura mater	During closing of hypodermis
MAP							
Group A	−21.4 ± 1.8[c]	−13.7 ± 2.0[c]	−23.0 ± 1.7[c]	−30.1 ± 1.2[c]	−26.7 ± 1.5[c]	−21.8 ± 1.4[c]	−18.7 ± 1.6[c]
Group B	−22.5 ± 2.4[c]	−12.1 ± 1.7[c]	−18.7 ± 1.7[c]	−22.0 ± 1.7[c]	−19.8 ± 2.0[c]	−17.6 ± 1.6[c]	−12.4 ± 1.7[c]
HR							
Group A	16.2 ± 4.7[c]	34.8 ± 4.9[c]	29.1 ± 4.4[c]	17.5 ± 3.8[c]	13.8 ± 3.4[c]	17.5 ± 3.7[c]	23.8 ± 3.8[c]
Group B	9.1 ± 3.5[a]	27.8 ± 4.6[c]	28.6 ± 4.7[c]	23.5 ± 4.2[c]	17.6 ± 4.0[c]	14.9 ± 3.8[c]	25.5 ± 4.9[c]
SI							
Group A	−34.4 ± 6.7[c]	−35.0 ± 7.7[c]	−40.4 ± 7.5[c]	−39.1 ± 7.1[c]	−37.9 ± 7.2[c]	−41.7 ± 5.9[c]	−47.7 ± 5.0[c]
Group B	−16.5 ± 4.4[cd]	−16.8 ± 5.6[cd]	−21.4 ± 5.3[cd]	−24.6 ± 6.6[c]	−32.2 ± 7.5[c]	−30.5 ± 8.0[c]	−33.4 ± 8.0[c]
CI							
Group A	−24.8 ± 5.7[c]	−16.6 ± 5.9[c]	−27.0 ± 6.8[c]	−29.6 ± 7.0[c]	−31.6 ± 5.8[c]	−34.8 ± 4.2[c]	−36.8 ± 4.3[c]
Group B	−13.7 ± 3.9[b]	−2.1 ± 4.7[d]	−3.8 ± 6.6[d]	−11.5 ± 6.1[bd]	−25.4 ± 4.7[c]	25.0 ± 5.0[c]	−21.6 ± 6.0[c]
HI							
Group A	−41.3 ± 4.7[c]	−35.1 ± 5.7[c]	−39.5 ± 8.1[c]	−46.3 ± 6.3[c]	−49.1 ± 4.8[c]	−50.5 ± 5.0[c]	−54.7 ± 5.7[c]
Group B	−31.7 ± 4.5[c]	−24.7 ± 5.3[c]	−29.8 ± 5.9[c]	−33.7 ± 4.9[c]	−47.1 ± 3.4[c]	−47.9 ± 3.4[c]	−46.6 ± 4.4[c]
TPR							
Group A	20.5 ± 14.8	6.7 ± 8.4	20.0 ± 13.5	24.8 ± 19.5	16.5 ± 10.6	27.2 ± 10.8[a]	38.4 ± 11.9[a]
Group B	−8.5 ± 4.9[d]	−8.2 ± 5.0	−7.5 ± 7.5[d]	−4.6 ± 8.7[d]	17.1 ± 8.7[a]	20.2 ± 7.7[b]	20.2 ± 8.3[b]

All values are mean ± SEM.
[a] $P < 0.05$, [b] $P < 0.01$, [c] $P \pm 0.001$ vs. before induction.
[d] $P < 0.05$, [e] $P < 0.01$ vs. group A.
MAP, mean arterial pressure; HR, heart rate; SI, stroke index; CI, cardiac index; HI, Heather's index; TPR, total peripheral resistance.

haled and expired) and hemodynamics during operation are shown in Tables 2 and 3.

Inhaled and expired concentrations of enflurane

The inhaled and expired concentrations of enflurane needed to maintain anesthesia in group B were significantly less than those in group A during anesthesia and operation. The Ce/MAC in group B decreased by 37.8%-47% compared with that in group A.

Hemodynamics

The changes of MAP and HR during operation were not significantly different between the two groups. The decreases of SI in group A (35%–47.7%) were greater than those in group B (16.8%–33.4%) during operation ($P < 0.05$). CI in group A decreased by 16.6%–35% in the whole period of operation, while in group B it decreased by 2.1%–11.5% during opening the cranium, which was less than that in group A ($P < 0.05$). HI showed no significant differences between groups A and B. TPR in group A increased by 16.5%–38.4% during operation. In group B, TPR did not change significantly during opening the cranium and then increased by 17.1%–20.2%.

Table 4. Recovery of spontaneous breath after controlled ventilation and recovery from anesthesia and postoperative complications

	Group A	Group B
Spontaneous breath recovery time (min)	6.4 ± 0.59	2.1 ± 0.25[c]
Respiratory rate (bpm)	14.3 ± 0.62	12.6 ± 0.62
TV (ml)	223.8 ± 13.0	344.6 ± 22.74[c]
MV (L)	3.19 ± 0.24	4.10 ± 0.24[a]
$Petco_2$ (mmHg)	55.4 ± 1.09	48.6 ± 1.14[c]
Time of awakening (min)	58.2 ± 1.95	24.3 ± 1.66[c]
Shivering during awakening	18/40 (45%)	8/40 (20%)[a]
Excitement during awakening	16/40 (40%)	10/40 (25%)
Hypertension during awakening	17/40 (42.5%)	8/40 (20%)[a]

Data are expressed as mean ± SEM.
[a] $P < 0.05$, [c] $P < 0.001$, vs. group A.
TV, tidal volume; MV, minute volume; $Petco_2$, partial end-tidal CO_2.

Recovery from anesthesia after operation

Table 4 shows significant differences in the recovery times of spontaneous breath, awakening times, TV, MV, and the incidence of shivering, restlessness, and hypertension in group A and group B.

Discussion

The research group of acupuncture anesthesia, Beijing Medical College, showed that the pain threshold in humans was increased significantly by acupuncture stimulation of the Hegu point (large intestine 4). The threshold rose slowly in onset, reached a plateau (65%–95% above the baseline) in about 20 to 30 min, remained at the high level during the 50-min stimulation period, declined exponentially after removal of the needle with a half-life of 15 to 17 min, and returned to the baseline in 45 min [4]. The mechanism of acupuncture analgesia is thought to activate the body's pain modulatory system, particularly increases in the release of endogenous opioids, thereby suppressing the transmission and perception of noxious information at various levels of the central nervous system (CNS) [1]. If this hypothesis is true, TEAS may potentiate the analgesic effect of anesthetics.

The results of this study showed that TEAS to the Hegu, Yuyao, and Fengchi points with HANS, using a dense-and-disperse frequency of 2 and 100 Hz, decreased the inhaled and expired concentrations of enflurane significantly during operation. The ratio between expired and standard minimum alveolar concentrations of enflurane in group B (0.64–0.82) was significantly less than that in group A (1.14–1.49). Cardiovascular depression was less in group B than in group A, and the patients recovered faster in group B after operation. It is well known that enflurane depresses cardiac function dose-dependently [5]. The smaller changes in hemodynamic parameters in group B might be due to the lower expired concentration of enflurane during operation, compared with group A. It might be concluded that acupuncture stimulation with HANS significantly potentiated the anesthetic effect of enflurane during craniocerebral operations and decreased the side effects after enflurane.

The detailed mechanisms of the action of acupuncture remain to be investigated. Since HANS with 2/100 Hz has been shown to accelerate the release of endorphins, enkephalins, and dynorphins in the CNS and to produce a potent analgesic effect, it may help to reduce the amount of anesthetics needed during surgical procedures [6]. The first branch of the trigeminal nerve issues under the Yuyao point and the occipital nerve branches are near the Fengchi point. The numbness on the operated side may be produced when the electric impulse passes through the scalp between the Yuyao and Fengchi points, which may increase the pain threshold.

In summary, TEAS to the Hegu, Yuyao, and Fengchi points with HANS may potentiate the anesthetic effect of enflurane during craniotomy and decrease the side effects after enflurane.

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