The Effects of Composition of Subarachnoid Gas Space and Anesthetic Gas Mixture on Cerebrospinal Fluid Pressure Changes during Cisternography for Transsphenoidal Craniectomy

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The effects of gas composition in the subarachnoid space (injection of air or N_2O) and in an anesthetic gas mixture (inhalation with or without N_2O) on cerebrospinal fluid pressure were studied in 22 patients with pneumocisternography for transsphenoidal craniectomy. N_2O (66%) anesthesia for 10 min increased cerebrospinal fluid pressure by up to 150% in 7 patients who were intrathecally injected with air. Withdrawal of N_2O from the anesthetic gas mixture for sixty minutes reduced cerebrospinal fluid pressure to the initial pressure. A second N_2O administration to the anesthetic gas mixture did not elevate cerebrospinal fluid pressure by as much as the first N_2O administration. In 7 patients receiving subarachnoid air injection, replacing 66% N_2O with 66% nitrogen prevented the change in cerebrospinal fluid pressure throughout the operation. In 8 patients N_2O anesthesia and N_2O intrathecal injection failed to eliminate the rise in cerebrospinal fluid pressure in 8 patients. Withdrawal of N_2O from the anesthetic gas mixture for 60 min is recommended to prevent an extreme increase in cerebrospinal fluid pressure during pneumocisternography. (Key words: N_2O, closed air-containing space, cerebrospinal pressure, pneumocephalus, transsphenoidal craniectomies)

(Oku S, Wakita K, Hunasaka M, et al.: The effects of composition of subarachnoid gas space and anesthetic gas mixture on cerebrospinal fluid pressure changes during cisternography for transphenoidal craniectomy. J Anesth 5: 221–227, 1991)

The large increase in the pressure and volume of closed air-containing spaces within the body, such as the closed intestinal gas space, air emboli and the middle ear, during nitrous oxide (N_2O) anesthesia is primarily of historical interest[1]. Introduction of the computerized tomographic scan (CT) in radiological examination has greatly decreased opportunities for pneumoencephalography (PEG). Therefore, clinical problems associated with PEG during N_2O anesthesia have diminished. CT facilitates the diagnosis of a pituitary micro-adenoma and other sellar or parasellar tumors, thereby increasing the number of transsphenoidal craniectomies. During this operation, neurosurgeons orientate the parasellar anatomy using fluoroscopic pneumocisternography (PCG). An-

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Table 1. Summary of patients studied, the gas volume injected intrathecally, postoperative complications within 48 hours and the size of aerocele found on CT scans

	Age	Sex	Weight (kg)	Diagnosis	Gas volume cc (cc/kg)	Postoperative complications	Size of aerocele
Group A							
1	25	M	68	suprasellar tumor	8(0.117)	headache	
2	19	F	61	pituitary adenoma	10(0.164)	headache	S
3	14	M	51	craniopharyngioma	7(0.137)	CSF leakage	M
4	39	F	60	pituitary adenoma	10(0.164)	headache	M
5	60	M	76	pituitary adenoma	13(0.171)	none	S
6	26	F	42	prolactinoma	5(0.119)	none	S
7	28	F	57	prolactinoma	10(0.175)	CSF leakage	S
Group B							
1	41	F	46	pituitary adenoma	7(0.152)	CSF leakage	S
2	31	F	54	pituitary adenoma	8(0.148)	headache	S
3	61	F	90	pituitary adenoma	10(0.111)	brainstem bleeding	M
4	64	M	54	craniopharyngioma	5(0.092)	none	M
5	40	F	40	pituitary adenoma	5(0.125)	diabetes insipidus	S
6	62	F	57	pituitary adenoma	7(0.123)	none	M
7	41	M	65	pituitary adenoma	15(0.230)	none	
Group C							
1	18	M	60	pituitary adenoma	15(0.25)	none	
2	58	F	64	pituitary adenoma	8(0.125)	none	
3	23	F	55	pituitary adenoma	10(0.182)	CSF leakage	M
4	59	F	65	empty sella	7(0.107)	headache	S
5	20	M	90	prolactinoma	20(0.222)	none	
6	38	F	54	pituitary adenoma	5(0.092)	none	
7	27	F	41	pituitary adenoma	5(0.122)	headache	M
8	37	F	71	pituitary adenoma	15(0.211)	vomiting	

M size, the aerocele noted in two serial scans. S size, aerocele noted in one scan.
Blank indicates no aerocele on any scan.
Groups A, B and C are described in the text.

other advantage of PCG during this operation is its delivery of tumor tissue from the hypophyseal region by its slightly raising cerebrospinal fluid pressure (CSFP). This operation is usually performing in the low sitting position. Many reports describe tension pneumocephalus in patients in the sitting position[2–7]. N_2O anesthesia during transsphenoidal craniectomy may cause tension pneumoencephalus due to this low sitting position. We therefore, decided to study the magnitude of the increase in CSFP after intrathecal air injection with and without N_2O inhalation. The effect of subarachnoid N_2O injection on CSFP variations was also studied during N_2O anesthesia. We examined the incidence and location of postoperative aerocele on CT scans. Postoperative complications are reviewed.

Methods

Twenty-two patients with different pituitary or parasellar tumors undergoing transsphenoidal craniectomy were studied (table 1). All patients were premedicated with atropine 0.5 mg and hydroxyzine 50 mg. Anesthetic induction was carried out with thiamylal followed by succinylcholine and endotracheal intubation. Anesthesia was maintained by 0.5–1.0 % enflurane with

Table 2. Rectal temperature, central venous pressure, Pa_{CO_2}, and Pa_{O_2}

		control	10 min	20 min	80 min	end
Temp (°C)	A	36.0 ± 0.4	35.9 ± 0.4	35.8 ± 0.3	35.7 ± 0.3	36.5 ± 0.4*
	B	36.2 ± 0.6	36.1 ± 0.5	35.8 ± 0.5	35.8 ± 0.5	36.5 ± 0.6
	C	36.1 ± 0.5	36.5 ± 0.5	36.0 ± 0.5	36.1 ± 1.2	36.5 ± 0.8
CVP (mmHg)	A	5.8 ± 2.9	5.0 ± 3.2	4.3 ± 3.5	5.0 ± 3.8	4.2 ± 3.3
	B	4.8 ± 2.8	5.2 ± 3.8	4.3 ± 3.5	5.0 ± 3.8	4.4 ± 3.2
	C	6.7 ± 3.2	6.1 ± 2.8	6.8 ± 2.5	5.2 ± 2.3	4.7 ± 3.0
Pa_{CO_2} (mmHg)	A	34.2 ± 5.6	34.1 ± 5.2	32.4 ± 5.0	32.9 ± 2.6	36.4 ± 4.1
	B	34.6 ± 5.6	34.1 ± 5.4	35.8 ± 4.3	35.0 ± 3.6	36.4 ± 4.6
	C	36.3 ± 2.7	35.0 ± 4.0	34.3 ± 3.1	32.2 ± 9.1	37.0 ± 2.3
Pa_{O_2} (mmHg)	A	172.6 ± 56.3	158.4 ± 27.2	150.3 ± 21.9	151.7 ± 28.4	168.5 ± 53.9
	B	162.8 ± 74.0	152.5 ± 64.4	153.4 ± 57.9	152.7 ± 51.6	159.8 ± 42.5
	C	153.2 ± 51.2	152.6 ± 59.4	163.7 ± 56.9	150.8 ± 30.9	140.9 ± 27.8

Measuring and sampling times are before subarachnoid gas injection (control), 10 min, 20 min and 80 min after subarachnoid gas injection, and at the end of the operation (end).

Data shown are mean ± SD.

pancuronium, fentanyl and diazepam. After stabilization of anesthesia, a lumbar puncture was performed at the L4–5 vertebral interspace with a 17 gauge Tuohy epidural needle. A 1.0 mm ID polyethylene catheter was inserted into the subarachnoid space and advanced about 5 cm cephalad from the intervertebral space. Two three-way stopcocks, one for air injection and the other for cerebrospinal fluid drainage, were interposed between a pressure transducer and the subarachnoid catheter. The leakage of cerebrospinal fluid during the procedure amounted to be less than 5 cc. Patients were placed in a low sitting position. A radial artery or dorsal pedis artery was cannulated. All transducers were calibrated to the level of the patients' external auditory meatus. Variations in cerebrospinal fluid pressure (CSFP) and arterial pressure were continuously recorded with amplifiers and a thermal recorder. A central venous line was also inserted through an antecubital vein. Ventilation was controlled to maintain Pa_{CO_2} levels of 30–40 mmHg. Rectal temperature, central venous pressure, and arterial pressure were monitored continuously. No diuretics, steroids or mannitol were given throughout the study.

Three different procedures were, thereafter followed.

Group A comprised 7 patients. The anesthetic gas mixture used consisted of 33% O_2 and 66% N_2O. Air (5–20 cc, depending on weight) was injected through the stopcock into the lumbar subarachnoid space under the control of fluoroscopy to confirm pneumocisternography of the peripituitary cisternae. The remaining air in the catheter was flushed out by 5 cc normal saline. The three-way stopcock was immediately switched to the monitor position in order to measure the maximum point of CSFP. Variations in CSFP were monitored for 10 min without changing the composition of the inhalation gas mixture. The 66% N_2O was then replaced by 66% nitrogen. After the continuous CSFP recording for 70 min while an air-oxygen gas mixture was administered, the 66% N_2O inhalation was reintroduced and this condition was continued until the end of surgery.

Group B consisted of 7 cases. The gas mixture from the start of anesthesia was 33% oxygen and 66% nitrogen. Intrathecal air injection was performed as described above.

Table 3. Mean arterial pressure (MAP), cerebrospinal fluid pressure (CSFP), and cerebral ciculatory pressure (CCP)

		control	max 1	10 min	20 min	80 min	max 2	end
MAP (mmHg)	A	77.7±9.0	82.6±6.3	82.7±9.9	94.0±11.5*	93.4±10.2*	94.8±20.0*	89.2±14.2*
	B	76.0±15.6	80.0±11.7	83.7±13.1	88.1±13.6	91.8±14.1*	90.8±10.0*	90.8±16.5*
	C	72.0±9.1	75.0±8.5	74.3±12.2	80.1±18.5	92.1±10.1**	94.1±11.8**	92.6±11.3*
CSFP (mmHg)	A	13.1±2.7	33.2±14.1**	19.4±2.3**	12.1±5.4	13.7±4.3	17.0±3.9*	12.0±5.2
	B	13.0±4.1	34.2±21.9**	11.7±5.0	11.2±4.6	10.8±5.4	13.2±3.3	10.1±6.6
	C	9.7±3.0	23.8±7.9**	14.2±5.6	11.8±4.8	14.8±5.6*	17.5±7.2*	12.7±6.8
CCP (mmHg)	A	64.1±11.2	51.1±15.8	63.2±11.6	81.5±10.5*	82.2±12.8*	82.1±15.0**	82.4±12.0*
	B	63.5±14.9	46.0±24.5	72.0±13.0	72.5±14.7	81.0±15.9*	82.2±3.2*	86.8±17.5*
	C	62.5±11.3	52.4±11.3	62.0±13.0	68.3±14.8	77.2±7.6*	71.2±10.3	80.2±7.3*

Measuring times are before subarachnoid gas injection (control), immediately (Max 1), 10 minutes (10 min), 20 minutes (20 min), and 80 minutes (80 min) after subarachnoid gas injection, and at the time of maximum CSFP. Data shown are mean ± SD.

Thereafter, with the exception of enflurane concentration, the gas composition remained unchanged with continuous pressure recording until the completion of surgery.

Group C comprised 8 cases. An anesthetic mixture of 33% oxygen and 66% N_2O was given. An subarachinoid injection of N_2O instead of air was given according to the same procedures for air injection. Inhalated gas composition did not change during the operation. Arterial gases were analysed using ABL2 (Radiometer) before, 10 min, 20 min, and 80 min after the intrathecal gas injection. Arterial blood pressure and central venous pressure were measured at the same time. Maximum CSFP (Max. 1) was checked immediately after subarachnoid injection and during the rest of the study (Max. 2). Cerebral circulatory pressure (CCP) was calculated by the following formula: CCP = MAP − CSFP. After the completion of surgery, all patients were transferred to the intensive care unit and extubated within 4 hrs. Next morning, 12 slices of CT scan on the cranium were routinely taken. The incidence, location and size of aerocele were examined at each slice level.

Statistical significance observed within the occasions were tested using the paired Student's t-test, and multiple comparisons were performed using the analysis of variance for repeated measurements among groups and the Bonferonni correction for the unpaired t-statistics. The χ^2-test was used to determine statistical significance in the incidence of aerocele.

Results

There were no statistically significant differences in rectal temperature, hemodynamics variables or blood gas parameters between controls and the various reading among the three groups (table 2,3). Before the intrathecal injection of air or N_2O, stable CSFPs of 7–16 mmHg were obtained in all patients. Compared to the other groups, Group C showed a slight but statistically insignificant lower mean CSFP. Therefore, in order to compare the effects of subarachnoid air or N_2O injection on CSFP, variations are better expressed as percent changes of the initial value (fig.). With the injection of air or N_2O into the subarachnoid space, an immediate but transient increase in CSFP up to 200% was seen in all groups. Under 66% N_2O inhalation in group A, CSFP decreased gradually within 10 min to 150% of the initial value. Within 10 min of replacing the 66% N_2O with 66% nitrogen, CSFP returned to the initial value. The CSFP remained over the next 60 min. After the second 66% N_2O administration to the anesthetic mixture, the

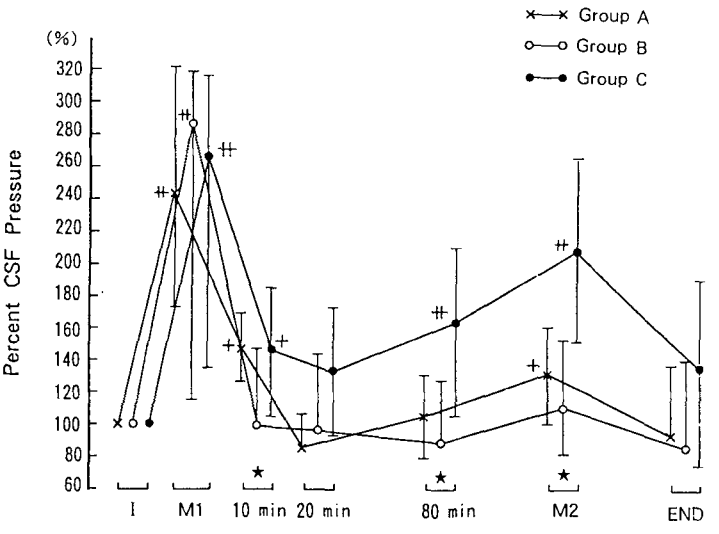

Fig. Percent changes in cerebrospinal fluid pressure (CSFP) : Group classification are seen in the text. Measuring times are before subarachnoid gas injection (I), immediately after subarachnoid gas injection (M1), and 10 min, 20 min, and 80 min after subarachnoid gas injection, at the time of maximum CSFP after the 80 min (M2), and at the end of the operation (END).
Data shown are mean ± SD. $+P < 0.05$ and $++P < 0.01$ indicate a significant difference from initial CSFP for that group. $\bigstar P < 0.05$ indicates a significant difference between group C and the other groups.

increase in CSFP was less than that after the first 66% N_2O. In group B, CSFP remained unchanged throughout the observation period despite the intrathecal air injection. Concerning group C, subarachnoid N_2O injection instead of air slightly raised CSFP above the initial value. This peaked at 205% of initial value at the maximum (M2). The subarachnoid gas injection transiently decreased cerebral circulatory pressure (CCP). Magnitude of the decrease in CCP depended on the injected gas and saline volume. Clinically, the decreases in CCP were not critical. Average CCPs among three groups did not significantly differ. CCP gradually increased in all groups after the start of operation due to a concomitant rise in arterial blood pressure. There was no statistical difference among three groups in the incidence and size of aeroceles demonstrated on CT scan (table 1). However, the incidence of aerocele in group C seems to be less. Most of aeroceles were located in the frontal subdural space. Some were found in the subarachnoid space of the Sylvian fissure. Locations of aeroceles are thought to depend on the patient's postoperative position. Postoperative complications are listed in table 1.

Discussion

Clinically, a number of factors can contribute to variations of CSFP. They include arterial carbon dioxide tension, arterial blood pressure, central venous pressure, body temperature, plasma osmotic pressure, and CSF volume. Intracranial space-occupying masses such as brain tumor, hematoma and intracranial entrapped air may also be factors. These first four factors remained almost unchanged throughout the study. Thus, fluctuations in CSFP mainly reflect to changes of volume, pressure, or both, of the gas space accumulated in the parasellar cisternae after lumbar subarachnoid gas injection. The volume and pressure of a closed gas containing space within the body increase under N_2O anesthesia depending on a partial pressure gradient of any gas existed between the gas space and the blood. This is because N_2O is carried to it in greater quantity and at a more rapid rate than nitrogen is carried away. Thus, a 66% N_2O-33% oxygen inhalation may produce a maximum increase of two-third of atmosphere theoretically[1]. As a result, expansion of the intracranial gas space may produce a marked increase in CSFP, as it is surrounded by a less compliant wall. This was seen in the record of group A, in which CSFP increased up to about one half of the initial value while N_2O was administered for ten minutes after subarachnoid air injection. Conversely, CSFP

did not change in group B. This is because under 66% nitrogen-33% oxygen inhalation, only a slight gradient in the partial pressure for nitrogen exists between the air space and the blood. These findings indicate that the volume and the composition of gases in the intracranial gas space mostly have the greatest effect on CSFP under N_2O anesthesia. Our clinical study also supported the hypothesis, based on experimental data, that the withdrawal of N_2O anesthesia during formation of an intracranial gas space leads to decrease CSFP, as N_2O diffuses from the cavity back into the blood[8]. A second N_2O administration to the inhaled mixture did not elevate CSFP as much as the first, as the intracranial gas space had become smaller during N_2O withdrawal from anesthetic mixture. Discontinuation of N_2O for 60 min during this procedures may prevent excessive CSFP elevation. If the contrast gas is N_2O, the increase in CSFP can theoretically be attenuated, even during N_2O anesthesia. Some investigators recommended N_2O contrast in PVG as it maintains CSFP within the normal limits[9,10]. The blood stream carries away more N_2O molecule from the intracranial N_2O space than it carries there. Because the partial N_2O pressure in the intracranial gas space is slightly higher than that in the blood. We had therefore, anticipated CSFP decreased. However, a gradual increase in CSFP about 200% was observed. Other mechanisms must contribute to this elevation, possibly including intracranial arterial pressure. We observed that a transient increase in CSFP was associated with a concomitant increase in arterial pressure. However, the continuous CSFP elevation not correlated to the transient increase in AP, was seen. This continuous CSFP elevation at the 80 min point may relate to the effect of N_2O on cerbral blood volume. It is known that N_2O associated with inhalation gases such as halothane, increases cerebral blood flow[11]. However, N_2O was administered from the start of anesthesia. This should not therefore, be the case. Our impression was that the intracranial gas space gradually shrank under fluoropscopic observation. The mechanism of delayed CSFP elevation is, therefore, unknown. This CSFP increase however, assist the delivery of pituitary tumor tissue from the parasellar region.

Tension pneumocephalus frequently occurs in posterior fossa surgery performed in the sitting position[2–7]. Toung and associates[12] showed an equally high incidence of aerocele in patients in the park-bench and prone positions as in the sitting position. The main contributing factor to the development of pneumoencephalus may be the amount of CSF drained during surgery[13,14]. Opportunities to drain CSF during transsphenoidal craniectomy which performed in the low sitting position, are rare. If a surgical penetration of basilar dura occurs, the gravity drains CSF and the air entrapment caused by the "inverted pop bottle"[3] phenomenon leads to tension pneumocephalus during N_2O inhalation. Discontinuance of N_2O administration must be indicated when surgeons report CSF leakage. We did find an insignificant correlation between the incidence and location of aerocele and the type of anesthesia. In our study, severe pneumoencephalus was not seen, even in cases in whom CSF leaked during surgery. A small amount of gas was entcaptured in the intracranial cavity. If N_2O fills the aerocele, it would be absorbed within 12 hr due to its high solubility in blood. Some patients complained of postoperative headache and vomiting. These symptoms may relate to the existence of intracranial aerocele. We also consider it better to discontinue N_2O administration before closure of the basilar floor. A case of postoperative diabetes insipidus was transient and a brain stem bleeding case in group B may not be correlated with the anesthetic technique, but with the surgical procedure.

Another critical event in the current anesthetic procedure is the transient decrease in CCP immediately after gas injection. However, this does not seem to damage the brain as it is not less than 40 mmHg. The arachnoid granulations are, probably able to compensate for the raised CSFP, permit overflow into the superior sagital sinus[15]. Al-

though the exact critical opening pressure is unknown, this compensatory mechanism may attenuate the immediate increase in CSFP after intrathecal gas injection.

In conclusion, we have confirmed the historical finding[16,17] that CSFP increases in patients injected with air into a cranium under N_2O anesthesia, even after less than 15 cc of intrathecal air injection for PCG. The withdrawal of N_2O from the anesthetic gas mixture for 60 min may help to reduce the extreme increase in CSFP during PCG. The mild increase in CSFP after the second N_2O administration to inhaled gas may help to deliver tumor tissue from the hypophyseal region. Nitrogen inhalation throughout PCG has the advantage of preventing an increase in CSFP, but has the disadvantage of increasing the possibility of intracranial aeroceles. N_2O inhalation after subarachnoid injection of N_2O fails to eliminate the rise in CSFP but does reduce the incidence of intracranial pneumocephalus after transsphenoidal craniectomy.

(Received Oct. 25, 1990, accepted for publication Feb. 21, 1991)

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