Positive End-expiratory Pressure Reduces Pneumocephalus in Spinal Intradural Tumor Surgery

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Abstract: We tested the hypothesis that 5 cm H_2O of positive end-expiratory pressure (PEEP) reduces the incidence of pneumocephalus in patients who undergo spinal intradural tumor surgery. Fifty-three ASA I to III patients who underwent thoracolumbar intradural tumor surgery between the years 2003 and 2006 were included in this study. All patients received propofol, fentanyl, and cisatracurium for induction of the anesthesia. Maintenance was provided by propofol infusion and, oxygen (50%) and air (50%). Group I (n = 28) did not receive PEEP whereas group II (n = 25) received PEEP as 5 cm H_2O. Cranial computerized tomography was taken at 8 hours after the surgery and cases were evaluated for pneumocephalus using BAB Bs200ProP Image System software. Pneumocephalus areas between 0.03 and 4.24 cm^2 were observed in 9 patients, 8 in group I and 1 patient in group II at the 8th postoperative hour, at various localizations. There were no neurologic findings in other patients except for 2 patients in group I who presented with headache and mental status change. Although the cerebrospinal fluid leakage is minimal, N_2O is not used and the patients are well hydrated, pneumocephalus with neurologic deficits may occur in patients undergoing microsurgical spinal intradural tumor surgery in prone position. In our study, we showed that using 5 cm H_2O PEEP perioperatively reduced the risk of pneumocephalus. However, more cases must be studied to support this hypothesis.

Key Words: intradural tumor, positive end-expiratory pressure (PEEP), pneumocephalus, prone

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Occurring in a variety of clinical settings, pneumocephalus has important anesthetic implications, particularly if N_2O is used. One common cause of pneumocephalus is a craniotomy or craniectomy. Patients undergoing these neurosurgical procedures may be at increased risk of tension pneumocephalus if N_2O is used during a subsequent anesthetic.[1] Furthermore, it is a well-known complication of spinal anesthesia due to dural puncture performed accidentally in execution of epidural anesthesia; especially when loss of resistance technique was used and posterior fossa surgery performed in sitting position. However, we are not aware of pneumocephalus reported after thoracolumbar intradural tumor surgery in prone position.[2–9]

We demonstrated widespread pneumoencephalus in cranial computerized tomography (CT) performed for headache and postoperative delayed recovery of a patient who underwent spinal intradural tumor surgery. During the following months, we have also observed pneumoencephalus in some other patients who underwent spinal intradural tumor surgery. Therefore, we decided to evaluate whether pneumoencephalus could be prevented when 5 cm H_2O of positive end-expiratory pressure (PEEP) is applied to patients receiving mechanical ventilation during surgery in prone position. We hypothesize that 5 cm H_2O of PEEP reduces the incidence of pneumocephalus because it increases the cerebrospinal fluid (CSF) pressure by way of increasing the intrathoracic pressure and minimizing the negative pressure effect caused by CSF leakage from the dural defect.

MATERIALS AND METHODS

The study was approved by the ethics committee of Ministry of Health, Okmeydani Research and Training Hospital and informed consent was obtained from each patient. Fifty-three ASA I to III patients undergoing thoracolumbar intradural tumor surgery were randomly assigned to 2 different groups (1 of 2 groups). Patients were allocated into 2 groups before the study and coded with computer-generated codes based on a 2-way randomization. Computer-generated codes were kept in sequentially numbered envelopes and the envelopes were opened 3 hours before the surgery. Exclusion criteria were body weight more than 130% of ideal body weight, uncontrolled hypertension (uncontrolled hypertension with blood pressure higher than 140/90 mm Hg), severe respiratory disease such as asthma bronchiale, ischemic cardiac findings at echocardiography (ECO) during preoperative visit or cardiac conducting defects (eg, second-degree atrioventricular block, left brunch block). It was impossible for us to perform ECO in all of the

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patients before the operation. ECO was performed only in required ones among patients excluded from the study.

Before the induction of anesthesia, routine monitoring of electrocardiography and pulse oximetry (Datex-Ohmeda S/5 Compact Critical Care Monitor) were started, and an IV line was placed. The Bispectral Index (BIS) electrodes were placed on the forehead and were connected to an A-2000 BIS monitoring system (Aspect Medical Systems, BIS XP, Framingham, MA). After preoxygenation for at least 2 minutes, anesthesia was induced with fentanyl 1 μg/kg and propofol in increments of 20 mg every 5 seconds until the BIS reached a predetermined value of 60. After induction with propofol, neuromuscular blockade was induced using cisatracurium in a bolus dose of 0.2 mg/kg followed by continuous intravenous infusion to maintain 90% suppression of the single twitch response. Anesthesia was maintained with air (50%), oxygen (50%), and propofol. The propofol infusion was started at a rate of 10 mg/kg/h and titrated to maintain a BIS in the range 40 to 60. Surgeries were performed under general anesthesia, using microsurgical techniques with posterior approach when the patient was in the prone position. Dose adjustment of fentanyl was based on standard clinical signs and hemodynamic measurements. Signs of inadequate analgesia, defined as an increase in heart rate and mean arterial pressure of more than 20% of the baseline were managed with increasing or decreasing the dose of fentanyl.

The patients were ventilated mechanically with an oxygen/air mixture to maintain an adequate oxygenation and a $PaCO_2$ level between 30 and 35 mm Hg (Datex-Ohmeda S/5 Avance). PEEP was not applied to patients in group I (n = 28) during surgery. Group II patients (n = 25) received PEEP in 5 cm H_2O. The operating room temperature was maintained at 20 to 21°C. A heating blanket was used with in all of the patients to save body temperatures between 35 and 37°C. Body temperature was measured with a probe inserted into the nasopharynx after intubation of the patient. Approximately 30 minutes before the end of the surgery, the cisatracurium infusion was discontinued. After discontinuation of the cisatracurium infusion, the patients were allowed to recover spontaneously until the return of T1 = 25%. Then a combination of neostigmine 0.02 mg/kg and atropine 0.01 mg/kg were given to antagonize the neuromuscular blockade. The times for return of T1 to 25% and return of the TOF ratio (T4/T1) to 70% were recorded. Propofol was discontinued on skin closure and the patient was allowed to wake up and was extubated. Cranial CT was performed in all patients 8 hours after the surgery to detect the presence and location of intracranial air. BAB Bs200ProP Image System software was used to calculate locations of pneumocephalus areas and their size. Appearance of new neurologic symptoms in the postoperative period was also recorded.

Statistical Analysis

Statistical analysis was made with $F\chi^2$: *Fisher exact 2-way test*, student *t* test, and χ^2 tests. A *P* value below 0.05 was considered significant. After power analysis, when we considered Δ:0.25 and the lowest success rate as 0.04 in the assessment performed according to incidence of pneumocephalus, sample size was determined as n:42 in the groups assigned for power:0.80, β:0.20, and α:0.05.

RESULTS

The 2 groups were similar in terms of age and sex. Intradural tumor had been located in thoracal region in 75% of the patients in both groups. However, no significant difference was found between the localization of the tumor and the occurrence of pneumocephalus ($P > 0.05$) (Table 1).

Pneumocephalus was observed in 1 patient in group II (4%) and in 8 patients in group I (28.6%) at the 8th postoperative hour, at a maximum of 10 localizations. The size of air on cranial CT ranged between 0.03 and 4.24 cm^2. In group I, early in the postoperative period, 2 patients had headache and changes in their consciousness level (Figs. 1–3). Locations of pneumocephalus and their size are shown in Tables 2 and 3.

DISCUSSION

Pneumocephalus is an important radiologic finding which may indicate severe pathologies. General status of the patient in the postoperative period and concomitant findings can give clues to diagnosis. The rarity of the condition may obscure the clinical diagnosis and lead to unnecessary procedures and prolonged patient discomfort.[2] Pneumocephalus may be localized at epidural, subdural, subarachnoid, parenchymal, ventricular, or

TABLE 1. Demographic Data

	Group I (n = 28)	Group II (n = 25)		*P*
Age (y)	44.96 ± 10.99	42.0 ± 11.81	*t*:0.946	0.349
Sex (m/f)	19/9	16/9	χ^2:0.088	0.767
Patients with pneumocephalus	8 (28.6%)	1 (4.0%)	FE	0.026
Location of the lesion				
Thoracic	21 (75.0%)	19 (76.0%)	χ^2:0.007	0.933
Lumbar	7 (25.0%)	6 (24.0%)		

Data are presented as mean ± SD.
FE indicates Fisher exact test; *t*, student *t* test.

FIGURE 1. Patient 1. Widespread air in the prepontin cystern, suprasellar cystern, left-right temporal fossa, left-right sylvian fissure, and interhemispheric fissure at the 8th postoperative hour.

FIGURE 2. Patient 1. Suprasellar cystern, left-right sylvian fissure, and interhemispheric fissure are marginal; however, newly produced air is seen in quadrigeminal cystern at the 32nd postoperative hour.

vascular regions. Air may be detected rarely in more than 1 compartment.[10,11] We tested the hypothesis that 5 cm H_2O of PEEP reduces the incidence of pneumocephalus in patients who undergo intradural tumor surgery because it increases the CSF pressure by way of increasing the intrathoracic pressure and minimizing the negative pressure effect caused by CSF leakage from the dural defect.

In our study, widespread pneumoencephalus, particularly in prepontine area, was seen in patients who did not receive PEEP; however, there was only 1 case of pneumocephalus among patients who received 5 cm H_2O of PEEP.

The development mechanism of pneumocephalus is mainly based on 2 factors: a reduction in intracranial pressure and the presence of a defect in the dura.[12] It is caused by either a ball-valve mechanism that allows air to enter but not to exit the cranial vault, or by CSF leakage which creates a negative pressure with subsequent air entry.[13,14]

Pneumocephalus frequently depends on the position of patient and the use of nitrous oxide during surgery. Nevertheless, pneumocephalus was reported in literature in a patient who underwent inguinal hernia repair after spinal anesthesia and in another patient who underwent

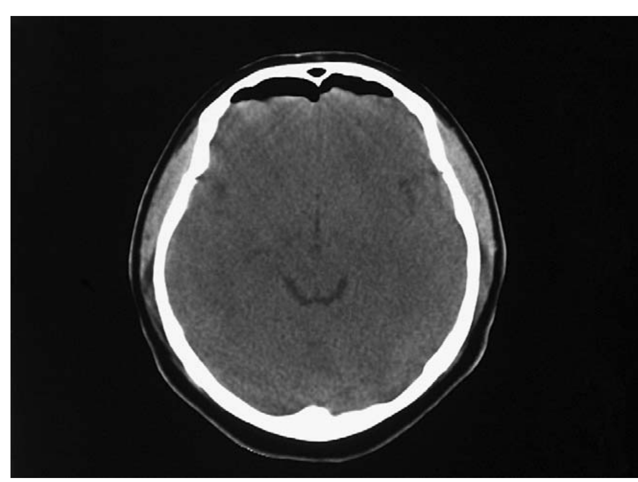

FIGURE 3. Patient 2. Air in left-right frontal region.

TABLE 2. Locations of Pneumocephalus on Cranial CT (n = Patients)

Left-right temporal fossa	n = 4
Prepontin cystern	n = 6
Left sylvian fissure	n = 3
Left lateral ventricle	n = 1
Right posterolateral medulla spinalis	n = 1
Right-left frontal region	n = 5
Suprasellar cystern	n = 5
Interhemispheric fissure	n = 2
Right cerebellum	n = 1

craniopharangioma surgery in supine position under general anesthesia.[15,16] Sitting position increases the probability of significant pneumocephalus.[9,17] In this position, air readily enters the subarachnoid space as CSF is lost during surgery. If nitrous oxide is used, it should be discontinued just before the closure of dura because of its potential to increase pneumocephalus. Expansion of a pneumocephalus after dural closure compresses the brain and delays awakening after anesthesia.[18]

Luce et al[19] investigated the PEEP value at which CSF pressure increase during mechanical ventilation under general anesthesia in dogs, and they demonstrated that 5 cm H_2O of PEEP increased CSF pressure by increasing superior vena caval pressure and subsequently decreasing cerebral venous outflow. In our study, anesthesia was maintained with oxygen (50%) and air (50%) in 2 study groups; nitrous oxide was not used and the patients were not operated in sitting position. With similar study settings, pneumocephalus was observed in only 1 patient in PEEP group which shows that CSF pressure increases along with the increase in vena cava superior pressure when the patient is positioned in prone. Similar to our study, Cotev et al[20] showed that 5 cm H_2O of PEEP increased CSF pressure in dogs as a result of increased intrathoracic pressure and $PaCO_2$.

PEEP therapy can increase lung volume, improve lung compliance, and reverse ventilation/perfusion mismatching which is reflected as a decrease in venous admixture and an improvement in arterial oxygen tension. Excessive PEEP, however, can overdistend alveoli causing an increase in dead space ventilation and reduction in lung compliance. Thus, the work of breathing may be increased significantly. By compressing alveolar capillaries, overdistention of normal alveoli can also increase pulmonary vascular resistance and right ventricular afterload. A higher incidence of pulmonary barotrauma is observed when PEEP is added during mechanical ventilation, especially at levels greater than 20 cm H_2O. Central venous pressure-raising may increase the severity of intracranial hypertension, and decrease hepatic and renal blood flow. Therefore, an optimal PEEP level should be selected without harmful effect associated with its maximal beneficial effects.[21]

We did not study the effects of higher PEEP values because it would be inappropriate for our patients without monitoring the intracranial pressure. Furthermore, the use of intracranial or cisternal monitoring in these surgeries would not be ethical only for investigational purposes.

Pneumocephalus usually appears with severe frontal headache, paresthesias, restlessness or agitation, vegetative symptoms, and hemodynamic changes.[22] Occasionally, there may be general convulsions and loss of consciousness.[4] Although the intensity of general symptoms is related to the air volume inside the brain, pneumocephalus causes other specific symptoms depending on the position of the air bubbles inside the nervous system.[23,24]

In our study, the consciousness levels of 2 patients with detectable pneumocephalus deteriorated after operations. The patients were symptom free before the operations. We have also not observed any improper monitoring findings revealing hemodynamic instability during the operation. The first patient began to reply to the verbal questions at the postoperative fourth hour; however, he complained of a severe frontal headache. The Glasgow Coma Scale was 10. He was maintaining his airway. Oxygen saturation was 98% to 99%. A CT scan was performed and pneumocephalus was detected in various localizations. His headache recovered on postoperative second day. The second patient replied to the verbal questions at postoperative third hour and was recorded as 11 on the Glasgow Coma Scale. His headache recovered on the second postoperative day.

In our study, patients were anesthetized in supine position and then repositioned to prone position. Jelly-rolls frames were used for all of the patients. To prevent the intracranial air accumulation during intracranial surgery, CSF leakage should be kept in minimum. In our study, CSF leakage was minimal for both groups due to the microsurgical approach used. Cerebral perfusion pressure was not monitored. Nevertheless, mean arterial

TABLE 3. The Size of the Air

	Mean ± SD	Minimum (cm)	Maximum (cm)	Count
Group II	0.48 ± 0.41	0.16	1.1	5
Group I	0.34 ± 0.35	0.09	0.56	7
Group I	1.66 ± 1.38	0.68	2.63	2
Group I	0.6 ± 1.28	0.03	4.24	10
Group I	0.62 ± 1.3	0.04	3.83	8
Group I	0.51 ± 0.63	0.07	1.56	6
Group I	0.76 ± 0.72	0.08	1.89	6

pressure was kept in a normal range and adequate hydration was maintained. Nitrous oxide was not used for any patient. Despite these precautions, pneumocephalus was observed in 8 patients in no PEEP group. Furthermore, pneumocephalus did not correlate with the thoracic or lumbar localization of the lesion.

Detecting the pneumocephalus by using imaging methods is important for the prognosis of the patient and for determining proper treatment protocol. If evaluation could be performed early after the trauma and surgeries, the possibility of diagnosing pneumocephalus would be higher.[5,25,26] However, because the rate at which a postoperative pneumocephalus resolves has not been well defined, the duration of this risk period is unknown.[1]

As in the Hernandez-Palazon et al[9] study, we obtained cranial CT scans of all patients at the 8th postoperative hour, and follow-up CT evaluations of patients with pneumocephalus were obtained at the 32nd postoperative hour. None of the patients had pneumocephalus at the 32nd hour except one who had a delayed postoperative recovery and headache.

In conclusion, pneumocephalus, which can appear with neurologic deficits, may occur in patients undergoing microsurgical spinal intradural tumor surgery in prone position. Although the CSF leakage is minimal, N_2O is not used and the patients are well hydrated. We showed that using 5 cm H_2O PEEP perioperatively reduced the occurrence of pneumocephalus. However, more cases must be studied to support this hypothesis.

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