diac performance in a heart already compromised by poor circulation. The preexisting beta-adrenergic blockade would have compounded the problems, since these drugs decrease cardiac muscle responsiveness and ability to compensate in the face of a failing heart. Also, pulmonary vasodilation and negative inotropic effects of acetylcholine would have decreased further the heart's ability to respond to changes in pulmonary compliance, leading to the development of pulmonary edema.

In summary, bronchospasm has not been reported previously as the primary event following systemic absorption of acetylcholine injected in accepted doses for myosis during routine cataract procedures. Because the drug is used widely for this purpose, it is important for both the anesthesiologist and the ophthalmologist involved in its administration to be aware of potential problems, especially in patients with a history of bronchospastic disease or severe coronary artery disease.

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Paradoxical Diuresis in Some Neurosurgical Patients Under Balanced Anesthesia

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Reduced urinary output and electrolyte excretion, especially sodium, occurs in patients subjected to anesthesia, possibly due to an approximate anesthesia induced 40% decrease in renal blood flow and 20–40% decrease in glomerular filtration rate.[1–3] Positive-pressure ventilation also decreases renal blood flow and glomerular filtration rate.[4,5]

Inappropriate secretion of antidiuretic hormone (ADH) occurs in certain cases of mediastinal tumors, expanding intracranial lesions, cerebral trauma, and coma. As a result hyponatremia, supranormal extracellular fluid volume, increase in glomerular filtration rate, and low blood urea nitrogen concentration occur.

We observed that some patients undergoing craniotomies for brain tumors have profound diuresis during induction of anesthesia. We, therefore, designed a prospective study to determine whether there was diuresis and, if so, what was the mechanism and does it correlate with the anatomic location or pathology of the intracranial lesion.

METHOD

Twenty-one consecutive patients undergoing neurosurgical procedures consented to participate in the study approved by the institutional review board. Five patients undergoing anterior or posterior cervical fusions constituted the control group. Sixteen patients underwent craniotomy for brain tumors. Patients undergoing craniotomies were restricted to fluid intake of 1,500–1,800 $ml \cdot day^{-1}$ and were receiving dexamethasone. They all had normal renal function as judged by their blood urea nitrogen (BUN) and creatine levels. All patients were premedicated with diazepam, 10 mg po, and atropine, 0.4 mg, or glycopyrrolate, 0.2 mg im. An indwelling urinary catheter was inserted at the time of premedication. After arriving in the operating room, an iv catheter was inserted into a peripheral vein for fluid administration and a radial artery catheter inserted for blood pressure monitoring and blood sampling. Prior to induction of anesthesia, the bladder was emptied completely and urine

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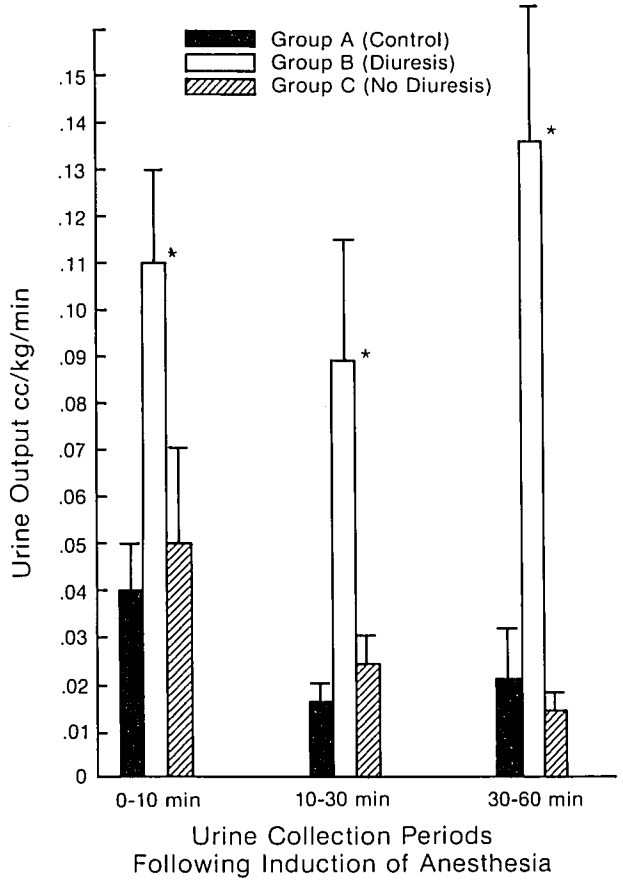

FIG. 1. Rate of urine output during the first hour following induction of anesthesia.

and blood samples were obtained. Anesthesia then was induced with thiopental, 2–4 mg/kg, morphine, 0.1–0.2 mg/kg iv in divided doses and maintained with 60% nitrous oxide and further increments of thiopental and morphine as needed. Patients were paralyzed with pancuronium, 0.1 mg/kg, and hyperventilated to maintain Pa_{CO_2} at 27 ± 2 mmHg. In patients undergoing craniotomies iv fluid administration was restricted to that needed for administration of drugs. Diuretics, furosemide or mannitol, were administered at the beginning of surgical stimulation as requested by the surgeon, but only after the 1-h observation period. Urine and blood samples were collected at 10, 30, and 60 min after induction and prior to surgical intervention and then every hour for a total of 5 h. Urine samples were analyzed for osmolarity and electrolytes and blood samples for electrolytes, osmolarity, and antidiuretic hormone (ADH) level by radioimmunoassay.[7]

Diuresis was accepted as urine output in excess of 2 $ml \cdot kg^{-1} \cdot hr^{-1}$. Patients were separated into two groups on the basis of observed urine output.

Statistical analysis of the data was done using Student's t test and a $P \leq 0.05$ was considered significant.[8]

RESULTS

Prior to surgical intervention, eight of the 16 patients undergoing craniotomies developed diuresis (group B) while the remaining eight did not (group C) as compared with the control group (group A). All three groups were similar with regard to age and weight. In the control group, the urinary output averaged 1.58 ± 0.37 $ml \cdot kg^{-1} \cdot hr^{-1}$ in which intravenous fluid was administered at a rate of 9.72 ± 1.57 $ml \cdot kg^{-1} \cdot hr^{-1}$. These results were not statistically different from group C, where urine output and intravenous fluid administered were 1.55 ± 0.24 and 6.20 ± 0.72 $ml \cdot kg^{-1} \cdot hr^{-1}$. The patients who had diuresis develop had a significantly higher urine output of 6.57 ± 1.23 $ml \cdot kg^{-1} \cdot hr^{-1}$ despite a fluid load of only 4.18 ± 0.85 $ml \cdot kg^{-1} \cdot hr^{-1}$ (Fig 1).

No differences were noted between the three groups with respect to plasma electrolyte concentrations or osmolarity or ADH levels (table 1).

Similarly, at the preinduction period no difference existed between the three groups regarding urinary electrolyte concentrations or osmolarity. Sixty minutes after induction of anesthesia, however, urine osmolarity had decreased from 576 to 243 mOsm ($P < 0.05$) in group B while groups A and C remained virtually unchanged. Likewise, the urinary sodium and potassium excretion decreased significantly in group B when compared with both preinduction levels and the control group excretion. Chloride excretion did not vary significantly between the groups (table 1).

During the surgical procedure, hourly urine and blood determinations revealed wide variation both within and between the groups, and no significant differences were noted.

There appeared to be no relationship between the development of diuresis and either location or histologic type of brain tumors in groups B and C (table 2).

DISCUSSION

The results of this study confirmed our observation that many patients undergoing craniotomy have an initial diuresis (group B). This diuresis is even more remarkable in that this group received the least amount of iv crystalloid administration. Abnormally low levels of ADH were ruled out as a cause because the ADH levels in the three groups were similar. The primary difference between group B and groups A and C appears to be a diuresis with a low osmolar load as expressed by a low urinary sodium and potassium content. The possible role of renin or aldosterone in the diuresis have not been explored. Hyperglycemia can cause diuresis but appears to be most unlikely in these cases because glucose load was limited to 20 g and there was no change in plasma osmolarity. Though our initial clinical impression was

TABLE 1. Changes in Urine and Plasma Osmolarity and Electrolytes and Plasma ADH

	Group A (n = 5)		Group B (n = 8)		Group C (n = 8)	
Sample Time	Preinduction	60 min	Preinduction	60 min	Preinduction	60 min
Urinary osmolarity (mOsm)	629.00 ± 57.67	520.40 ± 133.8	576.38 ± 70.83	243.38 ± 70.27*	599.25 ± 85.43	608.38 ± 61.22
Plasma osmolarity	272.60 ± 10.35	290.20 ± 5.53	281.13 ± 4.19	282.38 ± 6.40	277.0 ± 1.89	285.75 ± 3.06
Plasma electrolytes mEq/l						
Na	134.76 ± 5.70	138.54 ± 1.12	130.56 ± 2.91	130.84 ± 3.37	133.25 ± 2.59	134.0 ± 2.16
K	5.38 ± 0.62	5.57 ± 0.80	4.20 ± 0.30	4.13 ± 0.27	5.29 ± 0.93	4.62 ± 0.56
Cl	97.14 ± 2.72	103.02 ± 1.34	96.51 ± 2.48	98.19 ± 2.03	97.05 ± 2.08	98.66 ± 2.43
Urinary electrolytes mEq/liter						
Na	97.60 ± 33.13	92.95 ± 30.41	115.41 ± 22.45	23.60 ± 5.13*	72.49 ± 15.27	70.66 ± 8.41
K	39.86 ± 11.77	40.36 ± 22.27	43.23 ± 5.14	15.18 ± 4.31*	64.76 ± 10.17	69.03 ± 7.27
Cl	101.40 ± 26.16	86.60 ± 28.76	96.01 ± 15.77	65.76 ± 15.47	84.23 ± 18.95	69.03 ± 10.51
ADH uv/ml	3.05 ± 1.08	1.22 ± 0.20	2.24 ± 0.38	1.53 ± 0.35	2.22 ± 0.42	2.20 ± 0.57

Values are mean ± SE. * $P < 0.05$.

TABLE 2. Anatomic Location and Pathology of Tumors in Patients Undergoing Craniotomies

Group B (Diuresis)		Group C (No Diuresis)	
Anatomical Location	Pathology	Anatomical Location	Pathology
Frontal	Astryocytoma	Frontal	Astryocytoma
Frontal	Metastatic	Frontal	Glioblastoma
Frontal parietal	Glioma	Frontal	Meningioma
Parieto occipital	Meningioma	Parieto occipital	Glioblastoma
Temporal	Astryocytoma	Temporal	Meningioma
Suboccipital	Acoustic neuroma	Suboccipital	Hemangioblastoma
Suboccipital	Acoustic neuroma	Suboccipital	Hemangioblastoma
Suboccipital	Chondroma	Suboccipital	Facial nerve decompression

that the diuresis was seen primarily with frontal lobe tumors, this too was not confirmed by our study.

In summary, we found a group of patients undergoing craniotomy for tumors who develop a significant water diuresis before surgical stimulation, which appears to be unrelated to ADH levels and has no relationship to the location or type of tumor. Further studies are needed to isolate the mechanism involved in the genesis of the diuresis.

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