TABLE 2. Suggested Guidelines for Intraoperative Autotransfusion Trials in Patients with Sickle Cell Disease

<table>
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<tr>
<th>Preoperative considerations</th>
<th>Intraoperative considerations</th>
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<tbody>
<tr>
<td>Exchange transfuse to attain 60–70% Hb A and Hct 30–56%</td>
<td>Solutions with physiologic pH for wound lavage and cell washing</td>
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<tr>
<td>Bank autologous blood if feasible</td>
<td>Limit negative pressure at tip of large bore suction cannulae in surgical field to &lt;100 mmHg</td>
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<td>Compare smears of venous and processed blood prior to reinfusion to quantitatively assess sickling</td>
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<td>Monitor pH, PaO₂, and Hct of processed blood</td>
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<td>Anticoagulate harvested blood (heparin) until processing</td>
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<tr>
<td></td>
<td>Wash RBC with 1–2 l of normal saline to remove waste products and filter before reinfusion</td>
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had no adverse sequelae from IAT, it appears that intraoperative salvage of blood is possible in the patient with homozygous sickle cell disease if exchange transfusion is given preoperatively. Table 2 suggests considerations for future trials of IAT in patients with sickle cell disease. If extensive sickling is apparent after processing of blood, as determined by microscopic examination, reinfusion should be aborted. The key feature for successful IAT may well be adequate preoperative exchange transfusion to provide dilution of sickle cells such that extensive sickling does not occur in the centrifuge bowl of the autoinfusion device.

REFERENCES


Anesthesiology

Liquid Nitrogen Instillation Can Cause Venous Gas Embolism

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Cryosurgery utilizing instillation of liquid nitrogen is often employed to extend the surgical margin of excision in cancer operations. Liquid nitrogen boils at −195°C, rapidly producing nitrogen bubbles at room temperature. Although intravascular embolization of gas bubbles is a recognized hazard whenever a gas is introduced into a body cavity under positive pressure,1−5 we are unaware of any previous clinical reports describing the syndrome of pulmonary gas embolism coincident with pouring liquid nitrogen into a surgical field. Recently, however, one of our patients developed signs suggestive of pulmonary gas embolism during such a procedure.

CASE REPORT

A 58-yr-old, 105-kg man with a 20 pack-yr history of tobacco use was scheduled to undergo curettage of a suspected intraosseous low-

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grade (IA) chondrosarcoma of the left proximal humerus. This was to be followed by cryosurgery, involving instillation of liquid nitrogen into the tumor bed. The remainder of his medical history was non-contributory, and preoperative laboratory studies, ECG, and chest x-ray were normal. Preanaesthetic medication consisted of 1 mg midazolam, 8 mg morphine, and 0.2 mg glycopyrrolate.

Intraoperative monitoring included the following: ECG lead II, digital pulse oximeter, a 16-G central venous catheter inserted via the right internal jugular vein, a right radial arterial catheter, an esophageal stethoscope and temperature probe, and end-tidal gas analysis using a Perkin-Elmer mass spectrometer with continuous capnometry.

Anesthesia was induced with thiopental 300 mg iv and maintained via endotracheal tube with 60% N₂O in O₂ supplemented by isoflurane, 0.4–0.8% inspired. Total fresh gas flow was 5 l/min. Heart rate and blood pressure ranged between 60 and 88 beats per min and 100/60 and 158/90, respectively. Central venous pressure (CVP) ranged between 7 and 11 mmHg. End-tidal CO₂ tension (PETCO₂) was constant at 28 mmHg; end-tidal nitrogen tension (PETN₂) was noted to be undetectable. Vital signs and PETCO₂ remained normal and stable up to the time of cryosurgery.

After 105 min of surgery all visible tumor had been excised, leaving an opening in the humerus that measured approximately 5 cm × 2.5 cm to a depth of 1.5 cm. With the humerus in a horizontal position in the midaxillary plane, liquid nitrogen was poured into the tumor bed through a funnel, filling the surgically created cavity. Additional liquid nitrogen was instilled twice (total volume approximately 38 ml) as the fluid level decreased rapidly by evaporation. Approximately 30 s thereafter, the PETN₂ was noted to have increased dramatically, from 0 to 256 mmHg. The surgeon was notified of the appearance of exhaled nitrogen and the liquid nitrogen was promptly aspirated from the tumor bed. PETN₂ peaked at 380 mmHg 30 s thereafter, followed within 1 min by an increase in inspired nitrogen level (PIN₂) to 200 mmHg. Within 1 min of observing exhaled N₂, the PETN₂ had decreased to 8 mmHg.

A presumptive diagnosis of venous gas embolism was made and the following measures were taken: the operating table was tilted so that the patient’s left arm was below heart level, N₂O was discontinued, 100% O₂ was administered at 5 l/min, and 20 ml of blood was rapidly withdrawn from the central venous catheter with a syringe. Gas bubbles were not recovered despite the magnitude of the PETCO₂ and PETN₂ changes; there was no change in audible heart sounds, O₂ saturation, BP, or ECG. Arterial blood gas tensions at this time were as follows: PaO₂ = 512 mmHg, PaCO₂ = 34 mmHg, and pH = 7.45. Inspection of the anesthesia machine and endotracheal tube cuff revealed no loose connections or leaks that might have resulted in entainment of room air. Within 10 min PIN₂ and PETN₂ had returned to undetectable levels and PETCO₂ had increased to 24.1 mmHg. At this time blood gas tensions were as follows: PaO₂ = 471 mmHg, PaCO₂ = 36 mmHg, and pH = 7.42.

The humeral cavity was filled with methyl methacrylate under digital pressurization and the incision was closed. The remainder of the anesthetic was uneventful. In the recovery room vital signs were stable and arterial hemoglobin saturation was 98% by digital pulse oximetry while breathing room air. A thorough examination by a neurology consultant revealed no neurologic sequelae. The patient was discharged from the recovery room 4.5 h later and had an uneventful postoperative course.

DISCUSSION

Cryosurgery is defined as the repetitive freezing and thawing of tissues to at least −20°C. Liquid nitrogen has a boiling point of −195°C and is usually applied directly to a neoplasia in an attempt to cause its complete necrosis by freeze injury. 6 Although we are unaware of cryosurgery-related N₂ embolization in the anesthesia literature, at least one reported intraoperative death during cryosurgery was thought to be due to lethal gas embolization. 6 In the veterinary literature Harvey reported 2 instances of cardiac arrest following instillation of liquid nitrogen into the mandible narrow cavities of dogs after tooth extraction. 7 Postmortem radiographs of the thorax were performed immediately after resuscitative efforts were terminated. Air was demonstrated in the veins of the mediastinum, the right atrium, and the right ventricle. Given the prevalence of cryotherapy in oncologic surgery, particularly in richly perfused areas such as the bone marrow, it is perhaps surprising that more cases of gas embolism have not been reported previously.

By applying Charles’ law to correct for our patient’s body temperature, it is possible to calculate that the approximate 38 ml of liquid nitrogen poured into the tumor bed of the patient’s humerus would have rapidly vaporized into approximately 27.4 l of N₂ gas. 8 Although it is probable that the majority of this gas exited into the atmosphere through the surgical wound, it is obvious from the PETN₂ measurement of 380 mmHg that a considerable amount of nitrogen was suddenly transported to the pulmonary circulation and exhaled. Given an approximate 1-l lung and anesthesia circle system volume, we estimate that the PIN₂ of 200 mmHg represents a volume of 200/760 × 10 l, or a minimum of 2.6 l of exhaled N₂. With a fresh gas flow rate of 5 l/min, this calculation is somewhat conservative because some dilution of the exhaled nitrogen would have been ongoing by the time the PIN₂ of 200 mmHg was observed.

The question of how this N₂ was transported from the humerus to the lungs is subject to conjecture. The site of this patient’s tumor was in the proximal shaft of the humerus, near the major nutrient arterial and venous supply to the area. Thus, one simple explanation could be that N₂ bubbles produced by the boiling liquid N₂ entered the venous circulation and were carried to the alveolar capillaries and subsequently exhaled. The precipitous reduction in PETCO₂ and subsequent arteriovenous CO₂ tension gradients suggest that gas bubbles caused pulmonary vascular obstruction and wasted ventilation. There was, however, no change in blood pressure, heart tones, heart rate, or rhythm, and no bubbles could be recovered upon aspirating from the central venous catheter. It is common to be unsuccessful in recovering embolized bubbles from a central venous catheter, 6 however, and vital signs can remain reasonably stable despite unequivocal evidence of venous air embolism. 10 If it is difficult to conceive of 2.6 l

of embolized gas not causing more profound cardiovascular symptoms.

An alternative possibility is that a considerable portion of the N₂ was dissolved in blood passing through this richly perfused area and was then transported to the lungs. Nitrogen is poorly soluble in blood (Oswald solubility coefficient at 37°C C = 0.015), with only 1.5 ml of N₂ dissolved in 100 ml of blood at equilibrium. Because the PET₂ was nearly zero just before the liquid N₂ was instilled, it is possible that the size of embolized N₂ bubbles would have been slightly reduced by dissolving in the venous blood, but it is unlikely that 2.6 1 of N₂ could have been carried to the lungs in the dissolved state in 1 min. Furthermore, the second blood gas determination indicates that there was a considerable alveolar–arterial gradient for CO₂ present 10 min after the acute event. This is compatible with a residual effect of gas bubbles in the pulmonary circulation, a process that continues in excess of 10 min both clinically and experimentally.¹⁰,¹¹

Nitrogen embolism during cryosurgery is presumably a rare event. In over 800 orthopedic cases in which free gaseous was facilitated by venting the bone cavity, Mar- cove reported no clinical symptoms of embolism or shock.⁶ However, the possibility of N₂ entering the bloodstream as gas bubbles does exist and may be reflected merely as the appearance of ET₂ and a decrease in ETCO₂; alternatively, it may produce cardiovascular collapse or paradoxical embolization to the cerebral or coronary circu-

lations. Accordingly, anesthesia personnel should be suspicious whenever liquid nitrogen is being instilled into a body cavity. Appropriate diagnostic and therapeutic modalities for detection and treatment of gas embolism should be in use.

REFERENCES


Anesthetic Complications in an Infant with Hyperexplexia

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Hyperexplexia is a hereditary disease with an autosomal dominant inheritance pattern with incomplete penetrance.¹ The condition is characterized by neonatal onset of excessive muscle rigidity with repeated myoclonic jerks, increased muscle tone, prolonged seizures, life-threatening apnea spells, and an exaggerated response to startle.

There has been only a single case report describing anesthesia for such a patient to date, an infant who re-

ceived an anesthetic for bilateral inguinal hernia repair. We present here the preoperative evaluation and anesthetic management of a 4-month-old infant with hyperexplexia complicated by two episodes of sudden apnea and stiffness.

REPORT OF A CASE

A 4-month-old male infant born of a spontaneous vaginal delivery without complications was found to have excessive response to loud noises (the child would contract its upper and lower extremities, returning to normal shortly after being held by the parents). Shortly after birth the child was evaluated and diagnosed as having hyperexplexia. Consistent with the inherited nature of the disease, the child's father, paternal grandmother, and paternal grandmother's mother were described as having excessive response to startle. No medications were prescribed at that time, and the child had no episodes of apnea or cyanosis according to the parents. The child was discovered to have bilateral inguinal hernias and was scheduled for surgical repair.