History

A 10-year-old 10.8-kg (23.8-lb) neutered male Jack Russell Terrier was evaluated at the University of Florida College of Veterinary Medicine prior to surgical removal of an osteosarcoma involving the right zygomatic arch. Prior to surgery, a CBC and serum biochemical profile, including measurement of serum electrolyte concentrations, were performed, along with blood typing and crossmatching. Results of clinicopathologic testing were unremarkable, and the patient was premedicated with hydromorphone (0.1 mg/kg [0.045 mg/lb], IM) and acepromazine (0.03 mg/kg [0.014 mg/lb], IM). Propofol (5 mg/kg [2.27 mg/lb], IV) was administered to effect, and the trachea was intubated. Anesthesia was maintained with isoflurane (delivered concentration, 1% to 2%) and fentanyl (0.3 µg/kg/min [0.14 µg/lb/min], IV). Monitoring consisted of ECG, pulse oximetry, capnography, and continuous measurement of blood pressure. For measurement of blood pressure, an arterial catheter was placed in the left metatarsal artery and connected to a transducer positioned at the level of the right atrium and calibrated to atmospheric pressure. Positive-pressure ventilation was started at a tidal volume of 120 mL and rate of 20 breaths/min. Fluid therapy with lactated Ringer’s solution (10 mL/kg/h [4.54 mL/lb/h], IV) was instituted.

During the surgical approach, the right facial artery was transected, resulting in severe hemorrhage and hypotension, with MAP decreasing from 85 to 45 mm Hg over a period of 10 to 15 minutes. Hemorrhage was controlled in 45 minutes, and the total blood loss was approximately 250 mL (approx 30% of total blood volume). Hypotension persisted for approximately 60 minutes.

At the time hypotension was first noticed, dopamine was administered at a rate of 5 µg/kg/min, and 2 boluses of hetastarch (2 mL/kg [0.91 mL/lb], IV, each) and a single bolus of hypertonic saline (7% NaCl) solution (1 mL/kg [0.434 mL/lb], IV) were administered. However, this resulted in little change in blood pressure (MAP, 48 mm Hg). The crystalloid infusion rate was therefore increased to 20 mL/kg/h (9.1 mL/lb/h). Approximately 30 minutes after hypotension first developed, a transfusion (approx 270 mL) consisting of 28-day-old packed RBCs was administered IV. The infusion rate for the first 15 minutes was 30 mL/h; thereafter, the infusion rate was 500 mL/h. The crystalloid infusion rate was reduced to 5 mL/kg/h while the blood transfusion was being administered; total volume of crystalloid fluids administered after commencement of hemorrhage was approximately 200 mL.

The patient’s blood pressure normalized (MAP, 70 mm Hg) toward the end of the blood transfusion. Shortly afterward, the patient developed ventricular tachycardia (200 beats/min), which responded to administration of a bolus of lidocaine (2 mg/kg, IV). Following this, the dog became bradycardic (50 beats/min) with second-degree atrioventricular blockade. The bradycardia responded to treatment with atropine (0.02 mg/kg [0.009 mL/lb], IV), and the heart rate increased to 190 beats/min. An arterial blood sample was collected for blood gas analysis, which revealed respiratory acidosis (Table 1). The patient’s body temperature was now 36.1°C (97°F).

Table 1—Results of arterial blood gas and serum electrolyte analyses performed in a dog that developed hyperkalemia while anesthetized.

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>—</td>
<td>7.10</td>
<td>7.18</td>
<td>7.16</td>
<td>7.34</td>
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<tr>
<td>PaO₂ (mm Hg)</td>
<td>—</td>
<td>450</td>
<td>489</td>
<td>430</td>
<td>90</td>
</tr>
<tr>
<td>PacO₂ (mm Hg)</td>
<td>58.8</td>
<td>57.8</td>
<td>57.3</td>
<td>38.0</td>
<td></td>
</tr>
<tr>
<td>Serum bicarbonate (mEq/L)</td>
<td>22.4</td>
<td>21.9</td>
<td>22.1</td>
<td>20.6</td>
<td>23.0</td>
</tr>
<tr>
<td>Serum sodium (mEq/L)</td>
<td>140</td>
<td>146</td>
<td>142</td>
<td>140</td>
<td>141</td>
</tr>
<tr>
<td>Serum potassium (mEq/L)</td>
<td>4.0</td>
<td>7.0</td>
<td>7.1</td>
<td>4.6</td>
<td>3.8</td>
</tr>
<tr>
<td>Serum ionized calcium (mEq/L)</td>
<td>—</td>
<td>—</td>
<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>Serum lactate (mEq/L)</td>
<td>1.0</td>
<td>2.0</td>
<td>2.5</td>
<td>1.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

— = Not measured.

Sample 1 was collected the day prior to anesthesia. Sample 2 was collected following administration of a packed RBCs transfusion because of severe hemorrhage and hypotension. Sample 3 was collected 10 minutes after sample 2. Sample 4 was collected 50 minutes after sample 2, at the end of the surgical procedure. Sample 5 was collected 12 hours after the surgical procedure.
Calcium gluconate (30 mg/kg [13.6 mg/lb], IV) and dextrose (100 mg/kg [45.5 mg/lb], IV) were administered, and fluid therapy with lactated Ringer’s solution was discontinued. The infusion rate of hypertonic saline solution was increased to 20 mL/kg/h (9.1 mL/lb/h) until the end of anesthesia. Approximately 10 minutes after this treatment, a second blood gas analysis was performed, which revealed persistent hyperkalemia and respiratory acidosis (Table 1). Insulin (0.1 U/kg, IV), terbutaline sulfate (0.1 mg/kg, IM), calcium gluconate (50 mg/kg [22.7 mg/lb], IV), and dextrose (500 mg/kg [227 mg/lb], IV) were administered.

Immediately after completion of the surgical procedure, a third blood gas analysis was performed; respiratory acidosis persisted, but serum potassium concentration had normalized (Table 1). The dog was allowed to recover from anesthesia. Electrolyte concentrations remained within reference limits, and the patient was monitored overnight with no complications noted. Results of a blood gas analysis performed overnight were unremarkable.

**Question**

What is the likely cause of the hyperkalemia that developed during surgery in this dog?

**Answer**

Administration of aged packed RBCs was the most likely cause of the sudden increase in serum potassium concentration in the dog described in the present report. Hyperkalemia secondary to administration of a massive blood transfusion is a rare but serious complication that can occur as a result of the high potassium concentrations that can develop in stored blood products. In this patient, acidosis, hyperthermia, and, possibly, potassium leakage from damaged tissues may have also contributed to the increase in serum potassium concentration. Other potential causes of high serum potassium concentration pertinent to this case include massive tissue damage, reperfusion injury, equipment malfunction, and iatrogenic administration.

**Discussion**

The potassium concentration in the supernatant of packed human RBCs is higher than the plasma potassium concentration in healthy people, especially for units of packed RBCs nearing the end of their storage life. In a previous report, investigators found that the potassium concentration in the supernatant of stored units of packed RBCs was approximately 4 mmol/L on day 0 but had increased to approximately 46 mmol/L by day 21. However, except for RBCs from dogs of certain Asian breeds, such as Akitas and Shiba Inus, canine RBCs lack high intracellular potassium concentrations. As a result, high potassium concentrations should not be common in stored canine blood. Thus, in the dog described in the present report, transfusion with packed RBCs may not have been the only cause of intraoperative hyperkalemia.

In people, transfusion-associated hyperkalemia is more common when a large volume of packed RBCs is administered, especially when the transfusion is administered during a period of hypovolemic shock. Massive transfusion is arbitrarily defined as administration of a transfusion equivalent to the patient’s estimated total blood volume (90 mL/kg [40.9 mL/lb]) in dogs in any 24-hour period, administration of a transfusion equivalent to more than half the patient’s estimated blood volume in any 3-hour period, or administration of 1.5 mL/kg/min (0.68 mL/lb/min) of any blood product for at least 20 minutes. In a previous retrospective study, hyperkalemia occurred in 20% of dogs that received a massive transfusion. However, given the transfusion rate and body size of the dog described in the present report, the packed RBCs transfusion did not meet the criteria for classification as a massive transfusion. In the previous study, most of the patients that developed hyperkalemia also had acidosis but, as in the dog described in the present report, the degree of hyperkalemia was in excess of that predicted given the degree of acidosis. In instances of large-volume transfusion, ionized hypocalcemia can also occur if citrate was used as an anticoagulant.

Surgery-related tissue trauma can lead to cell breakdown and release of intracellular potassium, contributing to hyperkalemia. Persistent respiratory acidosis may also play a role because respiratory acidosis can cause potassium ions to leave the intracellular space in exchange for hydrogen ions, increasing the serum potassium concentration. In the dog described in the present report, respiratory acidosis was most likely caused by anesthesia-induced hypoventilation. At the beginning of the procedure, we elected to allow for mild hyperventilation and maintained an end-tidal partial pressure of CO₂ between 40 and 45 mm Hg, resulting in respiratory acidosis. Permissive hyperventilation is well tolerated and beneficial to anesthetized patients breathing a gas mixture with a high oxygen content. It allows for a higher blood pressure and better cardiac output and shifts the oxygen-hemoglobin dissociation curve to the left, promoting the unloading of oxygen into the tissue. Unfortunately, ventilator settings were not changed once hyperkalemia was diagnosed and the respiratory acidosis was only corrected at the end of the procedure. Adjusting the ventilator to create mild respiratory alkalosis (hyperventilation) would have been beneficial when dealing with the hyperkalemia. Nevertheless, the mild hypothermia and acidosis alone would not be expected to cause a clinically important increase in serum potassium concentration, although they could potentiate hyperkalemia by preventing potassium from the packed RBCs from distributing into the cells.

The choice of fluid therapy in this case also warrants discussion. A fresh blood transfusion might have been a more physiologic choice for ongoing hemorrhage. However, fresh blood collection and processing takes additional time in comparison to use of readily available stored packed RBCs, which can be preferable in an emergency situation. The amounts of colloid, crystalloid, and hypertonic saline solution administered in this case were also very conservative (ie, lower than the expected blood loss). Low-volume fluid resuscitation and permissive hypotension have been shown to be beneficial during uncontrolled hemorrhage.

**References**

An acute increase in serum potassium concentration to > 6.5 mEq/L should be promptly treated. Normally, the intracellular potassium concentration is much higher (140 mEq/L) than the extracellular potassium concentration (4 mEq/L). This difference in ion concentration is essential for the cell membrane action potential. Hyperkalemia decreases the cell membrane resting potential (ie, makes it more negative) and hyperpolarizes the cells, reducing their ability to conduct impulses. In the dog described in the present report, hyperkalemia was treated with calcium gluconate. By administering calcium gluconate, the cardiac cell threshold potential is decreased, thus normalizing the difference between resting and threshold potentials and restoring normal membrane excitability. Use of potassium-free fluids for fluid therapy (eg, saline [0.9% NaCl] solution) has a dilutional effect on high serum potassium concentrations and also ameliorates hyperkalemia by improving renal perfusion and enhancing urinary excretion. Dextrose administration stimulates the release of endogenous insulin and, in instances of high serum potassium concentration, helps move potassium to the intracellular space. The combination of exogenous insulin and glucose administration may result in a greater reduction of serum potassium concentration than administration of either alone. Administration of sodium bicarbonate also promotes the intracellular shift of potassium because hydrogen ions leave the cells to buffer the additional bicarbonate. Terbutaline and other β-adrenoceptor agonists increase uptake of potassium by stimulating cellular Na+-K+ ATPase pump activity.

High serum potassium concentrations disrupt the cardiac cell action potential and reduce the heart's ability to conduct impulses, causing ECG abnormalities. Electrocardiographic abnormalities caused by hyperkalemia are often characteristic. Increased amplitude and narrowing of the T waves together with shortening of the QT interval may occur with mild hyperkalemia. Moderate hyperkalemia may result in prolongation of the PR interval and widening of the QRS complex owing to slowing of electrical conduction. With progression of hyperkalemia, P waves initially widen and then become absent. Ventricular tachycardia is not commonly associated with hyperkalemia. However, in severe cases, the QRS complex may merge with the T wave, creating a sine wave appearance that may be confused with ventricular tachycardia, followed by ventricular fibrillation and asystole. In the dog described in the present report, the ventricular tachycardia that was diagnosed might in fact have been a result of wide QRS complexes merging with T waves. Causes of unexpected arrhythmias occurring during anesthesia that should be considered include primary cardiac disease, low cardiac output, hypoxia, drug-induced reaction, pain, autonomic nervous system dysfunction, and electrolyte abnormalities. The atioventricular block and severe bradycardia that followed allowed for rapid diagnosis and treatment of hyperkalemia, supporting the idea that any time an arrhythmia is observed during anesthesia, electrolyte abnormalities should be ruled out.

References


Correction: Anesthesia Case of the Month

In the Anesthesia Case of the Month article published in the October 1, 2011, issue (J Am Vet Med Assoc 2011;239:936–940), the description of results of ACTH stimulation testing provided in the third paragraph of the History section was incorrect. The sentence should read, “An ACTH stimulation test was performed; cortisol concentration prior to ACTH administration was 5.78 µg/dL (reference range, 1 to 6 µg/dL), and cortisol concentration 1 hour after ACTH administration was 13.4 µg/dL (reference range, <20 µg/dL).”