ECG of the Month

A 13-day-old 33-kg (73-lb) Holstein heifer calf was evaluated at the New Bolton Center for possible repair of a cleft palate and cleft lip that were diagnosed at birth. Physical examination findings and results of serum biochemical analyses and a CBC were within reference limits, except for high fibrinogen concentration (1,108 mg/dL; reference range for 6-week-old calves, 300 to 700 mg/dL).[1]

Five days later, the calf was anesthetized for palatoplasty and rhinoplasty. The calf became markedly sedate after IV administration of midazolam (0.3 mg/kg [0.14 mg/lb]), and its heart rate decreased from 150 to 72 beats/min. Anesthesia was induced by mask with isoflurane, and after nasotracheal intubation, the calf was placed in sternal recumbency. Anesthesia was maintained with isoflurane and oxygen by use of a small animal rebreathing circuit. The following variables were continuously monitored: ECG, arterial blood pressure (invasive method), airway gases (side-stream analyzer), oxygen saturation (pulse-oximeter), and rectal temperature. An isotonic solution was continuously infused throughout the procedure, and fluid boluses were also administered as needed to compensate for blood loss. If hypotension (mean arterial pressure [MAP], < 60 mm Hg) was evident, it was treated via IV administration of additional fluid boluses and infusion of dobutamine or phenylephrine. Before the start of surgery, values of MAP (range, 70 to 80 mm Hg), heart rate (range, 110 to 120 beats/min), oxygen saturation (99%), blood glucose concentration (77 mg/dL), and rectal temperature (38.5°C [101.3°F]) were within limits considered normal for anesthetized calves; end-tidal isoflurane concentration was 1.5%. During this period, the calf was breathing spontaneously (37 breaths/min). Arterial blood gas analysis performed 30 minutes after induction of anesthesia revealed respiratory acidosis and metabolic alkalosis (arterial blood pH, 7.365; Pa_{CO_2}, 66.5 mm Hg; Pa_{O_2}, 442 mm Hg; and bicarbonate concentration, 38.3 mmol/L); PCV was 29%, and total protein (TP) concentration was 4.9 g/dL. An attempt to institute mechanical ventilation failed because of the calf's strong spontaneous breathing activity. Flunixin meglumine, ceftiofur, and butorphanol (0.1 mg/kg [0.045 mg/lb]) were administered IV before the start of surgery.

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ECG Interpretation

During the first 2 hours of anesthesia (including the first hour of surgery), normal sinus rhythm with low-voltage QRS complexes was evident (S-wave amplitude, 0.18 mV; reference mean value for standing cows,[2] 0.794 mV; **Figure 1**). During this recording, the positive electrode was placed over the region of the left apex of the heart, and the negative electrode was placed over the right jugular furrow. When low-voltage QRS complexes were noticed, the negative electrode was repositioned to the area of the withers (high point of the shoulders) and also to the right hind limb with application of ample conducting gel, but the amplitude of QRS complexes remained similarly low in every recording. These findings were confirmed by use of a different ECG monitor and different electrodes.

Figure 1—Base-apex lead ECG traces obtained from an 18-day-old Holstein heifer calf obtained during anesthesia and surgical repair of a cleft palate and cleft lip. A—Representative normal sinus beat observed during the first 2 hours of anesthesia. B—Trace obtained at a time when anesthesia and antinociception were insufficient to prevent response to surgical stimulation. C—Trace obtained several minutes after that in panel B. Traces B and C reveal atrioventricular dissociation with an accelerated ectopic rhythm. Additionally, there are 4 premature depolarizations (second, fifth, eighth, and tenth complexes) present in trace C. All traces reveal low-voltage QRS complexes (S-wave amplitude, 0.18 mV). Black circles indicate P waves. Paper speed = 25 mm/s; 4 cm = 1 mV.

During the third hour of anesthesia (second hour of surgery), the calf began to tremble, its breathing pattern changed, and the eye-blink response and rectal temperature (39°C [102.2°F]) increased, all of which were interpreted as a response to surgical stimulation. End-tidal isoflurane concentration was increased (2.0% to 2.1%), but trembling continued intermittently. During this time, ECG recordings revealed isorhythmic atrioventricular dissociation[3] and low-voltage QRS complexes (Figure 1). The depolarization rate of the sinus node was 110 depolarizations/min; however, an ectopic focus was depolarizing at a slightly higher rate (114 depolarizations/min), thereby overriding sinus node activity and controlling ventricular activity. The site of the ectopic pacemaker was likely located within the atrioventricular node because the configuration and duration of the QRS complexes were normal. However, the QRS complex duration and electrical conduction pattern are not as closely related in the bovine heart as those of the canine heart because cattle belong to category B mammalian species, in which there is complete endocardial-to-epicardial penetration of Purkinje fibers[4] and the major masses of both ventricles are excited in a single burst of depolarization.[5]

A third ECG trace was recorded several minutes after detection of the arrhythmia (Figure 1). In addition to the atrioventricular dissociation, this trace revealed several premature depolarizations. The sinus node depolarization rate had decreased to 68 depolarizations/min, but most of the QRS complexes appeared to originate from the previously detected ectopic focus. However, because premature complexes were also present, the calculated heart rate was 110 beats/min. In this ECG recording, the second, fifth, and eighth complexes were premature and aberrantly conducted; the tenth complex was also premature but had a normal QRS morphology. The coupling interval of these 4 premature depolarizations was uniformly 0.36 seconds (intrinsic rate, 166 depolarizations/min), suggesting that they likely originated from the same ectopic focus and that intermittent functional blockade of the conduction system (eg, bundle branch block) was the cause of the variability of conduction velocity in these beats.[6] These premature beats occurred sporadically (18 depolarizations were recorded over a period of 3 minutes) and did not appear to induce any adverse hemodynamic effect; therefore, specific antiarrhythmic treatment was not warranted.[7] Analysis of another arterial blood sample collected after development of the arrhythmia revealed respiratory acidosis and metabolic alkalosis similar to the previous sample, and plasma electrolyte concentrations (Na^+, K^+, Cl^-, ionized Ca^{2+}, and Mg^{2+}), glucose, and lactate were within reference limits; however, PCV (23%) and TP (4.0 g/dL) concentration had decreased. Intravenous boluses of butorphanol (1, 1, and 2 mg) and ketamine (20 mg) were given in an attempt to provide better antinociception. Administration of larger doses of butorphanol or ketamine or administration of pure μ-opioid receptor agonists (eg, fentanyl) was considered but not undertaken.

The arrhythmia persisted for the remainder of the procedure. The duration of anesthesia was 3.4 hours. Total blood loss was estimated as 400 mL at the end of surgery; therefore, 2 units of bovine whole blood was transfused. The total volume of isotonic solution infused during the procedure was 2 L. The calf recovered well from anesthesia, and the next day, an ECG revealed normal sinus rhythm and the QRS voltage was within reference limits[2] (heart rate, 75 beats/min; S-wave amplitude, 1.8 mV). The calf remained in the hospital for another 43 days because of unrelated reasons, but no cardiovascular abnormalities were detected.

Discussion

The arrhythmias that occurred in the calf of this report are not commonly detected during anesthesia but can result from increased activity of ectopic pacemakers. Triggers for ectopic activity include increased sympathetic tone or circulating concentrations of catecholamines, drugs (eg, inotropes and anesthetic agents), acid-base and electrolyte abnormalities, fever, sepsis, hypotension, and hypoxemia.[3] The most likely reason for the arrhythmias in this calf was an increased sympathetic tone that resulted from surgical stimulation. Dobutamine, a β_1- and β_2-adrenoceptor agonist with short duration of action, may cause arrhythmias,[8] but in this calf, the infusion time was short and did not coincide with the changes in cardiac rhythm. Ketamine may also increase sympathetic tone and can contribute to the development of abnormal rhythms, but it was injected after the arrhythmia was evident. In canine atrial tissue, high plasma concentrations of isoflurane may act synergistically with epinephrine and increase its arrhythmogenic potential.[9] Likewise, an elevated Pa_{CO_2} value (such as that in the calf of this report) may facilitate the arrhythmogenic effects of epinephrine, given that the arrhythmogenic dose of epinephrine was lower in hypercapnic horses than in normocapnic horses during halothane anesthesia.[10]

Surgical procedures performed on the head are painful. This calf received flunixin meglumine (an NSAID) and butorphanol as analgesics prior to surgery. Nevertheless, the inhalant-anesthetic–sparing properties of carprofen (another NSAID) and butorphanol have been reported to be rather weak in dogs.[11] Thus, both drugs may not have provided sufficient antinociception in this calf. We hypothesize that insufficient antinociception was the main reason for development of the arrhythmia. Small doses of butorphanol and ketamine were later administered IV without any noticeable effect. Larger doses of butorphanol, ketamine, or pure μ-opioid receptor agonists were not administered because the pharmacokinetic properties of those drugs in young calves are largely unknown. Results of experiments in male Holstein calves indicated that the content of the cytochrome P_{450} enzyme system in the liver, which is responsible for metabolism of many injectable anesthetic and analgesic agents, is still less than adult values at 42 days of age.[12] Although opioids are effective analgesics in neonatal rats,[13] little is known about their effect in calves. The neuronal pathways responsible for conduction of nociceptive impulses to the CNS undergo considerable maturation in neonatal rats,[13] which has implications for how those animals respond to nociceptive input and how analgesics such as opioids affect pain perception. Similar data are not known for calves; therefore, the risk-to-benefit ratio and suitable dosing regimens for opioids are difficult to determine. Excessive amounts of anesthetic or analgesic drugs may adversely affect anesthetic recovery and may even lead to life-threatening complications such as prolonged recumbency, respiratory depression, or aspiration. A potentially effective method to provide intra- and postoperative analgesia would have been the use of local anesthetic techniques. In the calf of this report, a bilateral block of the branches of the maxillary nerve could have been performed in the pterygopalatine fossa. However, the efficacy and safety of this technique have not been established in calves.

We remain uncertain as to the cause of the transient low-voltage QRS complexes in the calf of this report. The QRS amplitude is dependent on cardiac, extracardiac, and measurement-related factors. Cardiac factors include the volume of intracardiac blood,[14] myocardial mass,[15] and pericardial effusion.[16] Extracardiac factors include the distance of the heart from the recording electrodes, which is influenced by size of the thoracic cavity, thoracic wall thickness, and obesity[16]; electrical impedance of thoracic organs and skin (eg, presence of emphysema, pneumothorax, and pleural effusion[16]; administration of large volumes of fluids perioperatively[17]; and dehydration); and mean electrical axis of the heart. Measurement-related factors may include faulty ECG machine components and ineffective electrode-to-skin contact. Most of the aforementioned causes can be excluded in this calf because the phenomenon was transient and the calf did not have any of the causative diseases or conditions. The most likely explanation appears to be a position-related change in the mean electrical axis of the heart, which resulted in low QRS complex amplitudes derived from the few ECG leads we used.

In our opinion, the development of arrhythmia in the calf of this report was caused by insufficient intraoperative antinociception. Although the arrhythmia was benign, such abnormalities may become life-threatening events if cardiac output is affected. Thus, the treatment of intraoperative nociception must be considered because it may adversely affect surgical outcome and the well-being of patients.

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