Comparison of abomasal luminal gas pressure and volume and perfusion of the abomasum in dairy cows with left displaced abomasum or abomasal volvulus

Thomas Wittek, Dr vet med; Peter D. Constable, BVSc, PhD; Manfred Fürll, Dr vet med habil

Objective—To compare abomasal luminal gas pressure and volume and perfusion of the abomasum in dairy cows with a left displaced abomasum (LDA) or abomasal volvulus (AV).

Animals—40 lactating dairy cows (25 with an LDA and 15 with an AV).

Procedure—Abomasal luminal gas pressure and volume and pulse oximetry values for the caudal portion of the dorsal ruminal sac and abomasal wall were measured during laparotomy. Abomasal perfusion was assessed on the basis of abomasal O₂ saturation (pulse oximetry) before correction of the LDA or AV. Abomasal perfusion was also assessed after correction of the LDA or AV by measuring venous O₂ saturation in the right gastroepiploic vein and calculating the abomasal oxygen-extraction ratio.

Results—Abomasal luminal gas pressure and volume were higher in cattle with an AV than in cattle with an LDA. Abomasal O₂ saturation was lower and abomasal oxygen-extraction ratio higher in cattle with an AV, compared with values in cattle with an LDA. In cows with an AV, lactate concentration in the gastroepiploic vein was greater than in a jugular vein, whereas no difference in lactate concentrations was detected in cows with an LDA. Abomasal luminal gas pressure was positively correlated (r, 0.51) with plasma lactate concentration in the gastroepiploic vein and negatively correlated (r, -0.32) with abomasal O₂ saturation determined by use of pulse oximetry.

Conclusions and Clinical Relevance—Abomasal perfusion decreases as luminal pressure increases in cattle with an AV or LDA.

Left displaced abomasum (LDA) and abomasal volvulus (AV) are common abdominal conditions of lactating dairy cows characterized by varying degrees of abomasal distension, with mortality rates of approximately 5% for cattle with an LDA and 30% for cattle with an AV. Except for abomasal ulcers and perforations in a small number of cows with an LDA, most of the deaths in cattle with an LDA are attributed to concurrent diseases such as hepatic lipidosis, metritis, mastitis, and pneumonia. In contrast, concurrent disease is less often seen in cows with an AV, and most of the deaths in cows with an AV are attributed to the effects of hemorrhagic, strangulating obstruction of the abomasum, duodenum, and possibly omasum (omasal-abomasal volvulus) and reticulum (reticulo-omasal-abomasal volvulus) and of increased luminal pressure that leads to ischemia, necrosis, and peritonitis. Reestablishment of normal blood flow after surgical correction of an AV may also result in reperfusion injury attributable to reactive oxygen species. In some cattle with an AV, stretching and tearing of the ventral vagus nerve also contributes to postoperative illness and death.

Abomasal distention in cattle with an AV is caused by variable mixtures of gas and fluid in response to luminal obstruction and vascular occlusion in the proximal portion of the duodenum and omasal-abomasal or reticulo-omasal junction. In contrast, distention in cattle with an LDA is caused primarily by entrapment of gas in the fundic region following organ displacement, and luminal obstruction or vascular occlusion is believed to be nonexistent. Abomasal distention in cattle with an AV or LDA is accompanied by an increase in luminal pressure because the abomasum is not a perfectly compliant organ. In general, luminal gas pressure will increase with the duration of an AV or LDA because production of abomasal gas is dependent on time and diet.

The effect of increased luminal pressure and venous and lymphatic occlusion on blood flow and oxygen delivery to the stomach and intestines and on postoperative survival has been evaluated in cats, dogs, rats, and horses. A sustained increase in luminal pressure causes a sustained decrease in gastric and intestinal perfusion. An increase in venous pressure also decreases tissue perfusion, and this effect is additive to that of increased luminal pressure. Extrapolating these results to cows with an LDA or AV leads to the hypothesis that abomasal blood flow decreases as luminal pressure and the severity of venous and lymphatic obstruction increase.

Pulse oximetry provides a continuous measurement of arterial oxygen saturation (SaO₂) and has been used to assess tissue viability in humans during gastrointestinal surgery. Pulse oximetry is most commonly used in veterinary medicine to monitor the adequacy of oxygen delivery during anesthesia and in neonates, although experimental use in animals undergoing gastrointestinal surgery has been reported in dogs and horses. The technique has been validated in newborn calves. On the basis of the measurement principles of pulse oximetry, the measured value for SaO₂ saturation should not be affected by tissue blood flow. However, in reality, decreased blood...
flow and decreased venous oxygen saturation (in response to increased tissue oxygen extraction) in metabolically active tissue result in a decreased oxygen saturation as measured by use of pulse oximetry despite unchanged SaO2. Therefore, pulse oximetry may be useful in estimating the adequacy of abomasal blood flow in cows with an LDA or AV because it reflects venous oxygen saturation in animals with normal arterial oxygen tension, particularly those with venous congestion.

The first objective of the study reported here was to assess adequacy of oxygen delivery to the abomasum of cows with an LDA or AV by use of pulse oximetry and analysis of venous effluent from the abomasum. The second objective was to measure abomasal luminal gas pressure and volume in cows with an LDA or AV and characterize the relationship between luminal pressure, volume, and indices of abomasal perfusion. The third objective was to confirm findings reported by our laboratory group in other studies in which luminal gas pressure6 and plasma lactate concentration25 were increased in cows with an AV.

Materials and Methods

Animals—All adult dairy cows admitted to the veterinary hospital at Lehigh University that had an LDA (25 cows in February 2001) or AV (15 cows between February and April 2001) were used in the study. Cows were 2 to 11 years old. Cows were mostly Schwarzbuntes Milchrind or Holstein-Friesian crossbred cattle or purebred Holstein-Friesians. This study was approved by an institutional animal care and use committee.

A routine physical examination was performed on each cow, and rectal temperature, respiratory rate (obtained by counting the number of thoracic excursions for 30 seconds), and pulse rate (obtained by palpation of the facial artery for 30 seconds) were determined. A preliminary diagnosis of an LDA or AV was made before surgery and confirmed during surgery. Left displaced abomasum was characterized by displacement of the abomasal body to the left dorsal quadrant of the abdomen between the left body wall and rumen, whereas AV was characterized by displacement of the abomasal body to the right dorsal quadrant of the abdomen between the right body wall and liver; this required rotation of the abomasal body in a counterclockwise direction (as viewed from the right side of the cow) and medial displacement of the liver by the distended abomasum. For comparison, cows with right displaced abomasum do not have a counterclockwise rotation of the abomasum (as viewed from the right side of the cow) and do not have the abomasum located between the liver and right body wall.

Pulse oximetry of the abomasal and ruminal wall—Laparotomy was performed via the right flank by use of region al angesia. The same investigator (TW) performed all laparotomies. The abdomen was explored to confirm the diagnosis of LDA or AV. The clamp probe of a pulse oximeter was attached to the most dorsal aspect of the gas-filled abomasum and the most caudal aspect of the caudal portion of the dorsal ruminal sac (Fig 1). The probe was used to measure oxygen saturation of the abomasal and ruminal wall, respectively (ie, O2 saturation measured by use of pulse oximetry [SpO2]). Pulse oximetry measurements could not be obtained from the tail or ears of the cow because of pigmentation; therefore, oximetry measurements for the caudal portion of the dorsal ruminal sac were assumed to equal SaO2.

Pulse oximetry measurements were obtained before the abomasum was decompressed and recorded when the pulse rate on the monitor was equal to the heart rate that was simultaneously determined by thoracic auscultation. The measurement procedure required 10 to 30 seconds. In 4 cows with an LDA, the probe had to be moved a few centimeters to obtain stable readings. Preliminary studies indicated that SpO2 values determined by this measurement technique were highly repeatable when 3 consecutive measurements were made at 1-minute intervals. For 8 cows with an AV and 10 cows with an LDA, the mean coefficient of variation for SpO2 measurements was 2.0% and 1.9% for the rumen and abomasum, respectively.

Abomasal gas pressure and volume—After pulse oximetry measurements were obtained, abomasal luminal gas pressure was measured by inserting a 14-gauge, 2.1-mm-diameter needle into the abomasal lumen and attaching the needle to an electronic manometer via a noncompressible tube. Gas pressure was monitored for 30 seconds, and mean values for variations caused by respiration were calculated as described elsewhere.

Abomasal gas volume was measured by aspirating the gas with an aspirator until the gas was completely evacuated, as assessed by palpation of the abomasal contents and continuous aspiration of fluid. The aspirated gas was transferred into a water-filled container; the displaced water volume was registered as the indirect gas volume. After evacuation of abomasal gas, an estimate of the fluid volume in the abomasum was obtained by use of palpation; fluid volume was based on the investigator’s estimation. The investigator had developed the ability to estimate fluid volume by palpating plastic bags filled with 5 or 10 L of water. The abomasum was quickly repositioned by manipulation, and the pyloric antrum region was exteriorized through the incision in the right flank. An omentectomy was performed that incorporated the greater omentum at a location 5 cm caudal to the pylorus. Routine postoperative care was provided and included IV and oral administration of electrolyte solutions and parenteral administration of antimicrobials.

Collection of blood samples—Immediately (ie, within 1 minute) after correction of an LDA or AV, blood samples were obtained anaerobically through a butterfly catheter (0.6 mm in diameter) from the right gastroepiploic vein into a heparin-coated capillary tube (for blood gas analysis) and a tube that contained sodium fluoride (for determination of plasma L-lactate concentration; Fig 2). Because only a portion of the pyloric antrum could be safely exteriorized during surgery, venous blood could only be obtained from veins near the pyloric antrum or pylorus; however, the right gastroepiploic vein drains the pyloric antrum and an aboral section of the abomasal body and therefore is a better representation of effluent from the pyloric antrum than effluent from the abomasal body.

At the same time that blood samples were obtained from the gastroepiploic vein, an assistant anaerobically collected
Jugular venous blood samples were obtained into a heparin-coated 1-mL plastic syringe (for blood gas analysis) and a sodium fluoride tube (for determination of plasma lactate concentration). Jugular venous blood was obtained for analysis because arterial blood samples could not be safely collected during surgery. Results of blood gas analysis for jugular venous samples were assumed to reflect mixed-venous samples because blood from the cranial vena cava accurately reflects mixed-venous blood in critically ill human patients. Plasma lactate concentrations in jugular venous samples were assumed to be equivalent to plasma lactate concentrations in arterial samples because there is an excellent correlation between lactate concentrations in central venous and arterial blood samples (r = 0.995) and between peripheral venous and arterial blood samples (r = 0.990) in human patients.

Blood gas analysis, measurement of plasma lactate concentrations, and serum biochemical analyses—Blood gas analysis was performed within 5 minutes after collection of samples and included pH, Pco2, Po2, venous oxygen saturation (SvO2), and concentrations of hemoglobin, carboxyhemoglobin, and methemoglobin. Measured blood gas values were adjusted on the basis of rectal temperature, and base excess was calculated by use of standard algorithms. Venous O2 content was calculated as (\(1.39 \times \frac{\text{percentage hemoglobin saturation}}{100} \times \text{hemoglobin concentration} + 0.003\)) \times\) venous Po2. Systemic arterial O2 content was calculated as (\(1.39 \times \frac{\text{SaO2}}{100} \times \text{hemoglobin concentration} + 0.003\)) \times\) arterial Po2, with hemoglobin concentration expressed in grams per deciliter and oximetry measurements of the caudal portion of the dorsal ruminal sac assumed to equal SaO2 and arterial Po2, assumed to equal 90 mm Hg. The oxygen-extraction ratio (OER) was calculated as follows: OER = (arterial O2 content – venous O2 content)/arterial O2 content.

Plasma l-lactate concentrations were measured in blood samples obtained from the gastroepiploic and jugular veins. Blood samples were immediately placed on ice and centrifuged at +4°C within 10 minutes after sample collection. Plasma was harvested and stored at –20°C until analyzed for plasma l-lactate concentrations. Plasma l-lactate concentrations were determined within 4 weeks after collection of samples and included pH, PCO2, PO2, and concentrations of hemoglobin, carboxyhemoglobin, and methemoglobin. Plasma lactate concentrations were measured in blood samples obtained from the gastroepiploic and jugular veins.

Figure 2—Schematic depicting venous drainage of the abomasum as viewed from the right side of the abdomen. Blood samples were obtained from the gastroepiploic vein in the pyloric antrum region (oval). P = Pylorus. A = Pyloric antrum. B = Body of the abomasum. 1 = Right gastric vein. 2 = Left gastric vein. 3 = Right gastroepiploic vein. 4 = Left gastroepiploic vein. (Adapted from Sack WO. Das Blutgefässsystem des Labmagens von Rind und Ziege. Zentralbl Veterinarmed [C] 1972;1:27–54. Reprinted with permission.)

Blood samples were immediately placed on ice and centrifuged at 4°C within 10 minutes after sample collection. Blood samples were assumed to reflect mixed-venous samples because blood from the cranial vena cava accurately reflects mixed-venous blood in critically ill human patients. Plasma lactate concentrations were measured in blood samples obtained from the gastroepiploic and jugular veins. Samples were obtained from the gastroepiploic vein in the pyloric antrum region (oval). P = Pylorus. A = Pyloric antrum. B = Body of the abomasum. 1 = Right gastric vein. 2 = Left gastric vein. 3 = Right gastroepiploic vein. 4 = Left gastroepiploic vein. (Adapted from Sack WO. Das Blutgefässsystem des Labmagens von Rind und Ziege. Zentralbl Veterinarmed [C] 1972;1:27–54. Reprinted with permission.)

were logarithmically transformed or ranked before the ANOVA was performed. The association between abomasal SpO2 and gastroepiploic vein SvO2 was determined by use of linear regression. The curvilinear relationship between abomasal luminal pressure and volume was assessed by the use of nonlinear regression and an exponential model with a nonzero asymptote. Pearson correlation coefficients were calculated to determine the association between abomasal luminal pressure and indices of abomasal perfusion. Categoric variables were compared by use of the Fisher exact test. A statistical software program was used for all analyses. Significance for all tests was set at P < 0.05.

**Results**

**Physical examination**—Mean ± SD preoperative heart rate was similar (P = 0.093) in cows with an AV (80 ± 24 beats/min) and cows with an LDA (70 ± 11 beats/min). Cows with an AV tended (P = 0.063) to have a lower respiratory rate (24 ± 7 breaths/min), compared with the respiratory rate for cows with an LDA (29 ± 9 breaths/min). Rectal temperature was similar between the 2 groups of cows (AV, 39.1 ± 0.6°C; LDA, 39.0 ± 0.6°C). Thirteen of 15 cows with an AV and 21 of 25 cows with an LDA were discharged from the hospital; these values were similar (P = 1.00). Two cows with an AV were euthanatized (1 because of generalized peritonitis and 1 because of sustained postoperative ileus and poor fecal production). Four cows with an LDA were euthanatized because of the lack of response despite aggressive treatment for concurrent severe hepatic lipidosis.

**Pulse oximetry**—Oxygen saturation in the caudal portion of the dorsal ruminal sac was similar (P = 0.40) for cows with an AV (88.9 ± 3.9%) or LDA (87.3 ± 4.1%), but abomasal SpO2 was significantly (P = 0.011) lower in cows with an AV (79.7 ± 6.9%) than in cows with an LDA (83.6 ± 5.2%; Fig 3). The difference between ruminal and abomasal SpO2 was significantly (P = 0.030) greater in cows with an AV (9.1 ± 7.9%) than in cows with an LDA (4.2 ± 5.8%).

**Luminal gas pressure and volume**—Mean abomasal luminal gas pressure in cows with an AV (12.2 ± 5.2 mm Hg) was significantly (P < 0.001) higher than that in cows with an LDA (6.1 ± 2.1 mm Hg; Fig 4). Similarly, mean abomasal gas volume in cows with an AV (10.4 ± 4.2 L) was significantly (P = 0.012) higher than that in cows with an LDA (7.8 ± 2.1 L). A nonlinear relationship was found between abomasal gas pressure and volume (Fig 5). The nonlinear regression equation (R2, 0.22) was as follows:

\[ \text{pressure} = -6.9 + 10.7 \times e^{0.08 \times \text{volume}} \]

Abomasal luminal gas pressure was significantly and positively correlated with gastroepiploic venous blood pH (r = 0.59; P < 0.001) and plasma l-lactate concentration (r = 0.51; P = 0.001; Fig 5). Luminal gas pressure was correlated, but not significantly, with OER (r = 0.29; P = 0.089). Abomasal luminal gas pressure was significantly and negatively correlated with chloride concentration in samples obtained from the gastroepiploic vein (r = –0.57; P < 0.001), sodium concentration in samples obtained from the gastroepiploic vein (r = –0.32; P = 0.049), and abomasal SpO2 (r = –0.32;
P = 0.048) and correlated negatively but not significantly with Po2 for samples obtained from the gastropiploic vein (r, –0.31; P = 0.061).

All cows with an LDA were estimated to have < 5 L of fluid in the abomasum. For the 15 cows with an AV, 4 had an estimated abomasal fluid volume of < 5 L, 7 had an estimated abomasal fluid volume of between 5 and 10 L, and 4 had an estimated abomasal fluid volume of > 10 L.

Blood gas analysis of samples obtained from the gastropiploic and jugular veins—Blood gas analysis of samples obtained from the gastropiploic vein indicated that cows with a AV had higher values for pH, PCO2, base excess, bicarbonate concentration, and OER, compared with values for cows with an LDA (Table 1). Mean amounts of carboxyhemoglobin (1.0 ± 0.3%) and methemoglobin (0.7 ± 0.2%) in samples from the gastropiploic vein were similar for cows with an LDA and those with an AV.

Blood gas analysis of samples obtained from a jugular vein indicated that cows with an AV had significantly higher values for PCO2, base excess, bicarbonate concentration, and OER and a significantly lower O2 saturation, compared with values for cows with an LDA (Table 1). Interestingly, pH, O2 saturation, and PO2 were significantly greater in samples obtained from the gastropiploic vein than in samples obtained from the jugular vein for cows with an AV or LDA. The OER for the abomasum was significantly lower than the systemic OER for cows with an AV or LDA.

Abomasal SpO2 (obtained from pulse oximetry) and gastropiploic vein SvO2 (obtained from blood gas analysis) were linearly related, suggesting that pulse oximetry measured venous saturation as well as arterial saturation (Fig 3). The linear regression equation (R2, 0.42; P < 0.001) was as follows: abomasal SpO2 = (0.39 • SvO2) + 48.3. Standard error of the coefficient and intercept values were 0.08 and 5.8, respectively.

Plasma and serum biochemical analysis—Biochemical analysis of plasma and serum samples obtained from the gastropiploic and jugular veins indicated that cows with an AV had significantly higher plasma lactate concentrations, significantly lower sodium and chloride concentrations, but similar potas-
that the mean sustained abomasal luminal gas pressure...In 54 cows with an AV (12 mm Hg) than in 25 cows with an LDA (6 mm Hg) was similar to that obtained in another study4 in which the median sustained luminal gas pressure values in 54 cows with an AV (12 mm Hg) were higher than in 50 cows with an LDA (9 mm Hg). The higher sustained luminal gas pressure values in cows with an AV result from functional orad and aborad abomasal obstruction, whereas in cows with an LDA, there is no orad abomasal obstruction, thus allowing reflux of abomasal fluid and gas into the forestomach.

We found that mean plasma lactate concentration in jugular venous samples was higher in cows with an AV (4.8 mmol/L) than in cows with an LDA (2.0 mmol/L), confirming findings that cattle with an AV have an increased blood lactate concentration (mean of 3.8 mmol/L in 41 cows25; mean of 7.3 mmol/L in 23 cows26; reference range, 0.6 to 1.4 mmol/L25). Tissue ischemia is the main cause for hyperlactatemia in cows with an AV because affected cattle have an increased lactate-to-pyruvate ratio.25 Our finding that the mean lactate concentration in the right gastroepiploic vein was greater than that in a jugular vein for cattle with an AV than in cattle with an LDA. Interestingly, serum potassium concentration was higher in samples obtained from the gastroepiploic vein than for samples obtained from the jugular vein in cows with an AV or LDA.

**Discussion**

We believe that the study reported here is the first to compare abomasal perfusion between dairy cows with an LDA and dairy cows with an AV. The main findings were that abomasal perfusion was decreased to a greater extent in cattle with an AV than in cattle with an LDA, that abomasal ischemia was evident in cows with an AV, and that abomasal luminal pressure was positively correlated with venous lactate concentration and negatively correlated with abomasal SpO2. The latter finding indicates that abomasal perfusion decreases as luminal pressure increases.

In healthy cattle, normal luminal gas pressure in the abomasum is unknown, but luminal fluid pressure ranges from 13 to 32 mm Hg. There are transient increases in luminal fluid pressure of 1 to 12 mm Hg during abomasal contractions, which occur at a frequency of 1.2 to 2.3 contractions/min.32,33 Our finding that the mean sustained abomasal luminal gas pressure was greater in 15 cows with an AV (12 mm Hg) than in 25 cows with an LDA (6 mm Hg) was similar to that obtained in another study4 in which the median sustained luminal gas pressure values in 54 cows with an AV (12 mm Hg) were higher than in 50 cows with an LDA (9 mm Hg). The higher sustained luminal gas pressure values in cows with an AV result from functional orad and aborad abomasal obstruction, whereas
small intestine of pigs by use of air (15 mm Hg)\textsuperscript{38} or the small intestine of horses by use of fluid (13 mm Hg)\textsuperscript{38} decreases intestinal blood flow; this decrease in the horses was accompanied by a decrease in jejunal venous pH and PO\textsubscript{2}. Intestinal obstruction lowers the luminal pressure required to decrease perfusion; a luminal gas pressure of 20 mm Hg decreased perfusion in rats with an obstructed small intestine but did not have an effect on perfusion in rats with an unobstructed small intestine.\textsuperscript{3} Distention of the small colon in pigs by use of air (45 mm Hg)\textsuperscript{39} and the small colon of horses by use of air (40 mm Hg)\textsuperscript{40} also decreases blood flow.

The S\textsubscript{v}O\textsubscript{2} and venous partial pressure of O\textsubscript{2} (PvO\textsubscript{2}) reflect, under certain circumstances, the state of tissue oxygenation.\textsuperscript{41} We found that S\textsubscript{v}O\textsubscript{2} and PvO\textsubscript{2} in abomasal venous effluent of cows with an AV or LDA were higher and OER lower, compared with values for the jugular vein. These results could have been attributable to a comparatively greater blood flow to the abomasal venous effluent of cows with an AV or LDA where the jugular vein, compared with the lactate concentration in the gastroepiploic vein, increased in lactate concentration in the gastroepiploic vein, compared with the lactate concentration in the jugular vein.

Abomasal S\textsubscript{p}O\textsubscript{2} was decreased in cows with an AV, compared with S\textsubscript{p}O\textsubscript{2} for the caudal portion of the dental ruminal sac, which was assumed to reflect systemic arterial O\textsubscript{2} saturation when perfusion of the rumen was unaffected by an AV. Support for this assumption was provided by ruminal S\textsubscript{p}O\textsubscript{2} values of 88% and 89% in cows with an LDA and AV, respectively, which were slightly lower than the S\textsubscript{p}O\textsubscript{2} values of 92% for the small intestine of humans,\textsuperscript{15} 91% to 93% for the jejunum, ileum, and proximal portion of the colon of dogs,\textsuperscript{10,39,42} 96% for the small intestine and tongue of dogs,\textsuperscript{10} 97% for the small intestine and tongue of dogs,\textsuperscript{10} 93% for the jejenum and ileum of horses,\textsuperscript{32} and 95% for the large intestine of horses.\textsuperscript{32} The latter studies were all conducted in anesthetized animals breathing 100% O\textsubscript{2}, which will increase venous PO\textsubscript{2} and S\textsubscript{v}O\textsubscript{2}. Because ruminal S\textsubscript{p}O\textsubscript{2} was similar for both groups of cows and therefore assumed to be constant, and because 42% of the variation in S\textsubscript{p}O\textsubscript{2} could be accounted for by differences in S\textsubscript{v}O\textsubscript{2}, our findings confirmed those obtained in other studies,\textsuperscript{39a} (ie, venous saturation influences the pulse oximetry value).

Analysis of the results of the study reported here indicated that abomasal perfusion decreases as luminal gas pressure increases. This finding suggests that cattle with a large and tightly distended abomasum attributable to an AV or LDA should have the abomasum decompressed as soon as possible to minimize the potential for ischemia-induced injury to the abomasal mucosa, such as abomasal ulcers and perforations. However, abomasal ischemia in this study was only identified in cows with an AV, as documented by an increase in lactate concentration in the gastroepiploic vein, compared with the lactate concentration in the jugular vein.

\begin{itemize}
  \item \textsuperscript{a}Kim JM, Mathewson HS. Venous congestion affects arterial hemoglobin saturation measured by the pulse oximeter (abstr). Anesthesiology 1985;63:A174.
  \item \textsuperscript{b}Cardiopac II-CG/EGK/gas monitor, Datex-Ohmeda Deutschland GmbH, Duisburg, Germany.
  \item \textsuperscript{c}BMT 401, RTL, Berlin, Germany.
  \item \textsuperscript{d}Churigiesauger GF 80, Aesculap GmbH, Karlsruhe, Germany.
  \item \textsuperscript{e}ABL 555 with CO-oximeter OSM 3, Radiometer, Copenhagen, Denmark.
  \item \textsuperscript{f}L-lactic dehydrogenase, Sigma-Aldrich Deutschland GmbH, Taufkirchen, Germany.
  \item \textsuperscript{g}SAS, version 8, SAS Institute Inc, Cary, NC.
\end{itemize}

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