Left-displaced abomasum is an economically important disease of dairy cattle, and a single case can cost $494.1 Annually, LDAs may cost the United States dairy industry up to $220 million.2 In North America, the mean incidence rates for LDA in lactating dairy cattle range from 1.4% to 5.8%/y, and the time of greatest risk for the development of LDA in dairy cows is in the immediate postpartum period, with 80% to 90% of cases developing in the first month of lactation.3

Risk factors for the development of LDA in dairy cows have been evaluated by several investigators and include concurrent postpartum disorders, high body condition score at parturition (≥ 4 on a scale of 1 to 5), lack of physically effective fiber in the feed, use of forage sources intended for dry cows, birth of twins, dystocia, clinical hypocalcemia (also called milk fever), and ketosis.3,4 In addition to these risk factors, an association between hyperketonemia and the development of LDA has been identified. Results of 1 study5 indicated that cows with circulating BHB concentrations ≥ 1.0 mmol/L at 1 week after giving birth were 13.6 times as likely to develop an LDA as were cows with BHB values under this threshold. In another study,6 cows with serum BHB concentrations ≥ 1.2 mmol/L in the first week after giving birth had 8 times the odds of developing an LDA, compared with cows that had serum BHB concentrations < 1.2 mmol/L. Other investigators reported serum BHB concentrations > 1.2 mmol/L to be the optimum cut point (yielding maximum sensitivity and specificity) to detect the risk of developing an LDA in the first week of the postpartum period.7 Our group previously found that cows with circulating BHB concentrations ≥ 1.0 mmol/L from 3 to 14 days after giving birth were also at increased risk for displaced abomasum.8

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Although the risk factors associated with the development of an LDA have been evaluated by several investigators, much less research has focused on factors associated with survival following surgical correction of this condition. To our knowledge, no research has evaluated BHB concentration in dairy cows at the time of surgical correction for LDA as a prognostic indicator of postsurgical survival. The objectives of the study reported here were to estimate the sensitivity, specificity, LRs, and PVs of various BHB concentrations measured in whole blood at the time of LDA surgery to determine associations between BHB concentration and removal from the herd (ie, death, slaughter, or euthanasia) ≤ 30 days after surgery. We also sought to estimate the postsurgical risk of removal from the herd for cattle with the BHB concentration that had the highest sensitivity and specificity for predicting this outcome.

Materials and Methods

Animals and study design—A prospective cohort study was conducted from a convenience sample of dairy operations within the veterinary practice area in Pennsylvania between December 13, 2009, and October 10, 2011. Cows were enrolled if an LDA was diagnosed by a veterinarian between 5 and 30 days in lactation (ie, DIM) and rectal temperature was between 38° and 39.7°C (100.5° to 103.5°F). Informed consent was obtained from all farmers prior to enrollment of cattle in the study, which was performed in compliance with Cornell University’s guidelines for research on animals.

Surgical procedures—Immediately prior to surgery, cows received 1 dose of cefetiraxone sodium hydrochloride sterile suspension (1.5 mg/kg [0.68 mg/lb], IM or SC, according to the surgeon’s preference). This is currently an unapproved use of cefetiraxone; however, the study was concluded prior to the US FDA’s prohibition of unapproved uses of cephalosporins in food animals. All cows enrolled in the study underwent surgical correction of the LDA via standing right-flank laparotomy, which was performed by 1 of 3 surgeons working in the practice (WSC, DCW, or DJZ). Surgical fixation of the abomasum was completed by means of omentopecty or pylorocantropexy as described elsewhere. Anesthesia was provided with lidocaine (2 to 3 mg/kg [0.91 to 1.36 mg/lb]) administered as a distal paravertebral nerve block in all cows. There was no postoperative analgesia administered.

Data collection—A form including surgeon, farm, and animal identification; date of surgery; breed of cow; DIM at surgery; parity; rectal temperature; BHB concentration in whole blood; and concurrent disease status was completed for each cow enrolled in the study by the veterinarian performing the surgery. Rectal temperature was measured with a mercury thermometer. The BHB measurement device was calibrated by use of the manufacturer’s instructions. The BHB measurement device is marketed for use in human patients. Then, immediately prior to the start of surgery, the cowside test for BHB concentration was performed by placement of 1 drop of blood from a sample collected from a coccygeal vessel onto the test strip. The BHB concentration was recorded on the form. In addition, information regarding concurrent diseases, including metritis, pneumonia, and dehydration, was recorded. Metritis was defined as fetid, watery vulvar discharge with or without fever (rectal temperature ≥ 39.5°C [103.1°F]). Pneumonia was diagnosed if abnormal respiratory sounds were detected on auscultation, with or without fever. Dehydration was diagnosed in cattle that had an apparent loss of skin elasticity (ie, skin tent duration > 2 seconds) and sunken eyes. After surgery, all cows received 360 mL of propylene glycol as a single bolus via oral drench once daily for 2 days. Cows were not enrolled in the study if the farmer was unwilling to administer the prescribed follow-up treatment.

Surgeons were not blinded to the BHB test results or other health conditions of the cows at the time of surgery. For ≥ 30 days following surgery, follow-up with the herd owner or representative was performed either in person or via telephone to ascertain whether each cow was still in the herd. In the analysis, no distinction was made among cows that died, were euthanized, or were culled; all were categorized as being removed from the herd.

Statistical analysis—Commercially available software was used to estimate ROC curves and 95% CIs for determination of the sensitivity and specificity of circulating BHB concentrations associated with the dichotomous outcome of removal from the herd within 30 days after surgery (yes or no), with the day of surgery considered day 0. The point on the ROC curve with the highest combined sensitivity and specificity was considered the critical threshold. This critical threshold was interpreted on the basis of the area under the curve such that a value of 0.5 was considered noninformative, and a value > 0.5 and ≤ 0.7 was considered accurate. Positive and negative LRs for removal from the herd for cattle with various BHB concentrations were also evaluated; these calculations incorporate the sensitivity and specificity of the test and provide a direct estimate of likelihood that an animal with a given BHB concentration will have the outcome of interest. The PV estimates probability that an animal will or will not have the outcome of interest given the test results, but these probabilities are driven by true prevalence (ie, a population with high true prevalence will have a larger positive PV, compared with a population in which the true prevalence is low). The positive PV indicates the probability that an animal with a positive test result will develop the outcome of interest; conversely, the negative PV indicates the probability that an animal with a negative test result will not develop this outcome.

The BHB concentration with the highest combined sensitivity and specificity was used as a categorical predictor to estimate the risk ratio of removal from the herd ≤ 30 days after surgery. Risk ratios and 95% CIs were estimated via Poisson regression with commercially available software. The effect of herd was evaluated as a clustering variable (ie, cows were clustered within herd). A repeated statement with an exchangeable correlation matrix was used, which allowed the differences between animals in a group to be less than between animals in other groups. The following were considered as potential confounding covariates: number of lactations...
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(1 [ie, primiparous cows] or ≥ 2 [multiparous cows]); surgeon; DIM at surgery; whether the cow had metritis, was clinically dehydrated, or had a rectal temperature > 38.9°C (102°F); and the cow’s sequential number in the study. These potential confounders were evaluated in a manual backward stepwise fashion with a conservative P value threshold for retention in the model of ≤ 0.1.

Results

One hundred and thirty-eight cows from 43 herds were initially enrolled in the study. The LDAs were distributed among herds with 1 to 13 affected cattle/herd. Data from 136 cows (136 surgeries) were used in the final analysis; information for 2 animals was excluded because of missing outcome information. Overall, the cumulative incidence of removal from a herd (ie, death, euthanasia, or culling) ≤ 30 days after surgical correction of an LDA was 22 of 136 (16%). One hundred five of 136 (77%) cows in the study had a BHB concentration ≥ 1.2 mmol/L in whole blood. The median number of DIM at the time of LDA diagnosis and surgery was 12.5 (range, 5 to 30). Eleven cows were diagnosed as being dehydrated, 25 had metritis, 2 had pneumonia, and 19 had a rectal temperature > 38.9°C. Thirty-four cows were in their first lactation.

The sensitivity and specificity of various blood concentrations of BHB associated with removal from the herd ≤ 30 days after surgery, as well as the positive and negative LRs and PVs for selected BHB concentrations, were summarized (Table 1). The area under the ROC curve was 0.64. The BHB concentration of 1.2 mmol/L had the highest combined sensitivity and specificity and was designated as the critical threshold.

Table 1—Results of ROC curve analysis to evaluate the use of selected BHB thresholds to predict removal of dairy cows from the herd ≤ 30 days after undergoing surgical correction of an LDA.

<table>
<thead>
<tr>
<th>Threshold (mmol/L)</th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>LR</th>
<th>Positive</th>
<th>Negative</th>
<th>PV</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>36 (17–59)</td>
<td>89 (81–94)</td>
<td>3.0</td>
<td>0.7</td>
<td>38</td>
<td>88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2*</td>
<td>50 (28–72)</td>
<td>78 (69–85)</td>
<td>2.0</td>
<td>0.6</td>
<td>31</td>
<td>89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>50 (28–72)</td>
<td>65 (55–73)</td>
<td>1.0</td>
<td>0.8</td>
<td>22</td>
<td>87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>59 (36–73)</td>
<td>54 (44–63)</td>
<td>1.3</td>
<td>0.8</td>
<td>20</td>
<td>87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>77 (55–92)</td>
<td>45 (36–55)</td>
<td>1.4</td>
<td>0.5</td>
<td>22</td>
<td>91</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data from 136 cows were included in the analysis; blood samples were obtained immediately prior to surgery and tested with a portable BHB measurement device. Sensitivity and specificity values are reported as percentages.

*This point on the ROC curve had the highest combined sensitivity and specificity and was designated as the critical threshold.

The BHB concentration in whole blood was measured immediately prior to surgery. Values were dichotomized for analysis. Only variables that remained significant in the final model are shown.

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Table 2—Results of multivariable regression analysis for removal of dairy cows from the herd ≤ 30 days after undergoing surgical correction of an LDA.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Risk ratio (95% CI)</th>
<th>SE</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHB (mmol/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1.2</td>
<td>2.5 (1.3–5.0)</td>
<td>0.88</td>
<td>0.008</td>
</tr>
<tr>
<td>≥ 1.2</td>
<td>Referent</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>No. of lactations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.9 (1.1–3.3)</td>
<td>0.52</td>
<td>0.01</td>
</tr>
<tr>
<td>≥ 2</td>
<td>Referent</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

---

Figure 1—Receiver operating characteristic curve for the use of BHB concentrations in whole blood to predict removal of dairy cows from the herd ≤ 30 days after undergoing surgical correction of an LDA. Blood samples were obtained from 136 cows immediately prior to surgery and tested with a portable BHB measurement device. The open circle indicates the point on the ROC curve that had the highest combined sensitivity and specificity (ie, the critical threshold; 1.2 mmol/L). The diagonal line represents the points at which values were equal to those occurring by chance.

Table 2—Results of multivariable regression analysis for removal of dairy cows from the herd ≤ 30 days after undergoing surgical correction of an LDA.

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times as likely to have this outcome as were multiparous cows, regardless of BHB concentration (the interaction was not significant \([P = 0.9])\).

Discussion

Results of the present study suggested that a BHB concentration < 1.2 mmol/L in whole blood immediately prior to LDA surgery may be a negative prognostic indicator for remaining in the herd for ≥ 30 days after surgical correction. Although it has generally been established that ketonemia is a risk factor for the development of LDA in dairy cattle, few studies have been performed to evaluate prognostic indicators for survival or for milk production in cattle undergoing surgical correction for this condition.

In a study\(^1\) of cows undergoing surgical correction for right-displaced abomasum, increased plasma 1-lactate concentration was found to be a useful negative predictor for remaining in the herd. Results of another study\(^2\) revealed that concurrent mastitis, increased age, and previous LDA in cows were negative prognostic indicators for remaining in the herd at 60 days after surgery. Other investigators found that survival in cattle following surgery to correct an LDA was related to severity of fatty liver changes.\(^3\) An LDA of extended duration, lameness, hemocoagulation, diarrhea, poor body condition, circulating electrolyte abnormalities, high circulating concentrations of urea or bilirubin, and high AST activity were found to be negatively associated with return to milk production in 1 study\(^4\); however, results of that study also indicated that acetonuria at the time of diagnosis was positively associated with short-term return to production, and lack of acetonuria at diagnosis was associated with cows being sold for slaughter, presumably because of poor production.

The study reported here was a prospective cohort study and as such has several inherent characteristics. One notable feature is the lack of ability to control all possible risk factors that may be associated with the outcome of interest. Thus, the results (eg, risk ratios) are measures of association. Cohort studies are useful for testing hypotheses in natural populations as well as generating hypotheses, as is done in pilot studies, to be tested with other study designs such as laboratory experiments or randomized trials. Although the current study may have good external validity (ie, the results can be generalized to similar populations), follow-up data such as information on milk production or additional treatments needed for each cow were not recorded. As such, other risk factors that could potentially be associated with culling decisions were not included in the analysis. Future studies may need to assess these other factors and evaluate their association with culling. However, because the objective of this study was to evaluate the association of blood BHB concentrations immediately prior to surgery with the risk of removal from the herd ≤ 30 days after this treatment, these limitations might not affect results related to the primary objective.

Results from the current study indicated that cows with low blood BHB concentrations (< 1.2 mmol/L) at the time of surgical correction were 2.5 times as likely to be removed from the herd in the period of interest as were those with high BHB concentrations (≥ 1.2 mmol/L). One possible explanation for this finding is that cows with low BHB concentrations may lack the capacity to return to normal milk production, and such cows may have been culled because of low profitability. Unfortunately, we did not evaluate milk production in the present study, nor did we distinguish among cows that died, were sold, or were euthanized. Another speculative explanation for this finding is that cows that had an LDA for longer periods prior to detection had decreased their milk production to the extent that ketogenesis was no longer occurring and that this resulted in low BHB concentrations. In our opinion, it is likely that cows that have LDAs for longer periods prior to detection are less likely to recover to full production, compared with cows in which the condition is rapidly detected.

To evaluate the usefulness of the BHB test, the sensitivity, specificity, positive LR, and positive PV at the 1.2 mmol/L cut point can be used. The sensitivity refers to the probability that an animal with the disease will have a positive test result, and the specificity refers to the probability that an animal without the disease will have a negative test result. It is important to keep in mind that in this study, the disease condition was defined as removal from the herd after LDA surgery, but the test was performed prior to the surgery. Although this test did not have a very high sensitivity (50%) or specificity (78%), it had a positive LR of 2. A positive LR of 2 indicates an approximately 15% increase in the probability that animals will leave the herd on the basis of this test result, compared with their pretest probability.\(^5\) For example, if 10% of the cows with a diagnosis of LDA leave the herd (pretest probability), then a cow with an LDA and a BHB concentration of < 1.2 mmol/L has a 31% chance of leaving the herd. The positive PV estimates the probability that a cow with a BHB concentration < 1.2 mmol/L would have a 31% chance of being removed from the herd. Predictive values also include the underlying prevalence of the disease, and in populations with low prevalence, such as that in the present study, where the risk of LDA is relatively low, the PVs may be small despite the sensitivity and specificity of the test.

Primiparous cows in the present study were at a higher risk (a nearly 2-fold difference) of being removed from the herd ≤ 30 days after surgery than were multiparous cows. This is in conflict with the findings of other studies\(^6,22\) that revealed either no association with parity or increased risk of removal from the herd with increasing parity in cattle that underwent surgery for treatment of LDA. It is possible that our selection criteria created a study population that had some characteristics that differed from those of cattle in other studies. Cattle were enrolled in the study only if they met the initial criteria for inclusion and if the producer was willing to administer only the prescribed follow-up treatments.

An unexpected finding of this study was the lack of association between very high blood BHB concentrations and removal from the herd following surgical cor-
rection of LDA. This appears to contradict the findings of a previous study, which high circulating BHB concentrations and hepatic lipidosis were negatively associated with survival following surgery to correct LDA. It stands to reason that high serum BHB concentrations would be positively associated with hepatic lipidosis in dairy cattle. Investigators in another study found that in cows with induced ketosis, fatty liver change was associated with high serum BHB concentrations; however, to our knowledge, no study has conclusively indicated association between these variables.

The current study was performed with client-owned animals in a private veterinary practice, which did not allow for blinding of farm personnel or investigators in regard to certain variables such as concurrent disease status of a cow. The concern with this lack of blinding is that if farm personnel and veterinarians involved in the study developed preconceived notions about the potential outcome for a cow on the basis of this information, their actions may have been biased, either in favor of or against the cow’s remaining in the herd. It could be assumed that as the study progressed, the probability of this bias would become more apparent; however, because the sequential numbering of cattle was not significantly associated with the outcome, we assumed that knowledge of the blood BHB concentration and concurrent disease status did not influence the outcome. In addition, the effect of surgeon was also evaluated and was not significantly associated with the outcome.

There was also no attempt to control herd management differences among farms. Some herd management practices may have been unique to individual farms; however, these variables were considered similar to what is encountered by many large animal ambulatory veterinarians. Another weakness of the study was the lack of milk production data for cows enrolled in the study. Retrieval of those data was not possible because daily milk weight data or even monthly test-day data were not available for some herds.

Left-displaced abomasum is a common condition in dairy cows, and surgical correction is attempted in many cases. Because surgical correction is expensive, the ability to use an objective, rapid, cow-side test for a factor associated with the likelihood of short-term survival after surgery (determined in the present study by a cow’s being kept in the herd for up to 30 days) may be a valuable part of the decision-making process. Blood BHB concentration in dairy cows undergoing surgical correction for LDA may potentially be a useful prognostic indicator for this purpose. The results of the present study showed that, after parity and herd were controlled for, cows with a blood BHB concentration < 1.2 mmol/L immediately prior to surgery were 2.5 times as likely to be removed from the herd ≤ 30 days after LDA correction, compared with cows that had BHB values ≥ 1.2 mmol/L. However, this study did not evaluate milk production or other herd-level risk factors that may be associated with this outcome.

References