Challenges and Opportunities for Technology to Improve Dairy Health Management[1]

Stephen LeBlanc
Population Medicine, Ontario Veterinary College
University of Guelph, ON Canada

Early detection of infectious or metabolic disease in transition cows is challenging, particularly as herd size increases. This difficulty is driven by a lack of skilled labour, the cost of labour, or lack of desire to train and supervise people. If technology is to relieve some of this problem, it must be better - faster, more accurate, more objective, or cheaper - than human monitoring and intervention. While many "precision farming" technologies seek to replace human tasks or assessments completely, a more attainable goal with the potential for widespread application may be to apply, develop, or combine technologies for screening of animals to increase the efficiency of humans' work or for decision support.

A few years ago we wrote, *"There is an ongoing challenge for prevention of many diseases; although there is still much to learn, information already exists to substantially reduce or prevent the disease altogether—the challenge is in effectively and consistently implementing the required management practices. Ever-better understanding of epidemiology and pathophysiology will not in itself reduce the incidence of disease. The ability to translate emerging knowledge into on-farm application and actual prevention of problems requires understanding of the farm as an integrated system, a major component of which is educating and motivating humans to implement well designed practices. Understanding and accomplishing this final major step in the disease prevention process is both an advance and an ongoing challenge."* (LeBlanc et al, 2006) The human element remains a key variable in implementing health management. Technology may, with rigorous validation and careful consideration, replace or improve on actions by people, but a greater use of sensor-based data gathering and data processing for decision support may be to increase the efficiency of health assessment and response tasks performed by skilled and conscientious people.

This paper reviews the importance of energy metabolism in transition dairy cows, its associations with disease and reproduction, and strategies for monitoring cows under field conditions during this critical time. Automated activity monitoring, and more recently, in-line progesterone testing have become established tools for management of reproduction (e.g., Friggens and Lovendahl, 2008). There is a growing body of research on automated data processing or sensor-based technology for detection of lameness or mastitis in lactating dairy cows, and general illness in calves on automated liquid feeders. This paper focuses on health problems of cows in the transition period around calving.

[1] Adapted from LeBlanc S. Monitoring Metabolic Health of Dairy Cattle in the Transition Period
J Reprod Dev 2010 56:Suppl. S29 – S35

Metabolic Challenges in Peripartum Dairy Cows and Their Associations With Health

The biology of dairy cow health and reproductive performance is multifactorial and complex. High producing dairy cows have been described as "metabolic athletes". However, 30 to 50% of dairy cows are affected by some form of metabolic or infectious disease around the time of calving. Essentially all peripartum dairy cattle experience: a period of insulin resistance, reduced feed intake, negative energy balance, lipolysis, and weight loss in early lactation; hypocalcemia in the days after calving; reduced immune function for 1 to 2 weeks before, and 2 to 3 weeks after calving; and, bacterial contamination of the uterus for 2 to 3 weeks after calving. Because of both high metabolic demands and pathogen challenges, cattle also routinely experience substantial oxidative stress at the same time (Sordillo and Aitken 2009). These factors, as well as dramatic changes in circulating progesterone, estrogen, and cortisol concentrations contribute to a substantial reduction of immune function, in particular of neutrophils, at this time (Goff and Horst, 1997). While metabolic and uterine disease are common, only a minority of cows experience these problems, between herds or even with a herd in which cows apparently have similar nutritional and management experiences. Prediction or early detection of which cows have health problems is an important goal.

To achieve the economic objective of pregnancy within 80 to 120 days after the previous calving, the uterus must return to a condition to support a new pregnancy, and a regular estrus cycle must be re-established. This is the result of a complex set of interactions and endocrine signalling among the brain, liver, ovaries and uterus (Wathes et al., 2007). While there is some research on the links between energy metabolism and reproductive function, there is a gap in examining the intervening component of uterine disease, which is at play in as many as half of all cows. Uterine health problems (RP, metritis (uterine infection causing systemic illness in early lactation), and endometritis (chronic low-grade uterine infection and inflammation between 3 and 9 weeks postpartum) affect up to half of dairy cows in the first 60 days postpartum (Sheldon et al., 2006).

Retained placenta is a disease of immune function, with changes in immune function at least two weeks before calving (Kimura et al 2002). Similarly, endometritis is associated with impaired innate immune function (Sheldon et al, 2009; Herath et al 2009), again with measurable changes present prepartum (Kim et al 2005), weeks before disease becomes manifest. Cows in greater negative energy balance, and in particular those that go on to have metritis or endometritis have more pronounced impairment of at least some immune functions (Hammon et al., 2006). Cows in a greater degree of negative energy balance prepartum, as evidenced by higher non-esterified fatty acid (NEFA) concentrations were 80% more likely to have RP, and accounting for the effect of NEFA, those with lower circulating vitamin E were at greater risk of RP (LeBlanc et al, 2004). This supports the notion that severe negative energy balance impairs immune function, which in turn makes RP more likely, but also underlines the fact that the development of RP is multifactorial. Metabolic disease that becomes clinically manifest as displaced abomasum, typically around 10 days postpartum, is preceded by significant changes in adipose mobilization and energy metabolism up to 3 weeks before the disease event (LeBlanc et al, 2005). It is increasingly clear that uterine disease that is expressed 1 to 8 weeks after calving, and return to a normal estrus cycle and ovulation by 9 week after calving are preceded by metabolic and immunologic changes before and soon after calving. While metabolic and immune function can be studied in detail for research, there are indicators or surrogate measures that be practical for clinical use.

Little is known about the determinants of uterine health, and how resistance to uterine disease may be enhanced through animal management. Contamination of the uterus with potentially pathogenic bacteria is nearly universal after calving (Sheldon et al., 2004), yet only a minority of cows develop clinical disease. Similar to RP, development of metritis depends largely on immune function in the early postpartum period (Hammon et al., 2006). Cows with severe metritis ate 2 to 6 kg DM less than healthy cows in the 2 to 3 weeks preceding the clinical signs of metritis (Huzzey et al, 2007). Lower feed intake is associated with increased NEFA which contributes to the risk of fatty liver, which in turn is associated with impaired neutrophil function (Zerbe et al, 2000). Additionally, NEFA have been shown to inhibit neutrophil function *in vitro* (Scalia et al, 2006). Healthy cows clear the uterus of bacteria by approximately 3 weeks postpartum but important gaps remain in understanding of the immunobiology of the reproductive tract of cattle. Approximately 17% of cows fail to clear bacterial infection and have clinical endometritis (LeBlanc et al., 2002) and an additional 15 to 20% have chronic subclinical inflammation (Gilbert et al., 2005). Both forms of endometritis are associated with substantial decreases in pregnancy rate. Recent research (Santos et al 2008) indicates that uterine infection predominated by *E. coli* in the first week postpartum and *A. pyogenes* in the third week is associated with subsequent endometritis.

Metabolites to Measure Energy Status in Transition Cows

Circulating concentrations of NEFA and β-hydroxybutyrate (BHB) measure aspects of the success of adaptation to negative energy balance. The concentration of NEFA reflects the magnitude of mobilization of fat from storage and mirrors DMI (Adewuyi et al, 2005), while BHB reflects the completeness of oxidization of fat in the liver. Ketone bodies (BHB, acetone and acetoacetate) are the intermediate metabolites of oxidation of fatty acids, specifically resulting from the incomplete oxidation of fatty acids. As the supply of NEFA to the liver exceeds the ability of liver to completely oxidize the fatty acids to supply energy, the amount of ketone production increases. Ketone bodies can be used by muscle as an alternative fuel source to glucose, sparing glucose for milk production. However, ketone production does not result in as much net energy release as complete oxidation of fatty acids. Additionally, increasing concentrations of ketones are thought to suppress feed intake (Allen et al 2009).

Glucose is the primary metabolic fuel, and is absolutely required for vital organ function, fetal growth, and milk production. In dairy cows, the massive energy demand to support milk production is largely met through gluconeogenesis. Glucose concentrations are under tight homeostatic control. Therefore, although glucose has a central role in metabolism, it is a poor analyte for monitoring or investigating herd problems.

Associations of NEFA and BHB with Disease, Production, and Reproduction

High NEFA (> 0.4 mmol/L) in the last 7 to 10 days before expected calving is associated with: 2 to 4 times increased risk of LDA (LeBlanc et al, 2005); 2 times increased risk of retained placenta (Quiroz-Rocha et al 2009); 2 times increased of culling before 60 days in milk (DIM) and 1.5 times increased risk of culling over the whole lactation (Duffield et al, 2005); and 1.1 kg/day less milk production in the first 4 months of lactation (Carson, 2008).

Subclinical ketosis (BHB > 1200 to 1400 μmol/L) in the first or second week after calving is associated with: 3 to 8 times increased risk of LDA (Duffield et al, 2009); 3 times greater risk of metritis when serum BHB in week 1 was > 1200 (Duffield et al, 2009); 4 to 6 times increased risk of clinical ketosis (Duffield et al, 2009); increased probability of subclinical endometritis at week 4 postpartum (Hammon et al, 2006); and increased duration and severity of mastitis but not with the incidence of mastitis (Duffield et al, 2009). Milk yield at first test reduced by 1.9 kg/d when BHB was > 1400 μmol/L in week 1 and by 3.3 kg/d when BHB was > 2000 μmol/L in week 2. Cows with serum BHB > 1800 μmol/L in week 1 had > 300 kg lower projected production for the whole lactation.

Ketosis is associated with reduced reproductive performance, which extends its impact much longer than many producers realize. It is worth emphasizing that health in the weeks before and after calving influences reproduction at least 2 months later. Cows with milk BHB > 100 μmol/L in the first week postpartum were 1.5 times more likely to be anovular at 9 weeks postpartum (Walsh et al 2006). Cows that experienced ketosis in the first two weeks of lactation had reduced probability of pregnancy at the first insemination.

Furthermore, cows that had ketosis in one or both of the first two weeks after calving had a lower pregnancy rate until 140 DIM. The median interval to pregnancy was approximately 108 days in cows without ketosis, was significantly longer (124 days) in cows with ketosis in the first or second week postpartum, and tended to be longer still (130 days) in cows that had subclinical ketosis in both of the first weeks of lactation (Walsh et al, 2007).

In summary, metabolic events starting two weeks before calving have effects on health from calving through 9 weeks later, which in turn have effects on reproductive performance weeks to months later. This at least offers of the possibility of early detection and intervention to mitigate health problems in the peripartum period.

Monitoring Programs

Objectives

Routine, proactive actions, observations, or analysis are intended to accurately and efficiently provide early detection of problems, to provide an opportunity for investigation and intervention in order to limit the consequences and costs of health problems and reduced animal performance or welfare. There are two main reasons for monitoring transition dairy cows in general, and running metabolic tests in particular. The objectives overlap, but are distinct and should be clear before embarking on a program. The objectives are: herd or group level - to monitor the success of current management with the goal of early detection of problems or deviation from the management program; individual level – to identify cows at high risk for disease with the goal of intervention for these individuals to prevent or mitigate clinical disease.

Automated or sensor-based technologies must detect disease with acceptable accuracy earlier or more efficiently (at lower cost or with less labour) than simpler programs based on observation of animals by people or application of routinely available data (e.g., daily or DHI milk yields; forestripping milk to detect mastitis; body condition scoring)

Methods of monitoring

The principles and practice of conventional screening programs for fresh cows have been well and critically described (Guterbock, 2004).

Clinical Disease Records

A starting point for assessment of peripartum health is to have accurate records of the farm-specific incidence of the clinical diseases of importance to the herd. This would typically include the number of cattle that had dystocia, RP, milk fever, metritis, and DA, or that were culled or died in early lactation divided by the number of cows that calved in a defined time period. The incidence of clinical mastitis and lameness per month or other time period is also useful although complicated by the risk period extending throughout lactation and the possibility for multiple occurrences in the same cow, which may not be independent events. For all diseases, it is important that the case definitions be clear, mutually exclusive, and consistently recorded. The records should allow for measurement of the incidence of the condition of interest, not the treatment rate. Investigation of the pattern of affected animals and the risk factors for disease is suggested if the following crude lactational incidence risks are exceeded: dystocia > 20%; RP > 10%; milk fever > 2%; metritis > 10%; DA > 5%. However, herd size, demographics, and management influence the expected incidence, so reference to herd-specific goals and recent history are more useful than broad benchmarks. Also, tracking the rates of clinical disease is necessarily retrospective and therefore at best allows for reaction to problems rather than early warning. Finally, clinical disease is typically only the "tip of the iceberg" with respect to health problems and therefore these records underestimate the prevalence of potentially performance-limiting health conditions. Trends in the prevalence of culling in early lactation may also provide an additional element of herd-level information (Nordlund and Cook, 2004).

Measurement of Feed Intake

Adequate feed intake by all peripartum cattle is crucial for health and production. It is therefore desirable to measure feed dry matter intake (DMI) in prepartum and early postpartum cows. Although measurement of only group average intake may be feasible in commercial free stall barns, that is still likely to be useful information. For example, if there is < 2% of feed remaining prior to the first feeding of the next day, then ad libitum intake is likely not be achieved by all animals in the group. Arguably, feed intake is one of the most important pieces of information that determines and identifies cow health and performance. Technology exists for automated capture of both individual DMI and feeding behaviour in group-housed cattle (Chapinal et al, 2007), and elements of such technologies may be applied on a commercial scale in the future.

Feeding Behaviour

An automated, auditory-based, telemetric neck strap-mounted rumination monitor has recently been validated against human observation and found to provide a high correlation for measurement of daily rumination time (Schirmann et al, 2009). However, the relationship between rumination time and DMI, or the predictive ability of rumination time for disease screening are not known.

There are small-scale yet compelling data that indicate that decreased DMI is strongly associated with the risk of developing metritis (Huzzey et al, 2007) and early lactation subclinical ketosis (Goldhawk et al, 2009). While excellent tools exist for research into feed and water consumption and feeding behaviour (Insentec, Marknesse, the Netherlands; Chapinal et al 2007), it is not clear that technology for direct measurement of individual daily fresh or dry matter intake on a commercial scale lies in the foreseeable future. However, DMI is highly correlated with time spent at the feeder ($r = 0.75$), which in turn is explained by the number of visits to the feeder ($R^2 = 0.53$) (Goldhawk et al, 2009). Therefore, simpler technology that records the number and/or cumulative daily duration of visits to the feeder (e.g., antennae mounted on the feed curb or headlocks that record cow presence each minute from RFID ear tags or strap-mounted transponders.

In a case-control study of 10 cows with serum BHB > 1000 µmol (subclinical ketosis; SCK) on at least one of days 0, 3 and 6 after calving, matched with 10 healthy herdmates, cows that developed SCK ate 18% (approximately 3 kg DM) less and visited the feed bins 18% fewer times in the week before calving. A 1 kg decrease in daily DMI in the week before calving was associated with more than 2 times greater odds, and explained 49 % of the variation of SCK in the week after calving (Goldhawk et al, 2009). In separate analogous analyses of feeding behaviour (surrogate measures of intake) time spent at the feeder, and the average daily number of visits to the feeder explained 57% and 36%, respectively, of the variation in subsequent SCK. For each 10 minute decrease in time at the feeder in week -1, the odds of subsequent SCK increased by 1.9 times. Similarly, in a related (Huzzey et al, 2007) and in a separate study (Urton et al, 2005) in the same research herd, a 10 minute decrease in time at the feeder in week -1 was associated with a 1.7 and 1.6 fold increase in the odds of metritis between 5 and 9 DIM.

Changes in feeding behaviour were reported to precede clinical ketosis and lameness (Gonzalez et al, 2008). A decrease of > 1.5 to 2.5 standard deviations from individual cow rolling 7 day average feeding time identified 80 to 90% of cows with ketosis or acute lameness. Among 8 cows diagnosed with clinical ketosis, feed intake was substantially reduced - an average of just over 10 kg as fed over 3.5 days – with dramatic decreases in the 1 to 2 days before diagnosis. Over the 3.5 days before clinical ketosis, average feeding time was reduced by 45 minutes; there were 11 fewer visits to the feeder/day, and 0.7 fewer meals/day.

Feed intake or its indirect measures are suggested to be less likely to be able to screen for mild or moderate mastitis because of the variability in clinical signs and pathogens (Gonzalez et al 2008). Further research is needed on possible changes in feed intake and other behaviours that are associated with, and may predict mastitis.

Water Intake

The is strong association between feed DMI and water intake, typically of the order of 4 L of water per kg of DMI, although numerous variables affect both water and feed consumption either jointly or separately. Lukas et al (2008) measured DMI and water intake in 70 cows in tie stalls using statistical process control for data processing. They found that fever was associated with a 6 kg/day decrease in water consumption, although this may have been underestimated because consumption was estimated from pairs of cows that shared a water bowl. They suggested that water consumption could be used as a surrogate measure of feed DMI. Cows that developed SCK in week 1 after calving drank about 10 kg/day less water in each of the two weeks before calving (approximately 35 to 37 kg/d vs. 45 kg/d), but there were no differences in the number of visits (9 to 11/day) or time spent (12 minutes/day) at the water bin (Goldhawk et al, 2009). Huzzey et al (2007), using a larger sample of the same animals as Goldhawk et al (2009), found that water intake in week -1 was a poorer predictor of metritis than was feed DMI.

Milk Production

Milk production is expected to increase rapidly in early lactation, and a consistent rise should result from good health and feed intake. Therefore, automated daily measurement of milk production in the first few weeks of lactation offers promise as a means to identify cows with clinical or subclinical health problems. The variability of daily milk yield is high, especially in early lactation, and is influenced by many factors beyond health (e.g. weather, changes in diet, movement of cattle to new groups, etc). However, decreased milk production often precedes clinical disease. For example, milk yields started to decline 6 or 7 days before diagnosis of ketosis or DA (Edwards and Tozer, 2004) and were 3 to 6 kg/day lower than for healthy cows from 5 days to 1 day before diagnosis. However, in the first 5 DIM, cows that later had DA produced more milk, and those that later had ketosis had the same average daily yield as cows that remained healthy, making early discrimination of affected cows very difficult. Lukas et al (2009) similarly reported that cows that experienced DA first made less milk (4 kg/d) than healthy cows 5 days before diagnosis, and yield was on average 3 kg/d lower at least 10 d before diagnosis of ketosis. However it is not clear how these differences are or can be applied in the field when most software systems rely on at least a 7 day learning or “burn-in” period for each cow before detecting excessive negative variation for that individual. Lukas et al (2009) generated a health monitoring scheme using daily milk yield or daily milk and electrical conductivity in a statistical process control (SPC) approach. To overcome the lag in generating usable baseline data in early lactation they provided a sample of parity and season-specific typical data for yield and EC for each cow to start the SPC charts. Using milk yield alone and with specificity set to 98%, the sensitivity for detection of metabolic disease (a total of 24 cases of ketosis, DA, or other digestive diseases) was 46%, which decreased to 38 and 25% as specificity was increased to 99 or 99.5%. Addition of SPC-processed EC and yield data to the scheme provided 58, 33, and 29% sensitivity when specificity was set to 98, 99, and 99.5 %, respectively.

Daily yield coupled with activity monitoring may be useful for screening of cows for earlier disease detection (Edwards and Tozer, 2004) but the actual performance of this approach was not reported. Trends in projected production from early lactation provide herd-level information on the success of transition into lactation (Nordlund and Cook, 2004).

Thermography

Infrared thermal imaging of accessible body surfaces has been explored for detection of several diseases in cattle, notably including mastitis. While the transient increase in udder temperature associated with mild to moderate (experimental endotoxin-induced) clinical mastitis was detectable, other signs were measurable earlier (Hovinen et al, 2008). The high correlation between rectal and udder surface temperature in their data suggest that thermography of the udder could be used as an automated and non-invasive means of detecting systemic fever.

Conductivity

The electrical conductivity (EC) of milk, measured at the quarter or composite levels, was a fairly early application of sensor-based automated real-time screening for clinical and perhaps subclinical mastitis (e.g., Norberg et al, 2004; Norberg, 2005). Lukas et al (2009) explored the hypothesis that EC might be associated with, and predictive of other diseases in addition to mastitis. Significant but small (2 to 8%; roughly 2 to 7 millisiemens) increases were detected as expected 1 to 3 days before severe or mild mastitis, respectively. Apparently similar increases were detected starting 2 days before diagnosis of DA and 9 days before diagnosis of ketosis, ending in both cases the day after diagnosis (in contrast to mastitis in which case increased EC continued for 2 to 7 weeks after diagnosis, inversely related with severity).

Activity

Lameness is expected to cause decreased activity due to the discomfort of standing and walking. As cows progress into some clinical illnesses (milk fever, severe mastitis) substantial decreases in activity may be expected, although these changes may happen over < 12 hours. In loose housing, feed and water consumption imply getting up and walking to the feed bunk, typically 5 to 10 times per day, such that there may be a useful association between the level of activity and feed intake, if variables such as estrus or social group changes are held constant. However, this relationship requires study. It is also less clear if there are detectable changes in activity that precede metabolic or infectious disease. There are preliminary data (Adewuyi et al, 2006) to suggest an association of activity level with blood NEFA concentration, although the direction of such an association is not clear (Brickner et al, 2007).

Because diseases usually affect only 2 to 15% of cows, researchers often combine several or all diseases into dichotomization of healthy and sick cows. Pooling of heterogeneous health conditions likely biases against detecting predictive changes in activity that may be associated with some diseases. Edwards and Tozer (2004) showed that cows with ketosis or displaced abomasum had higher activity than healthy herdmates 8 or 9 days before diagnosis, but their activity declined over the following week until about 1 day before diagnosis. Overall, cows with a health problem had activity 13 to 15 steps/hour lower than the average of healthy cows in the 2 days before diagnosis (detection by human observation). However, it is not clear if such a difference can be used to flag cows for closer attention, relative to the normal between-cow variation in activity. To overcome this problem, most activity monitoring systems consider the magnitude of deviation of for each cow relative to her own 7 to 10 previous day rolling average. This approach, while effective for estrus detection and perhaps for diseases that occur throughout lactation, has a major problem for common and important conditions that occur soon after calving. For example the median time of diagnosis of metritis is typically 5 DIM, for displaced abomasum, 10 DIM, and for ketosis, 10 to 14 DIM. Therefore, either another baseline is needed, or data should be captured at least daily before calving. The latter approach may be useful considering that intake and feeding behaviour (Huzzey et al, 2007; Goldhawk et al 2009), metabolic (LeBlanc et al, 2005), and immunologic (Kimura et al, 2002) changes that precede metritis, ketosis, DA, and retained placenta are occur starting 1 to 2 weeks before calving. On the other hand, processing of activity data through the peripartum period would have to account for the high variation and expected changes around calving.

Body Condition Scoring

Body condition scoring provides a rapid, simple, and acceptably precise estimate of subcutaneous body fat. It reflects the nutritional, metabolic, and to some extent, health history of a cow in the preceding weeks. Numerous studies have examined the association of BCS with health and reproduction (Bewley and Schutz, 2008), and while generally cows that calve in fat body condition, or moreover cows that lose 1 point or more of BCS in early lactation, are often reported to be at higher risk of adverse outcomes, BCS alone (other than extremes i.e. > 4 or < 2.5 at calving or at 40 to 60 DIM (brief summary in van Straten et al 2009)) is not a sensitive or specific tool for prediction of disease or reproductive performance. Recent research has suggested that the target BCS at calving should likely be lower (≤ 3.0) than previously advocated to optimize health and production (Garnsworthy, 2008)

Automated capture of digital images of cows can be used for body condition scoring (Ferguson et al, 2006). This technique has been validated (Bewley et al, 2008) as providing agreement to within 0.25 point of BCS (using the technique of Ferguson (1994) 93% of the time, even if only a top view of the hooks was assessed.

Body Weight

Cows normally, and for high production necessarily, lose body weight (BW) during the period of negative energy balance in early lactation (e.g., mean BW loss and timing from calving to nadir parity 1: 10 ± 6% to 42 ± 35 DIM; parity 2: 12 ± 6% to 65 ± 43 DIM; parity 3: 12 ± 7 to 74 ± 45 DIM; van Straten et al, 2009). The associations of loss of BW and BCS with reproductive performance were best expressed relative to calving within cow, and although the associations were conditional, generally cows that has more severe or longer-lasting loss of BW has worse reproduction (van Straten et al, 2009). Interestingly, there appear to be both 7 day and 21 day patterns of daily BW change in dairy cows. The latter is likely associated with the estrus cycle and detection of this BW cycle favourable for reproductive performance and may be useful as a means to detect anovulatory condition. The basis for the apparent 7 day pattern is not clear and needs to be explored in a wider variety of herds, but it was unfavourably associated with pregnancy at first insemination, and in some cases with time to pregnancy (van Straten et al 2009).

Ketone Testing

Serum or plasma NEFA concentrations measured 4 to 10 days before expected calving provide a uniquely useful component of assessment of peripartum health. The concentration of NEFA typically begins to rise 2 to 4 days before, and peaks approximately 3 days after calving, but the magnitude of increase is greater, and the increase starts earlier in cows that subsequently experience metabolic disease (LeBlanc et al 2005). Unfortunately, there are presently no on-farm diagnostic tests for measurement of NEFA, which implies the cost and delay of submission of samples to a diagnostic laboratory. Nevertheless, decision-support processing of clinical, production, BCS, and other data could automate strategic screening of which cows, at which days, should be sampled conventionally.

Numerous studies in Canada indicate that the vast majority of subclinical ketosis occurs within the first two weeks postpartum, with few new cases thereafter. Such ketosis is associated with management in the pre-fresh, maternity, and early post-fresh periods. Used with knowledge of their test characteristics to inform interpretation, serum BHB, whole blood BHB measured with Precision XTRA®, milk BHB measured with Keto-Test®, or Ketostix® in urine are valid diagnostic tests for subclinical ketosis. These 3 cow-side tests are economical, practical and sufficiently accurate relative to laboratory analysis of serum for use in the field (Table 1). As for NEFA testing, existing conventional technologies could be combined to increase the efficiency of selection of when, and which cows to sample. Beyond that, in-line milk ketone testing technology and data processing (sampling strategy selection) exist and have been validated (Nielsen et al, 2005).

Table 1. Performance of cow-side tests for detection of subclinical ketosis

Test substrate	Blood	Milk	Urine
Preferred test	Precision XTRA (MediSense, Abbott)	Keto-Test (KetoLac BHB) Sanwa Kagaku Kenkyusho Co.	Ketostix (Bayer)
Sensitivity*	87 – 93%	At 100 μmol/L on the strip: 83% At 200 μmol/L: 82%	At "small" level, when read after 5 seconds 79%
Specificity*	93 – 100%	At 100 μmol/L on the strip: 54% At 200 μmol/L: 94%	96%
Approximate cost**	$2 - 4/test; $ 40 for the meter	$ 2/test	$ 0.25/test
Validation	Iwerson et al, 2009	Summarized by Oetzel 2004	Carrier et al, 2004
Comments	Glucose tests available for this meter are less accurate in cattle than	Bioketone® powder (relative to serum BHB ≥ 1200 μmol/L): sensitivity = 28% and	Typically only able to induce 50% of cows to urinate when sampling.

	the BHB strips	specificity = 100% (Geishauser et al, 2000). The lack of sensitivity (too many false negatives) makes this test unsuitable for monitoring programs.	Acetest® tablet sensitivity = 100% but specificity = 59% (Nielen et al, 1994). The lack of specificity (too many false positives) makes this test unsuitable for monitoring for ketosis.

* Relative to serum BHB ≥ 1400 μmol/L measured in a diagnostic laboratory
** Based on costs in Canada

Test characteristics varied somewhat among studies, apparently largely as a function of the prevalence of subclinical ketosis among the cows being tested. As the prevalence increases, the sensitivity is generally greater, and the specificity lower. For confirmation of a diagnosis of clinical ketosis, all of these tests would be acceptable, and the performance of milk powders is also adequate.

Screening Cows for Uterine Disease

The pathophysiology (Sheldon, 2008), diagnostic criteria and treatment for metritis have been reviewed elsewhere (LeBlanc, 2008). Briefly, metritis may practically be identified based on fetid discharge, fever, and signs of systemic illness (dullness, inappetance, or decreased milk production). Cows with at least two of these signs are likely to benefit from 3 to 5 days of systemic treatment with ceftiofur or penicillin. Daily monitoring of rectal temperature for 7 to 10 days after calving may increase the rate of diagnosis of metritis, and if this practice is implemented it should not be the sole basis for treatment with antibiotics. Routine, systematic screening of fresh cows is likely useful to increase early detection of health problems, especially in large herds, but it is likely most useful if training and experience of personnel and facilities allow for assessment of the cows' attitude, appetite, ketosis status (once or twice weekly), rumination, and abomasal displacement.

Diagnosis of metritis illustrates both the opportunity and difficulties of application of sensor-based technologies to transition cow health. Technology exists for automated, and in some cases telemetric measurement of body temperature, through milk temperature, ruminal boluses, or short-term (e.g., 7 to 10 days) intravaginal devices with temperature probes. However, the cost, practicality, invasiveness, duration or durability, or lack of validation of these devices limit their current application. Even if one or more devices clear these hurdles, temperature alone lacks specificity, and sensitivity for diagnosis of uterine disease. However, automated, minimally invasive temperature data could be combined with clinical history (calving ease, twins, RP), production, feeding behaviour, and production in an algorithm that would selectively screen cows for detailed examination by skilled health workers.

Accurate diagnosis of clinical endometritis requires examination of discharge in the vagina after a minimum of 3 weeks postpartum (LeBlanc et al, 2002), which may be done with a vaginoscope, clean gloved hand, or a Metricheck device. Subclinical endometritis is common and has substantial impacts on reproductive performance (Gilbert et al, 2005). Subclinical endometritis is diagnosed by endometrial cytology obtained trans-cervically either by uterine lavage or cytobrush. Neither technique is sufficiently rapid or practical for widespread use in clinical practice.

What to Do With Early Warning Data? - Investigation of Underlying Causes, and Intervention

The ability to identify individuals or groups at increased risk of disease or unfavourable events, 1 day to several weeks before disease becomes obvious has (at least for metabolic diseases in the transition period) outpaced the development of effective treatments or responses for the identified cattle. Some (e.g. Lukas et al, 2009) have suggested that once cows are generically identified as being at higher risk of a disease event in the next few days, up to a week, these animals could be managed so as to mitigate that risk, such as by decreasing stocking density in their pen. Arguably, such management practices should already be in place to the benefit of all cows. The adage that “there are few grateful patients in preventive medicine, where success is a non-event”, as well as desensitization to excessive false positive signals from monitoring systems speaks to the need for critical appraisal of sensor-based monitoring systems, founded on large-scale validation under commercial field conditions.

A comprehensive investigation including disease and culling records and overall assessment of nutritional and management practices, the distribution of the time at which reduced feeding, weight loss, or ketosis occurs may give direction to further investigation and a working diagnosis. When ketosis is detected primarily in the first two weeks postpartum, emphasis should be placed on bringing cows to the dry period in moderate body condition (BCS = 3 to 3.5), avoidance of excess energy intake between dry-off and 3 weeks prepartum (Drackley, 2007) and particularly on measures to enhance feed intake in the last few weeks before, and through the calving period. Further investigation of an elevated prevalence of ketosis or rapid loss of condition in early lactation may be aided by NEFA testing of cows in the 10 days before expected calving. If there is little evidence of ketosis in the first two weeks postpartum, but an increased incidence 3 to 6 weeks postpartum, that suggests that preventive measures should be emphasize enhancing feed intake in post-fresh period.

Several practical guidance documents for investigation of health problems in transition dairy cows by veterinary practitioners or other advisors have been put forward (Mulligan et al 2006; O’Boyle, 2008; Cook and Nordlund, 2004; Nordlund et al, 2006; Nordlund, 2008). The critical principles are to investigate and ensure that all cattle have unrestricted access to feed at the time of fresh feed delivery, to clean water, and to a comfortable resting place.

Unfortunately, there is presently little evidence to inform choices of intervention in individual cows in response to elevated NEFA or BHBA. Administration of propylene glycol, insulin, or corticosteroids might be beneficial, but further research is needed on treatment regimes that might be effective at reducing the risk of disease or reduced performance among cows identified at high risk of these problems. Based on currently available data (Nielsen and Ingvartsen, 2004), propylene glycol may be a reasonable treatment for cows with elevated NEFA or BHB.

Conclusion

Early, automated detection of disease or screening of cows at increased risk of disease in order to enhance the efficiency of human labour is a worthwhile goal. Some of the biological functions that are important to health and also are targets for sensor-based data collection and processing include feed intake (which can be reasonably estimated from time spent at the manger), maintenance of normal activity level and lying behaviours, maintenance of normal body temperature, and avoidance of excessive loss of body weight and ketosis. If the goal is to augment the efficiency and effectiveness of identification of animals with health problems, existing technologies can be applied and integrated. In the future, there is the promise of ever-greater automation of the process but in either case, large scale validation studies under commercial field conditions are needed to critically assess the performance and profitability of new technology.

References

Adewuyi AA, Gruys E, van Eerdenburg FCM. (2005) Nonesterified fatty acids (NEFA) in dairy cattle. A review. Vet Q. 27: 117-126.

Allen MS, Bradford BJ, Oba M. (2009) Board-invited review: The hepatic oxidation theory of the control of feed intake and its application to ruminants. J Anim Sci 87:3317-3334

Bewley JM, Schutz MM. (2008) Review: An Interdisciplinary Review of Body Condition Scoring for Dairy Cattle. Professional Animal Scientist 24: 507-529.

Bewley J. M., A. M. Peacock, O. Lewis, R. E. Boyce, D. J. Roberts, M. P. Coffey, S. J. Kenyon, and M. M. Schutz. 2008. Potential for Estimation of Body Condition Scores in Dairy Cattle from Digital Images J. Dairy Sci. 91:3439–3453

Brickner A. E., R. R. Rastani,1 and R. R. Grummer2007. Technical Note: Effect of Sampling Protocol on Plasma Nonesterified Fatty Acid Concentration in Dairy Cows J. Dairy Sci. 90:2219–2222

Carrier, J, S. Stewart, S. Godden, J. Fetrow, and P. Rapnicki. 2004. Evaluation and Use of Three Cowside Tests for Detection of Subclinical Ketosis in Early Postpartum Cows. J. Dairy Sci. 87:3725–3735

Carson ME. (2008) The association of selected metabolites in peripartum dairy cattle with health and production. MSc Thesis, University of Guelph.

Chapinal N, Veira DM, Weary DM, von Keyserlingk MAG. Validation of a system for monitoring individual feeding and drinking behaviour and intake in group-housed cattle. J Dairy Sci 2007; 90: 5732–5736.

Cook NB, Nordlund KV. Behavioural needs of the transition cow and considerations for special needs facility design. Vet. Clin. Food Anim. 2004.; 20:495–520.

Drackley JK, Janovick-Guretzky NA, Dann HM. New approaches to feeding dry cows. Proc. Tri-State Dairy Nutrition Conference, April 24-25, 2007, Fort Wayne, Indiana.

Duffield, T., LeBlanc S, Leslie K. (2005) Impact of subclinical metabolic disease on risk of early lactation culling. J. Dairy Sci. 88(Suppl. 1)

Duffield TF, Lissemore KD, McBride BW, Leslie KE. (2009) Impact of hyperketonemia in early lactation dairy cows on health and production. J. Dairy Sci. 92:571–580.

Edwards JL, Tozer PR. (2004) Using activity and milk yield as predictors of fresh cow disorders. J. Dairy Sci. 87: 524-531

Ferguson, J. D., G. Azzaro, and G. Licitra. 2006. Body condition using digital images. J. Dairy Sci. 89:3833–3841.

Ferguson, J. D., D. T. Galligan, and N. Thomsen. 1994. Principal descriptors of body condition score in Holstein cows. J. Dairy Sci. 77:2695–2703.

Friggens N and P. Lovendahl. 2008. The potential of on-farm fertility profiles: In-line progesterone and activity measurements in Fertility in Dairy Cows, 1 – 7.

Garnsworthy P. (2008) Influences of Body Condition on Fertility and Milk Yield. Proc Dairy Cattle Reproduction Council Convention 63-72.

Gilbert RO, Shin ST, Guard CL, Erb HN, Frajblat M. (2005) Prevalence of endometritis and its effects on reproductive performance of dairy cows. Theriogenology. 64:1879-1888.

Goff JP, Horst RL. (1997) Physiological changes at parturition and their relationship to metabolic disorders. J. Dairy Sci. 80:1260-1268.

Goldhawk ,C, N. Chapinal , D.M. Veira , D. M. Weary and MAG von Keyserlingk 2009.

Prepartum feeding behavior is an early indicator of subclinical ketosis J. Dairy Sci. 92:4971–4977

Gonzalez, L. A., B. J. Tolkamp, M. P. Coffey, A. Ferret, and I. Kyriazakis. 2008. Changes in feeding behaviour as possible indicators for the automatic monitoring of health disorders in dairy cows. J. Dairy Sci. 91:1017–1028.

Guterbock WM. (2004) Diagnosis and treatment programs for fresh cows. Vet Clin Food Anim 20: 605–626

Hammon DS, Evjen IM, Dhiman TR, Goff JP, Walters JL. (2006) Neutrophil function and energy status in Holstein cows with uterine health disorders. Vet. Immunol. Immunopath. 113:21-29.

Herath S, Lilly ST, Santos NR, Gilbert RO, Sheldon IM. (2009) Expression of genes associated with immunity in the endometrium of cattle with disparate postpartum uterine disease and fertility. Reprod Biol Endocrin 7:55

Hovinen, M, J. Siivonen, S. Taponen, L. Hänninen, M. Pastell, A.-M. Aisla, and S. Pyörälä. 2008. Detection of Clinical Mastitis with the Help of a Thermal Camera. J. Dairy Sci. 91:4592–4598

Huzzey JM, Veira DM, Weary DM, von Keyserlingk MAG. (2007) Prepartum Behaviour and DMI Identify Dairy Cows at Risk for Metritis. J. Dairy Sci. 90:3220–3233.

Iwersen, M., U. Falkenberg, R. Voigtsberger, et al. 2009. Evaluation of an electronic cowside test to detect subclinical ketosis in dairy cows J. Dairy Sci. 92:2618–2624

Kim IH, Na KJ, Yang MP. (2005) Immune responses during the peripartum period in dairy cows with postpartum endometritis. Journal of Reproduction and Development 51: 757-764.

Kimura K, Goff JP, Kehrli ME, Reinhardt TA. (2002) Decreased neutrophil function as a cause of retained placenta in dairy cattle. J. Dairy Sci. 85: 544-550.

LeBlanc SJ, Duffield T., Leslie K., Bateman K., Keefe G., Walton J, Johnson, W. (2002) Defining and diagnosing postpartum clinical endometritis, and its impact on reproductive performance in dairy cows. J. Dairy Sci. 85:2223-2236.

LeBlanc SJ, Herdt T, Seymour W, Duffield T, Leslie K. (2004) Factors associated with peripartum serum concentrations of vitamin E, retinol, and β-carotene in Holstein dairy cattle, and their associations with periparturient disease. J. Dairy Sci. 87:609-619.

LeBlanc SJ, Leslie KE, Duffield TD. (2005) Metabolic predictors of displaced abomasum in dairy cattle. J. Dairy Sci. 88: 159-170.

LeBlanc, S, Lissemore, K, Kelton, D, Duffield, T., Leslie, K. Major advances in disease prevention in dairy cattle. Journal of Dairy Science 89: 1267-1279, 2006

LeBlanc S. (2008) Postpartum uterine disease and dairy herd reproductive performance – A review. The Veterinary Journal, 176:102-114.

Lukas, J. M., J. K. Reneau, and J. G. Linn. 2008. Water intake and dry matter intake changes as a feeding management tool and indicator of health and estrus status in dairy cows. J. Dairy Sci. 91:3385–3394.

Lukas JM, J. K. Reneau, R. Wallace, D. Hawkins and C. Munoz-Zanzi. 2009. A novel method of analyzing daily milk production and electrical conductivity to predict disease onset. J. Dairy Sci. 92 :5964–5976

Mulligan FJ, O'Grady L, Rice DA, Doherty ML. (2006) A herd health approach to dairy cow nutrition and production diseases of the transition cow. Animal Reproduction Science 96: 331–353.

Nielsen N. I, N. C. Friggens, M. G. G. Chagunda, and K. L. Ingvartsen 2005.Predicting Risk of Ketosis in Dairy Cows Using In-Line Measurements of β-Hydroxybutyrate: A Biological Model J. Dairy Sci. 88:2441–2453

Nielsen NI, Ingvartsen KL. (2004) Propylene glycol for dairy cows - A review of the metabolism of propylene glycol and its effects on physiological parameters, feed intake, milk production and risk of ketosis. Animal Feed Science and Technology 115: 191–213.

Norberg E. 2005. Electrical conductivity of milk as a phenotypic and genetic indicator of bovine mastitis: A review Livestock Production Science 96: 129–139.

Nordlund KV, Cook NB. (2004) Using herd records to monitor transition cow survival, productivity, and health. Vet Clin Food Anim 20: 627–649.

Nordlund K, Cook N, Oetzel G. (2006) Commingling Dairy Cows: Pen Moves, Stocking Density, and Health. Proc American Association Bovine Practitioners. St. Paul, MN. Sept. 20-24, 39: Pages 36-42.

Nordlund K. Fresh Cow Programs: The Key Factors to Prevent Poor Transitioning Cows. In: Proc 2008 Dairy Council Reproduction Council Convention: 73-76.

O'Boyle N. (2008) Nutrition of the periparturient dairy cow. In Practice 30: 495-500.

Oetzel GR. (2004) Monitoring and testing dairy herds for metabolic disease. Vet. Clin. N. Amer. Food Anim. 20: 651-674.

Quiroz-Rocha GF, LeBlanc SJ, Duffield T, Wood D, Leslie K, Jacobs RM. (2009) Evaluation of prepartum serum cholesterol and fatty acids concentrations as predictors of postpartum retention of the placenta in dairy cows. J Am Vet Med Assoc 234:790–793.

Scalia,D., Lacetera N, Bernabucci U. (2006) In Vitro Effects of Nonesterified Fatty Acids on Bovine Neutrophils Oxidative Burst and Viability. J. Dairy Sci. 89:147–154.

Schirmann K, MAG von Keyserlingk , DM. Weary, DM. Veira and W. Heuwieser 2009. Technical note: validation of a system for monitoring rumination in dairy cows J. Dairy Sci. 92:6052–6055

Sheldon IM, Dobson H. (2004) Postpartum uterine health in cattle. Animal Reproduction Science 82–83: 295–306.

Sheldon IM, Lewis GS, LeBlanc S, Gilbert R. (2006) Defining post partum uterine disease in cattle. Theriogenology 65:1516-1530.

Sheldon IM, Williams EJ, Miller ANA, Nash DM, Herath S. (2008) Uterine diseases in cattle after parturition. The Veterinary Journal 176: 115–121.

Sheldon IM, Cronin J, Goetze L, Herath S. (2009) Defining Postpartum Uterine Disease and the Mechanisms of Infection and Immunity in the Female Reproductive Tract in Cattle. Biol. Reprod. DOI:10.1095/ biolreprod.109.077370

Sordillo LM, Aitken SL. (2009) Impact of oxidative stress on the health and immune function of dairy cattle. Vet Immunol Immunopath 128:104–109.

Urton, G., M. A. G. von Keyserlingk, and D. M. Weary. 2005. Feeding behaviour identifies dairy cows at risk for metritis. J. Dairy Sci. 88:2843–2849.

van Straten M, NY. Shpigel and M. Friger. 2009. Associations among patterns in daily body weight, body condition scoring, and reproductive performance in high-producing dairy cows J. Dairy Sci. 92 :4375–4385

Walsh RB, Kelton DF, Duffield, Leslie KE, Walton JS, LeBlanc SJ. (2006) Prevalence and Risk Factors for Postpartum Anovulatory Condition in Dairy Cows J. Dairy Sci. 90:315–324.

Walsh R, Leslie K., LeBlanc S, Kelton D., Walton, J., Duffield, T. (2007) The effect of subclincial ketosis in early lactation on reproductive performance of postpartum dairy cows. J Dairy Sci. 90: 2788-2796.

Wathes DC, Fenwick M, Cheng, et al. (2007) Influence of negative energy balance on cyclicity and fertility in the high producing dairy cow. Theriogenology 68: S232-S241.

Zerbe HN, Schneider, Leipold W, et al. (2000) Altered functional and immunophenotypical properties of neutrophilic granulocytes in postpartum cows associated with fatty liver. Theriogenology 54: 771-786.