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A 100-Year Review: Metabolic health indicators and management of dairy cattle[1]

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ABSTRACT

Our aim in this *Journal of Dairy Science* centennial review is to describe the evolution of focus on metabolic indicators, from discovery and description to evaluation at the individual cow and subsequently herd levels, over the past 100 yr. Furthermore, we discuss current and future technologies that will be used in the dairy industry to utilize these indicators widely going forward. Knowledge of chemical changes in various fluids (e.g., blood, urine, and milk) accompanying numerous metabolic disease states in the dairy cow has existed since almost the beginning of the *Journal of Dairy Science* 100 yr ago. However, only during the last 25 yr have these metabolic indicators been developed into useful tools for cow- and herd-level monitoring for disease and management. From the 1920s through the 1940s, our understanding of the changes in blood chemistry accompanying milk fever and ketosis increased, as did our understanding of the underlying biology. In the 1950s and 1960s, workers studying ketosis and energy metabolism began to evaluate changes in lipid metabolism reflected by concentrations of circulating nonesterified fatty acids; furthermore, initial development occurred for on-farm tests of milk ketones. During the 1970s, blood metabolic profiling was applied to dairy farms but found to be of varied and limited usefulness. The turning point occurred when large epidemiologic studies of periparturient cow disease were pioneered in the United States, Canada, and Europe in the 1980s; these studies further solidified our understanding of risk factors and epidemiological interrelationships among disease, production, and reproduction. In the early 1990s, scientists first incorporated indicators of metabolic health into large observational studies and determined important epidemiological relationships between these indicators and outcomes of interest. This field of study blossomed during the 2000s as several research groups conducted multiple investigations into metabolic indicators related to energy metabolism and began to develop cow-level thresholds and herd-level alarms for use in monitoring and management. This work was accompanied by additional studies to validate point-of-care instruments that could be used to implement these strategies at the cow and herd levels. Work in the 2000s continued to identify and evaluate other physiological indicators of inflammation and oxidative stress; however, these have yet to be incorporated into large-scale cohort studies. Finally, use of technology (e.g., activity monitoring, cow-monitoring collars and tags, milk-based analysis using Fourier transform infrared spectroscopy) continues to receive significant attention going forward to eventually allow for real-time and automatic monitoring of metabolic indicators and improved health and herd management on dairy farms.
Key words: transition cow, technology, metabolic disease

INTRODUCTION

Recognition that clinical diseases and disorders are accompanied by chemical changes in blood, urine, or milk of dairy cattle has existed for almost 100 yr. Remarkably, only during the past 25 yr or so have we begun to realize the value of analytes measured in these fluids for both cow- and herd-level disease detection and monitoring. This realization, combined with advances in technology that enable practical measurement at the cow and herd levels through on-farm tests, has created a rapidly growing appetite among dairy farm managers, veterinary practitioners, and other herd consultants for this type of information. Continued gains of knowledge related to the chemistry of fluids that are readily measurable on farm and their relationships with disease and other economically important outcomes related to milk yield and reproductive performance, along with the rapid advancement of technologies that will enable real-time, automated measurement, will continue to revolutionize how we approach the monitoring of metabolic function and health in dairy cattle.

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In this *Journal of Dairy Science* (**JDS**) centennial review, we describe the evolution of knowledge of metabolic health indicators from the early days of discovery, description, and eventual use in individual cow medicine to the determination—beginning in the 1990s and rapidly expanding through the 2000s—that these indicators are associated more broadly with cow- and herd-level disease, milk production, and reproduction. Furthermore, we review the progression of focus from clinical to subclinical disease detection and monitoring at the herd level and how use of these metabolic health indicators has been an integral part of both the research and eventual on-farm application of programs targeting subclinical disease. We present what we think are the key milestones in Appendix Table A1. Concurrent with research on the biology and epidemiology of subclinical disease and metabolic dysfunction has been progress on the development and validation of technologies that can be applied on farm; we describe the state of our knowledge in this rapidly evolving area. Finally, we provide our perspectives on the development and use of metabolic health indicators in the management of dairy cattle going forward. We focus primarily on contributions made within JDS; however, given the nature of this topic, we also refer to selected works in other journals as appropriate.

THE EARLY DAYS: THE FIRST 75 YEARS

Evidence in the scientific literature that clinical health disorders such as milk fever and ketosis were related to changes in blood and urine chemistry began appearing in the 1920s and 1930s. Various scientists and veterinary practitioners (e.g., Hayden and Scholl, 1923; Dryerre and Greig, 1925; Little and Wright, 1925) determined that cows with milk fever had decreased blood Ca concentrations and hypothesized that dysfunction in the regulation of Ca metabolism in the cow caused milk fever. Others (e.g., Stinson, 1928; Sampson et al., 1933; Lormore, 1934; Boddie, 1935) reported that concentrations of acetone in blood and urine were elevated dramatically in cows diagnosed with ketosis, although causative and predisposing factors were not well recognized at the time. This early work provided the basis for what was to come with more focused work on these chemical changes in blood and urine.

Metabolic Indicators and Hypocalcemia

The first reports in JDS on blood Ca and P and relationships with milk fever appeared during the 1930s. Initially, these papers largely characterized "normal" concentration ranges (later commonly referred to as reference intervals) of these minerals (Anderson et al., 1930; Palmer et al., 1930; Palmer and Eckles, 1930) and provided some initial characterization of how nutrition and management factors may affect them. Wilson and Hart (1932) assessed the dynamics of Ca and P during the immediate periparturient period in both healthy cows and cows diagnosed with milk fever and suggested that blood samples should be collected at multiple time points relative to calving to adequately characterize the decrease at parturition and recovery of blood Ca concentrations postcalving that occurred even in normal cows; furthermore, patterns of blood P concentrations were much more variable than blood Ca concentrations during the same period.

With the exception of additional reports (Kennedy et al., 1939; Vanlandingham et al., 1942) related to concentrations of Ca and P in blood and various factors affecting them related to age and stage of development, further studies of the relationships of blood chemistry with milk fever were not reported in JDS until the 1950s. Blosser and Smith (1950a) measured serum Ca and citric acid concentrations in both healthy cows and cows with milk fever and determined that citric acid and Ca concentrations generally followed the same pattern in normally calving cows and cows with milk fever; however, concentrations of citric acid were elevated during the immediate prepartum period in cows that subsequently developed milk fever. They determined that cows that developed milk fever had increased urinary excretion of citric acid during the immediate prepartum period and few other changes in urine chemistry other than increased excretion of Mg from d 3 to 16 prepartum. These cows also had increased serum Mg accompanying milk fever during the postpartum period (Blosser and Smith, 1950b). Van Soest and Blosser (1954) noted that cows with milk fever had elevated concentrations of blood glucose and strongly negative correlations between blood glucose and P concentrations.

By this time, milk fever was a well-recognized disorder and the linkage between milk fever and blood Ca concentrations was well established; therefore, scientific focus turned to the mechanisms underpinning Ca metabolism in the cow (e.g., Mayer et al., 1969; Ramberg et al., 1970; Ramberg et al., 1976; Horst et al., 1977) and management strategies to prevent milk fever (reviewed by Horst et al., 1997). Few additional reports relating to the specific use of blood Ca and related analytes as indicators of Ca metabolism appeared in JDS until Ballantine and Herbein (1991) evaluated the relationships of ionized (more metabolically active) and total Ca and determined that the relationships between the two varied by time relative to parturition; the proportion of total Ca in the ionized form was highest during the early postpartum period. Furthermore, Szenci