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DIFFERENCES IN BEHAVIORAL AND PHYSIOLOGICAL VARIABLES MEASURED WITH PRECISION DAIRY MONITORING TECHNOLOGIES ASSOCIATED WITH POSTPARTUM DISEASES

I Ching Tsai
University of Kentucky, nicky771004@gmail.com
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I Ching Tsai, Student

Dr. Jeffrey. M. Bewley, Major Professor

Dr. David L. Harmon, Director of Graduate Studies

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THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture, Food, and Environment
at the University of Kentucky

By

I-Ching Tsai

Lexington, Kentucky

Director: Dr. Jeffrey M. Bewley, Associate Extension Professor of Animal Sciences

Lexington, Kentucky

2016

ABSTRACT OF THESIS

DIFFERENCES IN BEHAVIORAL AND PHYSIOLOGICAL VARIABLES MEASURED WITH PRECISION DAIRY MONITORING TECHNOLOGIES ASSOCIATED WITH POSTPARTUM DISEASES

The transition period is defined as the three weeks before and three weeks after the cow calves. Transition cow diseases are considered production diseases. Precision dairy monitoring (PDM) technologies measure physiological, behavioral, and production indicators on individual animals to improve management strategies and farm performance. The objective of the first study was to assess how hypocalcemia, hyperketonemia, and metritis affected variables measured by PDM technologies. The objective of the second study was to use variables from multiple commercially available PDM to examine alert performance generated from different analyses.

KEYWORDS: Transition cow, PDM, Metabolic disease, Ca, NEFA

I-Ching, Tsai
October 12, 2016

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By

I Ching, Tsai

Dr. Jeffrey M. Bewley
Director of Thesis

Dr. David L. Harmon
Director of Graduate Studies

October 12, 2016

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FREQUENTIY USED ABBREVIATIONS

DMI = Dry matter intake

NEB = negative energy balance

Ca = calcium

NEFA = non- esterified fatty acids

BHBA = β – hydroxybutyrate

BCS = body conditional score

Hp = haptoglobin

RP = retained placenta

PDM = precision dairy monitoring

CHAPTER ONE

REWIEW OF LITERATURE

INTRODUCTION

Transition period is defined as the three weeks before and three weeks after cows calved (Drackley, 1999). Management of late lactation, health, and productivity are crucial during this time (Kim and Suh, 2003, Esposito et al., 2014). Because of the dramatic metabolic, immune and endocrine changes, cows are prone to contract more diseases during this time (Bernabucci et al., 2005, Sordillo et al., 2009, Ospina et al., 2010). Transition cow diseases are considered production diseases, and reflect a cow's inability to meet metabolic demands. High incidence rates of these diseases are related to the cost of the treatment. Understanding how cows adapt to the transition period can help producers manage cows through this transition (LeBlanc, 2006). Hormones affect the cow's metabolic system during transition. When the metabolic system is compromised, low dry matter intake (**DMI**) also occurs (Cameron et al., 1998). In addition, herd management and environment change mean cows need to adapt to new feed rations and social hierarchies.

Dairy cow nutrition requirements differ according to the stages of lactation. From pregnancy to lactation, their nutritional requirements alter from nourishing the fetus to producing milk. Nutrient demands in the transition cow period cause a dramatic change. Often, a close-up diet is provided three weeks before calving. From close up to the early stages of lactation, the diet changes dramatically in a short period of time (Goff and Horst, 1997). The change of the diet affects the rumen bacterial populations and absorption ability of the rumen papilla. (Goff and Horst, 1997). Horst et al. (1997) mentioned that ruminal microflora take four weeks to develop and adopt to the changes and rumen papillae take more than five weeks. The key to supporting milk production and fertility is to supply cows with energy and nutrients which can bolster biochemical processes (Khiaosa-ard and Zebeli, 2014).

Also, during this period of time, the secretory mammary epithelium prepares to rebuild and is remodeled for the next cycle of lactation (Strange et al., 1995). Normally, six to eight weeks is sufficient for cows to rest, rebuild, and store energy after lactation. Capuco et al., (1995) indicated that the optimal length of the dry period for dairy cows to get enough rest and renewal of mammary glands was eight weeks. Further, the nutritional requirements of the fetus reach peak levels at three weeks before calving, especially requiring glucose and amino acids for development. Glucose, amino acids, and calcium are needed by the mammary gland following calving in order to meet lactation requirements (Overton and Waldron, 2004). The increase in energy required after calving for milk production coupled with insufficient dry matter intake (**DMI**) could lead to negative energy balance (**NEB**) in early lactation (Ingvartsen and Andersen, 2000, Drackley et al., 2001). The nutritional insufficiency and high nutrient demand resulting from milk production cause cows to experience NEB, which leads to production diseases.

Dry matter intake (**DMI**) consistently decreases before calving (Hayirli et al., 1998, Robinson and Garrett, 1999). Three weeks after calving, DMI typically increases by 1.5 to 2.5 kg per week (Grant and Albright, 1995). Although the nutrient requirements increase, DMI decreases from 10% to 30% (Bell, 1995, Bell et al., 2000). But, increased energy content in the close-up ration could help improve production and health in the early stages of lactation despite the decrease in overall DIM (Grummer, 1995, McNamara et al., 2003, Rabelo et al., 2003). If high energy feed were offered during the far-off dry period, it would increase the possibility of the decline in DMI and negative effects from that decline (Minor et al., 1998, Olsson et al., 1998). Improving energy balance in the transition period decreases the incidence rate of production diseases (Duffield and LeBlanc, 2009).

In early lactation, homeorhetic metabolism utilizes nutrients for milk production instead of body reserves and reproduction (Drackley and Cardoso, 2014). But in the long term, fertility is most affected by dietary imbalance (Zebeli et al., 2015). Thus, after continually lacking sufficient energy, metabolic diseases, such as endometritis, ketosis, displaced abomasum, and retained placenta occur (Drackley, 1999, Duffield, 2000). Metabolic diseases have a major impact on future production and fertility. Preventing metabolic disease is highly preferred over treating it (LeBlanc, 2010). All these diseases are related to increasing culling rates and financial losses (Fetrow et al., 2006). Hadley et al. (2006) analyzed a large amount of data from the United States and found that average culling rate was 31.6%, of which 79.5% were caused by health issues.

Diseases are categorized as clinical or subclinical. Clinical means that cows exhibits an obvious symptom, while subclinical means there are no visual signs of having diseases. Subclinical diseases tend to impact the producer's economic outcomes more than clinical diseases. If producer do not recognize signals of subclinical diseases, cows will go without treatment. Van Saun and Sniffen (2014) showed that costly fresh cow disorders affected productivity and reproductive performance. Incidence rates increased under the combination of high production and modern intensive management system (Pritchard et al., 2013).

The incidence rate of left displaced abomasum was estimated from 3% to 5% (LeBlanc et al., 2005b). In McArt et al. (2012a) the incidence rate of subclinical ketosis ranged from 26% to 56%. The incidence rate of retained placenta was reported at 7.8% by Goff (2006b). Lean et al. (2006) indicated that the mean incidence of hypocalcemia was 21%. Sheldon and Dobson (2004) pointed out that dairy cows had a 10 to 20 % chance of developing metritis after calving. These diseases are important because of their economic impact (McArt et al., 2013). Hypocalcaemia

has been reported at $335 per case (Guard, 1994) and the loss to a 2,000 dairy cow herd was $ 12,000 per year (Oetzel and Eastridge, 2013). Subclinical hypocalcemia was $125 per case (Reinhardt et al., 2011), and a 2,000 cow herd would lose over $ 48,750 per year (Oetzel and Eastridge, 2013). The cost of metritis ranged from $146 to $175 per case (Mahnani et al., 2015). Ketosis was $145 per case (McArt et al., 2012a), and subclinical ketosis was $67 per case (Drackley et al., 2001, Gilbert et al., 2005, Ingvartsen, 2006). Retained placenta was $285 per case (Kelton et al., 1998). Therefore, reducing the cost of treatment and decreasing the incidence of the diseases is essential. Closely monitoring cows during this critical period is imperative to cow longevity. Systematic observations could provide accurate and efficient early detection of all diseases. With early detection, dairy producers could limit the loss of milk production and the minimize the cost of health problems (LeBlanc, 2010).

Dairy cattle physiology and endocrinology in the transition period

Physiological changes

When a cow is pregnant, her energy demand and nutrient requirements are used for fetus and mammary gland development. Different stages of the dry period also require different rations. For example, far-off cows are fed feeds high in neutral detergent fiber (Goff and Horst, 1997). The rumen environment is changed during the dry period, the bacterial population switches (Andersen et al., 1999). Fetal demands rapidly increase in the last four weeks of pregnancy. When cows calve, they are switched to a diet with high energy content, which creates a high risk of development of rumen acidosis due to the rapid change (Goff and Horst, 1997). The high-energy feed provides the energy during the transition period to fulfill the demand. Glucose, amino acids, and fatty acids are among the nutrients in high demand at lactation, which affect mineral utilization and immune functions. Bell (1995) showed that the estimated demand

for glucose is tripled at 250 days of gestation, the amino acid demand is doubled in the lactating mammary gland, and fatty acid demand is fivefold of the demand at four days postpartum. The requirement of calcium increases approximately four times more than normal during the time of parturition (Bell et al., 1995). Lactation creates these high nutrient demands and, if the requirements cannot be fulfilled, metabolic diseases are fatty liver occur.

Glucose demand

The major adaptation of glucose metabolism from the dry cow to the lactating cow is increased hepatic gluconeogenesis (Reynolds, 2006). At the same time, glucose is oxidized from peripheral tissue (Bennink et al., 1972). This directs glucose to the mammary gland for lactose synthesis (Overton and Waldron, 2004). Reynolds et al. (2003) showed that the glucose balance of a cow was zero to nearly negative during the transition and early lactation. If cows cannot satisfy nutrient demands, the unavoidable physiological NEB occurs (Grummer et al., 2004). Glucose is a key factor for regulation of hormones and metabolic processes. A low blood glucose level and infertility are typically found in postpartum dairy cows (Lucy et al., 2013). Glucose in postpartum dairy cows is used to synthesize milk (Bell et al., 1995). Cows can only meet 85% of the glucose requirement during early lactation, and this leaves an estimated 500 grams of daily loss of glucose (Bell, 1995). Although glucose is released by hepatic gluconeogenesis and rapidly increases after calving, the decrease of glucose is unavoidable (Reynolds et al., 2003, Larsen and Kristensen, 2009). In order to obtain an endocrine status favoring less fat mobilization, the nutritional focus should be increasing gluconeogenesis in the liver of prepartum cows for the greatest outcome. Thus, increasing the absorption of glucose in the small intestine could reduce fat mobilization and increase exogenous glucose supply. Cows often undergo

hypoglycemia and hyperketonemia before calving, which potentially negatively impacts their health, production, and overall well-being (Grummer, 1995).

Amino acid demand

Homeorhetic processes and lactogenesis are associated with adapting amino acids to sustain and increase demands for the mammary gland (Ingvartsen, 2006). Gluconeogenesis is a slow process during calving and the peak lactation, but the process builds up faster in the first weeks of lactation (Bell et al., 1995). In order to support lactation, protein and fatty acids become mobilized and are used for mammary milk protein synthesis and gluconeogenesis in the liver (Bennink et al., 1972). Collins and Reid (1980) showed that the skeletal muscle is an important source of endogenous amino acids in early lactation. About 25% to 27% of total body protein in dairy cows has the potential to be mobilized at calving (Belyea et al., 1978). Grummer (1995) suggested that transition cows use the reserves from body protein to support lactation. Therefore, by increasing prepartum protein reserves, the possibility of metabolic disorders can be reduced (Grummer, 1995). For milk production, it is important to balance the ratios of specific amino acids'(Rulquin et al., 1993).

Calcium demand

Under non-inflammation conditions, regulating serum concentrations of calcium (**Ca**) and phosphate (**P**) are based on endocrine control, the level of intestinal absorption, bone reabsorption or release, renal reabsorption, and milk secretion (Overton and Waldron, 2004). To respond to hypocalcemia in dairy cows, calcium metabolism is regulated by the parathyroid hormone (**PTH**). Ca and P stimulate the bone to release vitamin D because of PTH (Thiede, 1994). Reinhardt et al. (2011) indicated that Ca concentration in the blood differs by age, stage

of lactation, and parity. Serum concentrations of Ca around calving decrease to below 2.0 mM (8.0 mg/dL) in 25% of first lactation heifers, 41% of second lactation cows and up to 54% in fifth lactation cows (Reinhardt et al., 2011). Normal serum concentration of Ca in healthy mid-lactation cows ranges from 2.1 to 2.8 mmol/L (8.5 and 10 mg/dL) (Goff, 2008). Minimizing the usage of Ca circulation in the blood reserves, increasing absorption from rumen or intestines, mobilization from tissue, and most importantly Ca reserves in bone, are all required to meet the Ca demand (DeGaris and Lean, 2008). Ca concentration of plasma was high in gestation but dramatically decreased at calving. The challenge faced by transition cows is the sudden change of nutrition requirements for milk production. This occurs simultaneously with the DMI and nutrient supply falling behind. In order to support the milk production, galactopoiesis is accompanied with the mobilization of body reserves to meet high demand of nutrients (Grummer et al., 2004, Ingvartsen, 2006).

Dry matter intake (DMI)

Despite the greater demands of energy, feed intake decreases in the transition period (Kertz et al., 1991, Bertics et al., 1992, Grant and Albright, 1995, Grummer, 1995). The DMI decreases 35% when cows are close to calving (Marquardt et al., 1977) and feed intake will not return to the peak level until weeks 9 to 13 of lactation (Kertz et al., 1991). The decrease of DMI occurs because of the growth of the fetus that takes up abdominal space and reduces rumen volume (Grant and Albright, 1995). Hormones and physiology also play an important role in the adjustment of feed intake in dairy cows (Grant and Albright, 1995). When intake is insufficient, cows mobilize fat reserves from adipocytes (Grummer, 1995). Therefore, in the transition period – prepartum and postpartum – cows consume less energy than required which leads to NEB. Monitoring DMI would be a useful tool to screen cows for diseases during the transition period

(Huzzey et al., 2007, Goldhawk et al., 2009). Cows with less feed intake are more likely to be diagnosed with metabolic and infectious diseases during the transition period (Marquardt et al., 1977, Zamet et al., 1979). To achieve the goal of early detection, producers can monitor DMI and analyze non-esterified fatty acids (**NEFA**) and β-hydroxybutyrate (**BHBA**) in the blood.

Non-esterified fatty acids (NEFA)

Non-esterified fatty acids (NEFA) and β-hydroxybutyrate (BHBA) are considered to be the markers of NEB, due to the relationship between energy demand and energy reserves (Ospina et al., 2010). High amounts of NEFA in the blood from adipose tissue were found in dairy cows from pregnancy to lactation (Bell, 1995). When DMI decreases, NEB occurs and cows compensate by intensive lipolysis, or the breakdown of adipose tissue to maintain the balance between energy requirement and intake (Oldick, 1999). When the adipose tissues are broken down, fatty acids are released into the blood (Kaneene et al., 1997). Factors seen when NEB is present include increased concentration of BHBA (Bell, 1995), decreased concentration of glucose (Vazquez-Anon et al., 1994, Grum et al., 1996), development of fatty liver due to accumulation of triacylglycerol (**TAG**) (Bertics et al., 1992, Grummer, 1995), and decreased body condition score (**BCS**) (Wildman et al., 1982). If NEFA in the blood is excessive then it could lead to toxicity (Herdt, 1988, Emery et al., 1992, Bell et al., 1995), because of the limited capacity for NEFA metabolism to export TAG from the dairy cows' liver (Adewuyi et al., 2005). When maximum NEFA exists in the blood, which implies maximum TAG in the liver, Acetyl-CoA does not return to the tricarboxylic acid (**TCA**) cycle to generate glucose. So, acetyl-CoA converts to ketone bodies, acetone, and acetoacetate (Caldari-Torres, 2009), which could be found in the blood, milk, and urine (Grant and Albright, 1995).

Excess TAG in the liver can decrease metabolic capacity in the liver (Shearer, 1992, Byers, 1995, Rukkwamsuk et al., 1999b, Heuer et al., 2000, Jorritsma et al., 2001). When cows experience lipolysis, they could develop fatty liver syndrome (Byers, 1995, Grummer, 1995, Rukkwamsuk et al., 1999b). Fatty liver syndrome normally does not respond well to treatment, and this could cause greater mortality rates in cows (Shearer, 1992). Measuring NEFA and BHBA thresholds can help producers with early detection of NEB, preventing fatty liver syndrome. McArt et al. (2013) pointed out the high correlation between NEFA and BHBA and successful reproduction and milk production. If the NEFA in the blood reaches a maximum level of 1.0 mEq/L in the postpartum period, cows are at greater risk of having diseases. (LeBlanc et al., 2005c, Ospina et al., 2010, Chapinal et al., 2011, Roberts et al., 2012b). Thus, monitoring the concentration of NEFA is crucial to the management of postpartum health in dairy cows.

β-hydroxybutyrate (BHBA)

With decreasing DMI, the cow's body will try to maintain energy balance to satisfy the nutrient requirement by using body fat and breaking down adipose tissue (Oldick, 1999, Rukkwamsuk et al., 1999b). This results in fatty acids in the blood (Herdt, 1988). This mechanism is related to NEFA, meaning it reaches capacity in the liver. A large amount of TAG in the liver and Acetyl-CoA will not transfer back to TCA cycle, therefore, it will convert to ketone bodies. Then a high concentration of BHBA is found in the blood, milk, and urine (Grant and Albright, 1995). McArt et al. (2013) indicated that there is a relationship between energy demands, energy stores, and the metabolic rate between NEFA and BHBA. High NEFA and BHBA in the blood could increase the incidence rates of DA, culling rate, and infertility, and decrease milk production (McArt et al., 2013). Managing transition period cows by monitoring NEFA and BHBA concentrations and DMI could be an easy solution for producers. If BHBA

levels are greater than 1.2 mmol/dl, the chance to have subclinical ketosis rises (LeBlanc et al., 2005c). BHBA maximum is still being debated, but recent results showed that levels greater than 1.4 mmol/dl create a greater possibility of developing metabolic diseases (Duffield, 2000, LeBlanc et al., 2005c, Walsh et al., 2007, Ospina et al., 2010, Roberts et al., 2012b).

Negative energy balance

Understanding how NEB affects immune responses relative to transition cow disease may help to reduce the illness in the herd. In order to support the energy requirement, a cow's body switches from nutrient accumulation to rapid production of milk by mobilizing protein and lipid stores (Bell et al., 1995). The long-term effect of NEB and physiological disorders could cause the decrease in milk production and reproductive performance (Bell, 1995). The challenge of the transition cow is the increase of nutrients required to produce milk during the late dry period when the DMI decreases. When energy demand is not met by feed intake, NEB occurs (Bauman and Currie, 1980). Energy demands, energy reserves, and the metabolic association are related to NEFA and BHBA. After body fat was mobilized, NEFA concentration increases, and constantly rises in the prepartum transition period, but with a dramatic boost in the last three days of postpartum. Cows that undergo NEB increase in NEFA and BHBA which were widely used to monitor and prevent of diseases early (LeBlanc et al., 2005c), and for culling after calving (Duffield and LeBlanc, 2009).

Cholesterol

Fatty liver is a lipid-related metabolic disorder (Grummer, 1993). Particularly during the transition period, lipid metabolism is changed to fulfill the increased demands for energy (Kessler et al., 2014a). Therefore, as lipolysis NEFA increase, the liver struggles to continue

mobilizing or to recycle TAG (Grummer, 1993). When TAG synthesis exceeds the liver capacity and is exported as very low-density lipoprotein (**VLDL**), fatty liver occurs (Goff and Horst, 1997). The rate of TAG synthesis is related to plasma NEFA concentration, and fatty liver occurs while NEFA increases (Grummer, 1993). Additionally, fatty liver could cause clinical spontaneous ketosis (Grummer, 1993). The ratio of liver triglyceride to glycogen could be used to predict ketosis in cows (Grummer, 1993). Therefore, measuring total cholesterol could help to diagnose transition cow diseases (Sommer, 1975). The normal range of cholesterol in six to eight weeks prepartum is between 90 mg/dL and 150 mg/dL (Sommer, 1975, Kweon K, 1986). But Kweon K (1986) and Kessler (2014) had shown that cows with greater levels of cholesterol from 120 mg/dL to 170 mg/dL would have greater than normal milk yield. However, cows could have different ranges of cholesterol in different stages of lactation, milk yield, seasons and around parturition (Kweon K, 1986, Kessler et al., 2014b).

Haptoglobin

Haptoglobin (**Hp**), an acute phase protein, is related to uterine infection (Skinner et al., 1991, Smith et al., 1998, Regassa and Noakes, 1999, Sheldon et al., 2001). In veterinary diagnosis, the possibility of using acute phase proteins to diagnose disease has been developed (Åkerstedt et al., 2006). Acute phase proteins are a group of blood proteins that change concentration while under attack, infection, inflammation or trauma (Åkerstedt et al., 2006). The major acute phase protein in cows is Hp. Haptoglobin is produced by different cytokines (Gruys et al., 1994, Murata et al., 2004, Petersen et al., 2004). Serum Hp is an unspecific marker of disease and there are many factors that would cause Hp increase in serum (Åkerstedt et al., 2006). However, milk Hp is not commonly used in commercial farms. When infection occurs in mammary glands, the concentration of acute phase proteins, such as lactoferrin and Hp, can

increase in milk (Molenaar et al., 1996, Eckersall et al., 2006, Thielen et al., 2007). So, Hp could be a biomarker for diagnosing metritis, because the concentration of Hp increases 2 days before showing the clinical signs (Humblet et al., 2006, Huzzey et al., 2007, Silvestre et al., 2011). This provides an early detection method to monitor herds and to help improve management and prevent disease from happening.

β-Carotene

β-Carotene is the major precursor of vitamin A and can be found in the feed (Spears and Weiss, 2008). The major role of β-Carotene, similar to vitamin A, is to enhance the host's defense mechanisms. Other functions of β-Carotene are maintaining immunity, reproduction ,and antioxidant status (Engstrom, 2010) ,which can decrease mastitis (Chew et al., 1982) and the risks of retained placenta (Michal et al., 1994). In the transition period, cows experience the negative energy, calcium, and protein balances, which profoundly impacts steroid hormones, minerals, and vitamins (Goff et al., 2002). One of the important consequences is impaired immune function (Mallard et al., 1998), and the decrease of vitamin A around calving. These deficenses could damage immune function as well (NRC, 2001). Endocrine changes are associated with decreased immune function and intake (Goff and Horst, 1997). The results of vitamin A deficiency are abortion, retained placenta, reduced immune function, and mortality (NRC, 2001). β-Carotene would frequently decrease around dry period because of the formation of colostrum and decreased intake (Johnston and Chew, 1984, Michal et al., 1994, Calderón et al., 2007). Graham (1991) suggested 3.0 µg/ml of serum β-Carotene as the beneficial level of supplementation (Graham, 1991). LeBlanc et al. (2004) found 75% of serum β-Carotene used in U.S dairy fram was less than 3.0 µg/ml. Additionally, in Canada, researchers found a mean of 1.12 µg/ml of serum β-Carotene from 1,828 samples from cows in the peripartum period

(LeBlanc et al., 2002b). Lotthammer and Hoffmann-La Roche (1979) pointed out that the lack of β-Carotene is associated with a low milk fat percentage. Also, cows receiving greater amounts of β-Carotene supplements have lesser chance of having mastitis (Bian et al., 2007). Therefore, maintaining adequate amounts of vitamin A in feed could help to improve production, immunity, and reproduction.

Effects of early postpartum disease

Metabolic disease

The concept of metabolism involves physical and chemical processes occurring in the living cells and the breakdown or synthesis of necessary organic molecules in the body (Payne J. M., 1989). The processes of metabolism release metabolites which can either build or degrade the body (Payne and Payne, 1987). During this process, cells, organs, and systems pull out energy from nutrients and use them to maintain the body's needs (Payne and Payne, 1987). Therefore, the major role of metabolism is to keep the body functioning normally and to support life. Insufficient energy supply increases the incidence rate of metabolic and microbial related diseases, such as milk fever, endometritis, ketosis, displaced abomasum and retained placenta (Drackley, 1999, Duffield, 2000). Around 30% to 50% of dairy cows develop metabolic diseases or infection around calving (LeBlanc, 2010). Milk fever is a complex metabolic disorder that occurs at the beginning of lactation, and it is related to an increased demand for Ca (LeBlanc, 2010). Ketosis occurs when the cow undergoes NEB in early lactation. Retained placenta (**RP**) occurs when the villi of the fetal cotyledons did not separate from the crypts of the maternal caruncle. Left displaced abomasum (**LDA**) is a common and economically important problem for producers. In LDA, the abomasum becomes enlarged with gas and fluid, it is displaced from the normal position to the left side, between the rumen and the left lateral abdominal wall

(Coppock, 1974). Cows with a metabolic disease struggle to keep up with the metabolic demands during the high production period (Mulligan and Doherty, 2008).

Hypocalcemia (Milk fever)

Hypocalcemia, a metabolic disease, involves the imbalance of Ca concentration at the onset of lactation (Goff and Horst, 1997). Hypocalcemia increases the incidence rate of other parturient diseases and reduces immune cells' abilities to respond to stimuli (Kimura et al., 2006). Additionally, hypocalcemia causes the reduced contraction of smooth muscle in the rumen and abomasum which lead to abomasum displacement, thus reduced feed intake (Goff, 2008). Hypocalcemia causes continuous neuromuscular dysfunction with flaccid paralysis, circulatory collapse, and depression (Oetzel, 2011). Therefore, some hypocalcemia cases showed the sign of hyperesthesia and tetany in early stages. Cows with the symptoms would fall into flaccid paralysis, which worsens until the neuromuscular activity is completely blocked (Oetzel, 2011). In order to increase and generate milk yield for offspring, a cow utilizes Ca for fetal growth and milk production by creating a unique physiologic condition (Ramberg et al., 1984). About 75% of hypocalcemia cases occur 24 hours after calving, and 12% occur 24 to 48 hours after calving (Oetzel, 2011). The incidence rate of clinical hypocalcemia is approximately 5% in the United States (McLaren et al., 2006), and about 50% of periparturient cows suffer from subclinical hypocalcemia with low blood calcium concentration without signs. Low blood Ca concentration is measured between 1.38 and 2.0 mmol/L (5.5 to 8.0 mg/dL) (Goff, 2008). Chapinal et al (2011) showed that total serum Ca for hypocalcemia is below 8.5 mg/dL, which is greater than in the previous studies (Kimura et al., 2006, Chapinal et al., 2011).

Older cows have a greater incidence rate of hypocalcemia, because of the reduction in bone Ca capacity (Van Mosel et al., 1993). Reinhardt et al (2011) pointed out that 25% of the

first lactation heifers,41 % of second-lactation cows, and 54% of fifth- or greater lactation cows that their serum Ca decreased to below 8.0 mg/dL after calving (Reinhardt et al., 2011). Economically, subclinical cases cause greater losses than the clinical cases because of the greater incidence rate: four times greater than the clinical cases (Oetzel, 2011). Subclinical hypocalcemia results in cows with reduced DMI after calving, decreased milk production and fertility, and increased risk of secondary disease (Oetzel, 2011). The economic losses of clinical cases of milk fever include deaths (around 8 % of affected cows), premature culling (around 12%), treatment costs, and decreased milk production in the subsequent or current lactation. Milk fever and subclinical milk fever have a high influence on reducing milk production during lactation, and this increases the risk of other metabolic diseases, such as displaced abomasum.

Hyperketonemia (Ketosis)

Ketosis is a metabolic disease that increases the concentration of ketone bodies in the blood, urine, milk, and other fluids (Geishauser et al., 1998). In early lactation, ketone body synthesis in ruminants would be regarded as a physiological process (Herdt et al., 1981, Emery et al., 1992). The major ketone bodies are produced in the liver from acetyl-CoA, and include BHBA, acetoacetate, and acetone (Jorritsma et al., 1998, Ballard et al., 2001). The cause of ketosis is the accumulation of ketone bodies in body tissues, and fluid (Andersson, 1988, Nielen et al., 1994). During ketosis in early lactation, which is a common metabolic change, triacylglycerol accumulates and fatty liver develops (Kronfeld et al., 1960, Gröhn and Lindberg, 1985). Ketosis is classified into two categories, clinical and subclinical: clinical ketosis is defined by greater levels of ketone bodies in the blood, urine, and milk, which combine with other visible signs such as weight loss, and decreased feed intake (Duffield et al., 1997b, Geishauser et al., 1998, Jorritsma et al., 1998). Subclinical ketosis is determined by greater levels

of ketone bodies in the blood, urine, and milk as well, but is different from clinical ketosis as it has no visible clinical signs (Andersson, 1988).

Ketosis normally occurs within two months after calving (Gillund et al., 2001), and subclinical ketosis is a common disease of the transition period in the dairy cattle: about 40 % of lactating cows are affected (McArt et al., 2012a). Ketosis is related to the decrease in milk production, the high incidence rate of left displaced abomasum, metritis, mastitis, cystic ovaries, and resumption of postpartum luteal function (Dohoo and Martin, 1984a, Correa et al., 1993). A threshold value to test blood serum for BHBA for clinical ketosis is greater than 1,400 μmol/L, and subclinical ketosis threshold is 1,200 μmol/L (Duffield et al., 1997b, Geishauser et al., 2001, Oetzel, 2004). Additionally, the economic losses in dairy industry from ketosis are high because of the decreased milk production and lowered reproductive efficiency, which increases involuntary culling and veterinary cost (Geishauser et al., 1998). In order to reduce economic losses, early detection of subclinical ketosis is crucial for the treatment of individual cows and improvement of their diets (Enjalbert et al., 2001). The clinical ketosis incidence rate is 2% to 15% (Erb and Grohn, 1988b, Østergaard and Gröhn, 2000), and the incidence rate of subclinical ketosis is 40%, with about 10% of cases showing signs of central nervous disorders. The economic losses of ketosis are decreased milk production, conception rate, intake, rumen contraction and weight loss, and increased culling rate (Reist et al., 2000).

Displaced abomasum (DA)

Displaced abomasum could be on either the left side of abdominal or the dorsal to the right side of the abdominal. If it is on the left side, it is called left displaced abomasum (LDA) and if it is the right side it would be right displaced abomasum (RDA): normally 80 to 90% of displaced abomasum are on the left side (Guard, 1990). Right displaced abomasum can twist the

abomasum which leads to the obstruction of the flow of abomasum digestion and interferes with the blood flow to abomasum (Parish, 2011). Normally 80% of DA occur one month after calving (Parish, 2011). Left displaced abomasum occurs when the abomasum expands with fluid, gas, or both (Coppock, 1974).

In late pregnancy, most of dairy cows experience decreasing intake, decreasing rumen volume, and the uterus pushing against the rumen which will make the abomasum go toward the left side rather than normal position (Niehaus, 2008). The factors that cause DA could be fetus gender, age, season of year (Coppock, 1974, Constable et al., 1992), parity, breed (Erb and Martin, 1978), birth of twins (Markusfeld, 1986), stillbirth (Markusfeld, 1986), dystocia, diseases, and diet (Curtis et al., 1985, Markusfeld, 1986, Correa et al., 1993). In addition, having NEB around time of calving increases the risk of DA (Cameron et al., 1998). The decrease of intake that results in NEB would slow build up after calving (Goff, 2006a). According to Kelton, in studies published between 1982 and 1995, the median incidence rate of LDA was 1.7% in 22 studies. More recent studies show that the incidence rate of LDA has increased from 1% to 7% over ten years (LeBlanc et al., 2005b). There is an association between subclinical ketosis (serum BHBA $\geq$ 1400μmol/L) and increased risk of LDA in the first two weeks postpartum (Geishauser et al., 2001). The risk of LDA increases while serum BHBA is greater than 1.2 mmol/L, NEFA greater than 0.8 mmol/L, and Ca less than 2.2 mmol/L, respectively (LeBlanc et al., 2005b, Roberts et al., 2012b). Additionally, DA is one of the economically important diseases in early lactation cows because of the cost of treatment, culling, lost production, and death (Detilleux et al., 1997). Current treatment per case ranges from $100 to $200, and 10% of the herd diagnosed with DA either die or are culled (Gröhn et al., 1998). Further, cows treated with DA produce 350 kg less milk than cows without DA (Gröhn et al., 1998).

Metritis

Metritis is a postpartum disease, which involves the growth of unhealthy bacteria in the deep layer and lining of the uterus after cows calve. Metritis severely impacts the future reproductive performance of dairy cows (Sheldon et al., 2009). It is present as an inflammation of the uterus with signs of sickness, which include fever and foul-smelling, red-brown, watery uterus discharge (Sheldon et al., 2006). Normally metritis occurs in the first week after calving. After calving, the uterine environment becomes the ideal place to support the growth of the variety of aerobic and anaerobic bacteria (Sheldon et al., 2008). The incidence rate of metritis is 10.1% to 65.5% in dairy cows (Borsberry and Dobson, 1989). Based on the pathophysiology, researchers found metritis in cows with high NEFA concentration in serum, BHBA serum, serum concentration of Haptoglobin (**Hp**), and low DMI (Hammon et al., 2006). Also, a high concentration of Hp was proven to increase the risk of metritis (Smith et al., 1998, Sheldon et al., 2001, Huzzey et al., 2007).

The factors that increases risks of metritis are dystocia, twins, retained placenta, stillbirth, and abortion (Gröhn et al., 1990, Correa et al., 1993, Kaneene and Miller, 1995). This disease profoundly affects dairy cows in three ways: by reducing milk production, reducing reproduction performance, and shortening longevity, which increases culling rate (Gröhn et al., 2003). The uterine disease affects the time of return to ovarian cyclicity (Sheldon and Dobson, 2004). Early studies showed that the cost to dairy producer with uterine infection was $106 (Bartlett et al., 1986). Uterine infection could have a big impact on the profitability of the dairy industry (Lewis, 1997). Cows with severe metritis tend to have decreased feed intake, typically 2 to 6 kg less than sound cows 2 to 3weeks prior to exhibiting the clinical signs of metritis (Huzzey et al., 2007). For early metritis detection, amount of time eating and day matter intake could be a variable for

the producer to use, the cow with reduce amount of time eating and dry matter intake before calving would have a greater incidence of metritis (Urton et al., 2005a, Huzzey et al., 2007).

Endometritis

Endometritis is also a uterine inflammation which occurs after 20 days in milk, diagnosed based on the clinical or cytological signs, and reduces reproductive performance (Dubuc et al., 2010). Unlike metritis, endometritis infects the localized lining of uterus instead of the deeper layers of the uterus, evidenced by white pus mixed with mucus discharged from the uterus into the vagina (Sheldon et al., 2008). Subclinical endometritis is an inflammation of the uterus without systemic illness signs and is defined by purulent or mucopurulent discharge or cervical diameter greater than 7.5 cm after 20 days postpartum (LeBlanc et al., 2002a). Cytological endometritis has a high proportion of polymorphonuclear cells (PMN) found in endometrial cytology samples (Kasimanickam et al., 2004), low-volume uterine lavage (Gilbert et al., 2005), or biopsy samples (Bonnett et al., 1993). Subclinical endometritis is defined by the presence of leukocytes within the uterine lumen but without clinical signs of endometritis (Földi et al., 2006).

Endometritis is associated with decreased intake, NEB, and disturbed immune function (Urton et al., 2005a, Hammon et al., 2006, Huzzey et al., 2007). Endometritis could affect reproductive efficiency, culling rate, milk discard, labor, as well as increased cost of treatment. The risk factors of endometritis are RP, twins, dystocia, parity, and season (Markusfeld, 1987, Gröhn et al., 1990, LeBlanc et al., 2002b). Evidence indicates that increased NEFA, BHBA and decreased DMI could be associated with endometritis (Hammon et al., 2006). Increasing Hp concentration in early lactation was linked to increasing the incidence of endometritis (LeBlanc et al., 2002a). Metabolic disorders such as DA, hypocalcemia, and ketosis are associated with the

incidence rate of endometritis (Markusfeld, 1987, Correa et al., 1993, Whiteford and Sheldon, 2005).

Retained placenta (RP)

Retained placenta occurs when the placenta fails to pass within 24 hours of live birth (Kelton et al., 1998). Normally, 95% of cows pass their placenta within 12 hours (Van Werven et al., 1992). If RP occurs, the placenta would be retained for seven days on average (Eiler, 1997). Kelton et al. (1998) showed that the mean incidence rate of RP in 50 studies was 8.6% (Kelton et al., 1998), and also mentioned that the risk factors of RP are twins, dystocia, stillborn calf, abortion, milk fever, and older age (Sandals et al., 1979, Correa et al., 1993, Gröhn and Rajala-Schultz, 2000). The cause of RP is the cotyledon-caruncles, which detaches after delivery, and fails to breakdown (LeBlanc, 2008). Other causes of RP are uterine motility (<2% of cases), physical damage such as birth complication, caesarean section, or twisted uterus. These can cause the edema of chorionic villi, and uterine infections caused the cellular dysfunction and necrosis, and more (McNaughton and Murray, 2009, Drillich, 2011).

When cows have greater NEB during prepartum, and thus greater NEFA level, they were 80% more likely to have RP; additionally, lower levels of vitamin E also creates a greater risk of RP (LeBlanc et al., 2004). Seifi et al (2007) found that cows with RP have greater serum concentration of NEFA and BHBA, and low serum concentration of vitamin E and calcium (Seifi et al., 2007). The intracellular Ca plays a crucial part in dairy cows and is linked to hypocalcemia and immune function (Kimura et al., 2006). However, passing the placenta is related to a decrease in the immune system during the end of pregnancy. RP is also related to metritis and endometritis, which impact the reproductive system. The issue has been reported to have a huge economic impact because it can cause other reproductive and productive problems

(Laven and Peters, 1996, Trevisi et al., 2008, Dubuc et al., 2010). The average cost of RP per case, which includes treatment cost, milk loss, and prolonging days open, is around $285 (Kelton et al., 1998). Around 7.8% of RP cases (range 1.3% to 39.2%) economically impact US dairy cows (Kelton et al., 1998). However, a concentration of NEFA greater than 500 μEq/L was pointed out as indicator of RP (LeBlanc et al., 2004, Ospina et al., 2010, Chapinal et al., 2011).

Body condition score (BCS) change

In order to provide nutrients for the neonate, mammals metabolize fat and muscle for a period of time after giving birth (Roche et al., 2009). Likewise, to nurture the newborn calf, a dairy cow loses body condition from her tissue stores, for about 40 to 100 days after calving before making up the lost tissue (Bauman and Currie, 1980, Friggens et al., 2004, Roche et al., 2006, Roche et al., 2007, Roche et al., 2009). Body weight could be a variable to indicate body reserves, but body weight alone is not a good indicator. Body weight is affected by parity, stage of lactation, frame size, gestation, and breed (Stockdale, 2001, Berry et al., 2006b). Due to tissue mobilization in early lactation, feed intake increases, but the weight of body tissue decreases. This can be observed by gastrointestinal fill. Thus, body weight changes do not precisely reflect changes in weights of adipose and lean tissue (Berry et al., 2006a, Roche et al., 2006, Roche et al., 2007). Frequent body weight measurement could overcome this issue, but for accuracy adipose and lean tissue measuremedments, body condition score (**BCS**) is needed (Thorup et al., 2012). Body condition is the ratio of a body's fat and nonfat components (Murray, 1919a). Body condition score varies between countries, but the low score always represents thin cows, and high score indicates obese cows. Most of the metabolic diseases relate to BCS losses, inadequate nutrition, or failure to process the change from calving to lactation. The BCS around calving and the amount of BCS loss is associated with milk production, reproduction, and health. Days to

first service changed from 1.6 d to -5.2 d for cows with a decrease in BCS greater than 1.0, respectively (Pryce et al., 2001). The BCS is an easy and reliable method to assess the nutrition status and feed system for dairy producers (Edmonson et al., 1989, Chamberlain and Wilkinson, 1996).

Precision dairy monitoring (PDM)

Precision dairy monitoring (**PDM**) technologies measure physiological or behavioral production in individual animals as an indicator to help dairy farmers improve management strategies and overall efficiency (Bewley, 2010). These variables include daily milk yield, number of steps, temperature, milk conductivity, and body weight which can help producers monitor each cow (Bewley, 2010). Since these variables can be monitored, producers can improve their farm performance, management, and efficiency by using PDM technologies (El-Osta and Morehart, 2000). Devices were developed to measure a health indicator, and devices could be in or on an individual cow (Hogeveen et al., 2010).

Sensors fall into two categories, attached and non-attached. Attached sensors would be the sensor on or inside the cow's body. Non-attached sensors would be off a cow's body measuring as a cow walks past or through the devices, or a sample taken to run an analysis. The developed sensor systems are divided into four different levels, (**I**) capability of measuring behavior about the cow (e.g. activity); (**II**) interpreting and summarizing the change of sensor data (e.g. increase in activity) in order to provide information of cow status (e.g. estrus); (**III**) combining information (e.g. economic information) and produce advice (e.g. whether to inseminate a cow or not); (**IV**) making decision autonomously of producers or sensors (e.g. the inseminator is called) (Rutten et al., 2013). The Web of Science database indicated that from January 2002 to June 2012, most studies concerned the detection of mastitis (25%), fertility

(33%), and locomotion problem (30%), but comparatively few studies (16%) related to the detection of metabolic problems (Rutten et al., 2013).

Recently, technologies have been improved and perform better; there are more variables and monitor systems on the market. So, dairy producers have more options to implement in their own farming system. But few of them understand the information that technologies provide (Russell and Bewley, 2013). In other words, dairy producers have a little understanding about technologies that are available and how best to adapt their system. Around 25% of US farmers are aware that technologies are not adapted well, but only 5% of them are adapting some aspects of the technologies (Daberkow and McBride, 2003).

However, the best indicators are those with both high sensitivity and high specificity. The accuracy test should rarely show false positives (type I error; test shows positive when the animal is actually healthy) or false negatives (type II error; test shows negative when the animal is actually sick) (Weary et al., 2009). The high accuracy combined with high sensitivity (the ratio of true positives to the total of true positives and false negatives), and high specificity (the ratio of true negatives to the total of false positives and true negatives), can lead to identifying sick animals correctly. (Weary et al., 2009).

The trend of technologies being applied in the dairy industry is unstoppable and moving toward larger farms. The trend of the technologies is a big impact of structural advancement (Cochrane, 1965, Musser and White, 1975). The innovative technologies involved in the dairy industry, and influences financial opportunities, innovations, and potential capital (Boehlje, 1992). To have PDM is an important investment and a challenge for producers to implement and might be used for several years (Borchers and Bewley, 2015). In order to choose a PDM, producers take long-term decision making (Boehlje and Schiek, 1998), financial scale and

demographic in consideration (Khanal et al., 2010). In order to build up a well- managed and efficient environment, this study will help producers to understand the importance of the information that technologies provide. This could benefit producer profits and cows well-being. For producers, technologies can detect low physical activity, low feed intake or low temperature, which are the sign of sickness. For economic purposes, using technologies can help producers find ailing cows, and reduce possible medical treatment cost. Easy access to this data could help them understand about cows' health status sooner. In order to prevent transition cow diseases, PDM could be an important tool for reducing the loss or cost of treatment. More research is necessary, but for cow health and management, more technologies will become available. In the future, producers will have smart ways to manage their herds.

Automated detection of health

Metabolic disorders have a major impact in transition cows that affect their future performance. During this time cow's experience a series of changes in nutrition, physiology, and social environment, which leave cows vulnerable and developing metabolic diseases (Goff and Horst, 1997). Economic losses increase because of premature culling, decreased milk yield or milk quality, and increased treatment or labor (González et al., 2008). Traditional methods for detecting diseases are visual observation followed by additional tests, using blood, urine, or milk sample (Sepulveda-Varas et al., 2014b). It is unclear which indicators are the best reflection of metabolic disorders (Rutten et al., 2013). Weary et al. (2009) explained that changing behavior can point out pain and illnesses which are related to health, and could also predict the risk for diseases. These indicators could be positive, such as an increased frequency when cows are sick, or negative, such as a decreased frequency when cows are ill (Weary et al., 2009). Take feeding behavior as an example, the cow with the onset of ketosis, acute locomotion problems, and

lameness changes their feeding behavior (González et al., 2008). Further, the radio frequency technology could identify a sick cow 4 days earlier than visual detection by measuring the time spent at the feed bunk (Quimby et al., 2001).

Health could be detected by behavioral signs— inconsistent feeding, drinking, and a decrease in activity (Weary et al., 2009). These variables could help producers understand a cow's health status instantly. In turn, early detection of the signs that indicate illnesses, or physiological and behavioral changes, could help to reduce the loss of milk yield and treatment costs. In this decade, the increase of milk yield and subsequent production stress raise the incidence rate of having disease (Fleischer et al., 2001). Although veterinary treatment and management have become more efficient, the early detection of sick animals could improve animal welfare and reduce costs of treatment (González et al., 2008). Research showed that daily monitoring of ruminating, eating, and activity could assist with individual cows' health and productivity (Liboreiro et al., 2015b). There are several technologies that have been developed on the market: activity (Roelofs et al., 2005), feeding (Rutter et al., 1997, Kononoff et al., 2002), and rumination monitors (Schirmann et al., 2009a, Burfeind et al., 2011a, Goldhawk et al., 2013). Therefore, PDM technologies could help aid decision making and improve producers' profit and production (Van Asseldonk et al., 1999).

Activity, steps, lying time and lying bouts

In the last several decades, animal behavior has been linked with animal health (Fox, 1968). The discussion has changed to recognize and solve the problems of animal behavior (McKeown and Luescher, 1988). Several technologies are able to detect the behavioral changes by different animal movement. Activity monitors attached around the neck are one example, such as Alpro (DeLeval, Sweden), Heatime (SCR Engineers Ltd., Netanya, Israel), HeatPhone

(Medria, Châteaubourg, France), and MooMonitor (DairyMaster, Tralee, Ireland). Standing and lying time monitors attached to the leg, such as IceTag3D (IceRobotics Ltd, Edinburgh, Scotland), AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), CowScout S Leg (Gea Farm Technologies GmbH, Bönen, Germany), and IceQube (IceRobotics Ltd, Edinburgh, Scotland) are the main examples of today's activity monitoring systems (Jónsson et al., 2011). Physical injuries and diseases can lead to body malfunctions whether cows feel sick or not. And their physical clumsiness could be hard to distinguish from feeling ill (Huzzey et al., 2014b).

Researchers contend that many behavioral signs shown by sick animals indicate the start of an action to fight off disease (Hart, 1988, Dantzer, 2004). Behavior is a crucial indicator that is affected by energy expenditure. Huzzey et al. (2014a) indicated that behavior declines could provide a long-term observation method, and body temperature could provide the short-term. Monitoring standing time for early of detection illness in dairy cows has been developed. Ill cows increase resting time to conserve energy for fever response and activation of the immune system instead of eating and engaging in normal activities (Hart, 1988). Lying behavior could vary by stage of lactation, for example, lying time and lying bouts would increase as DIM increases (Munksgaard et al., 2005, Vasseur et al., 2012, Ito et al., 2014) and decrease as cows produce more milk (Fregonesi and Leaver, 2001, Norring et al., 2012). Further, lying behavior could be affected by health, for example, and lame cows would have longer lying time and lying bouts (Chapinal et al., 2009, Ito et al., 2010). However, lying time could benefit cows recovering from illness (Hart, 1988, Johnson, 2002). Researchers indicated that the average lying time for a cow is approximately 12 to 13 hours per day, which is the target for a lactating dairy cow in the freestall housing (Drissler et al., 2005, Fregonesi et al., 2007, Gomez and Cook, 2010). Changes in standing and lying behavior could be useful for detection of health problems in the transition

period, such as lameness (Proudfoot et al., 2010, Calderon and Cook, 2011a), dystocia (Proudfoot et al., 2009), and subclinical hypocalcemia (Jawor et al., 2012a).

Body and rumen temperature

Poikalainen et al. (2012) and Risco et al. (2005) suggested that temperature could be used to identify cows' illnesses and estimate their physiological status. Many different diseases affect dairy cow physiology, such as metritis, mastitis, acidosis, retained placenta, left placed abomasum, hypocalcemia, and lameness (Kelton et al., 1998, Kristula et al., 2001, Adams et al., 2013). Among these diseases, metritis, mastitis, and lameness have been proven to increase body temperature above normal (Schutz and Bewley, 2009). Researchers, producers, and veterinarians agree that using rectal temperature to monitor health and disease could be a successful tool (Risco et al., 2005). Rectal temperature is the most common approach for dairy producers to classify and monitor sick cows because the operation is easy and the cost is low (Hicks et al., 2001, Aalseth, 2005, Burfeind et al., 2010). Continuously measuring rectal temperature 5 to 10 days after calving could easily catch the cow that needs attention. Most importantly, this operation has been integrated into fresh cow management and disease prevention (Kristula et al., 2001). Studies showed that the threshold value for body temperature is 39.4 to 39.7 ºC (Smith and Risco, 2005, Benzaquen et al., 2007, Wagner et al., 2007). All of these diseases would cause economic losses to dairy producers by reducing milk yield, increasing veterinary treatment costs, and increasing culling rate (LeBlanc et al., 2002a, Juarez et al., 2003).

Rumen temperature is a remote method for monitoring a cow's core temperature by a rumen bolus. Comparatively, rumen temperature is easy to use and is less labor intensive. A rumen bolus is given to a cow orally using a bolus gun. After a bolus is placed, no other labor is needed. The bolus stays in the cow's rumen and transmits temperature information continuously

(Adams et al., 2013). According to researchers, there was no significant difference between body temperature readings obtained by rectal temperature or the implanted sensors (Hicks et al., 2001). Also, there was a strong correlation between rectal temperature and reticulum temperature ($r = 0.645$), reticulum temperature was approximately $0.45 \pm 0.33^{o}C$ greater than rectal temperature (Bewley et al., 2008a). However, ambient temperature, stage of lactation, estrus, feed and water intake, and overall health of the cow would affect reticulum temperature (Wrenn et al., 1960, Lefcourt et al., 1999, Bewley et al., 2008b, Schutz and Bewley, 2009). Overall, using temperature could benefit both producers and cows.

Milk and blood levels

Homeorhetic mechanisms change dramatically during peripartum, in order to meet the demands of mammary gland for milk production (Bauman and Currie, 1980). So during the transition period, cows are prone to develop possible metabolic diseases, such as hypocalcemia (Mulligan and Doherty, 2008). In study by Fourichon et al. (1999), they indicated metabolic and digestive disorders affect milk yield. Also, these metabolic disorders influence cows' health and production in the lactation period. Goff (2008) showed that the decrease of milk yield after calving is related to the occurrence of health disorder following metabolic stress. However Rajala-Schultz et al. (1999) found that before a diagnosis of clinical ketosis, milk yield decreased and continually fell for at least two weeks after diagnosis. Further, according to researchers, cows lose 4 to 10 kg milk per day with clinical ketosis, and 1 to 3 kg per day with subclinical ketosis (King, 1978, Dohoo and Martin, 1984b, Deluyker et al., 1991a). With a diagnosis of LDA 250 to 800 kg milk is lost during 305 days of lactation (Martin et al., 1978, Deluyker et al., 1991a). Therefore, measuring daily milk production in the first few weeks of lactation could help to determine if the cow is suffering health problems or not. A decrease in

milk production often points out clinical diseases. Daily milk yield measurement combined with activity monitoring could be useful for early detection of cows' health problems (Edwards and Tozer, 2004a).

The concentration of NEFA, BHBA, and glucose responded to the adaptation of energy balance (LeBlanc, 2006). Monitoring NEFA in the week before calving and the first week after calving could help detect displaced abomasum (Cameron et al., 1998, LeBlanc, 2006, Ospina et al., 2010). Additionally, elevated NEFA before calving could be related to retained placenta and uterine diseases (LeBlanc et al., 2004, Hammon et al., 2006, Quiroz-Rocha et al., 2010a). For detection of post calving disorder, prepartum NEFA level with the highest sensitivity and spceificity was from 0.3 mEq/L to 0.5 mEq/L (Ospina et al., 2010, Chapinal et al., 2011, Roberts et al., 2012a). The postpartum NEFA level to predict health problem is 0.07 to 1.0 mEq/L (LeBlanc et al., 2005b, Ospina et al., 2010, Roberts et al., 2012b), but the thresholds were different by the different stages of lactation, and different type of disease. So depending on the disease, the cut point varies. Although, the threshold being debated provide an idea for producers to identify cows with a NEB.

Blood BHBA at the first week after calving could be associated with displaced abomasum (Cameron et al., 1998, LeBlanc, 2006, Ospina et al., 2010), and ketosis. According to LeBlanc et al. (2005a) at BHBA concentrations greater than 1.2 mmol/dl, the chance to have subclinical ketosis is greater. BHBA cut point is still being debated, but the recent studies show that at BHBA levels greater than 1.4 mmol/dl, the possibility to develop metabolic disorder would be greater (Duffield, 2000, LeBlanc et al., 2005c, Walsh et al., 2007, Ospina et al., 2010, Roberts et al., 2012b). However, several studies showed that the Ca level in blood is different by age and stage of lactation. Serum concentration of Ca around cow calving always decreases

below 2.0 mM (8.0 mg/dL). Normal Ca concentration in healthy mid-lactation cows is 2.1 to 2.8 mmol/L (8.5 and 10 mg/dL), but is less during the week after calving, < 2mmol/L (8 mg/dL) (Goff, 2008). The percent of cows with low Ca levels variers by parity: 25% of heifers, 41% of second lactation cows and up to 54% of fifth lactation cows (Reinhardt et al., 2011).

Rumination time and feeding behavior

Dry matter intake, rumination time and feeding time are important variables for detecting illness. In order to increase milk production, energy requirements must be met. Researchers indicated that disturbances of fermentation and rumen activity can lead to subclinical and clinical diseases (Nocek, 1997, Maekawa et al., 2002). Consistently monitoring feeding behavior is a tool for tracking the health status of the whole herd or individual cows (Hansen et al., 2003). During the transition period, cows experience decreased feed intake and NEB. So, early detection of disease is the goal for producers. Urton et al (2005) indicated that feed intake during this time is crucial. Weary et al. (2009) found that ill animals appeared depressed, lethargic, or off feed. Cows which have lesser intake have a high possibility to be diagnosed with metabolic and infectious disease (Urton et al., 2005a). For dairy cows, the time spent eating and the pattern of meals could affect intake (Grant et al., 2000). Therefore, changes in intake and feeding behavior are good indicators for researchers to use to understand dairy nutrition (DeVries et al., 2003).

Rumination is a natural behavior for cows utilized to break down the feed particle size and create a greater concentration of bacteria for fermentation (Russell and Rychlik, 2001). Rumination also helps to increase saliva secretion and to improve rumen function by using saliva as a buffer (Soriani et al., 2012). Rumination is associated with health in dairy cows (Radostits et al., 2006). Lately, it has been applied to assessing dairy cows' acute stressors (Bristow and Holmes, 2007, Burfeind et al., 2011b) and diseases (DeVries et al., 2003). But, rumination

monitored by visual observation (Krause et al., 1998, Couderc et al., 2006) or from video (Lindström et al., 2001) is labor intensive and can only monitor a few cows at once. So, scientists and researchers built a monitoring device that can determine rumination by jaw movement, which is attached to or inside a halter (Luginbuhl et al., 1987, Matsui and Okubo, 1991, Dado and Allen, 1993). These devices help the producer monitor rumination remotely. Many studies show that jaw movement is related to chewing and ruminating (Beauchemin et al., 1989, Matsui and Okubo, 1991, Dado and Allen, 1993). Less rumination time during the first 10 days in milk would indicate a cow prone to health disorders (Soriani et al., 2012).

CONCLUSIONS

Early detection of diseases would be a crucial improvement to reduce dairy cows' treatment cost and stress. In the market, precision dairy technologies are available for monitoring and detecting behavior as it relates to disease. Many factors could influence the accuracy of the detection system, such as management, environment (Lightning, wild animals, and storms) etc. Every herd's management and environment are different and specific. The behavior of cows would be the easiest way to detect diseases; however, other variables measured by precision dairy technologies may provide efficiently detect illness as well.

CHAPTER TWO

Differences in behavioral and physiological variables measured with precision dairy monitoring technologies associated with postpartum diseases

I.C. Tsai[*], L.M. Mayo[*], B.W. Jones[*], A.E. Stone[*], D. L. Ray[*], J.D. Clark[*], H. M. White[†], S. A. Janse[‡], Y. M. Chang[§], and J.M. Bewley[*]

[*]University of Kentucky, Lexington, Kentucky 40546, Department of Animal and Food Sciences

[†]University of Wisconsin-Madison Department of Dairy Science

[‡]Department of Statistics, University of Kentucky, Lexington, 40546

[§]Research Support Office, The Royal Veterinary College, London, United Kingdom

ABSTRACT

Precision dairy monitoring (**PDM**) technologies are used to measure physiological, behavioral, and production variables on individual animals to improve management strategies and farm performance. The objective of this study was to assess PDM measured variable effects on 3 transition cow diseases: metritis (**MET**), hyperketonemia (**KET**), and hypocalcemia (**CAL**). The PDM variables included: lying time (AfiAct Pedometer Plus, Track a))) cow, IceQube, SmartBow), step count (AfiAct Pedometer Plus, Track a))) cow, IceQube), lying bouts (AfiAct Pedometer Plus, Track a))) cow, IceQube), rumination time (HR tag, CowManager SensoOr, SmartBow), eating time (CowManager SensoOr), time at the feed bunk (Track a))) cow), reticulorumen temperature (DVM bolus), milk yield (AfiMilk MCP), milk conductivity (AfiMilk MCP), milk fat % (AfiLab), milk protein % (AfiLab), milk fat:protein (AfiLab), milk lactose % (AfiLab), and body weight (AfiWeigh). A physical examination was conducted for MET at 3, 5, 7, 11, 14, 17, 19, and 21 DIM using a MetriCheck device. A scoring system of 1 to 3 was used (Sterrett et al., 2014) with a score ≥ 2 classified as MET. A blood sample was collected on 3, 7, 14, and 21 DIM for detection of KET (β-hydroxybutyrate concentration ≥ 1.2 mmol/L of blood) and CAL (calcium concentration ≤ 8.6 mg/dL of blood serum). The relationships between each technology variable and disease status were analyzed individually using the MIXED procedure of SAS 9.3. Variables were compared with disease status (Yes (**Y**) or No (**N**)) for MET, KET, or CAL. Through the MIXED procedure, variables that were significant predictors of MET, KET, or CAL, DIM was as a covariate. For days with significant differences in cows with diseases ($P < 0.05$), MET cows experienced greater milk fat (Y: 4.42 ± 0.10 vs. N: 3.95 ± 0.12 %/d), greater fat: protein (Y: 1.35 ± 0.05 vs. N: 1.18 ± 0.09 fat:protein), lesser step count (Y: 2,125 ± 1,215 vs. N: 2,689 ± 1,637 steps/d), and lesser rumination time (Y: 473 ± 29 vs. N: 537 ± 35 min/d). For

days with significant differences ($P < 0.05$), KET cows experienced greater lying time (Y: 10.9 ± 1.7 vs. N: 9.8 ± 1.6 h/d), greater milk fat (Y: 4.44 ± 0.26 vs. N: 4.14 ± 0.25 %/d), greater body weight in multiparous cows (Y: 750 ± 18 vs. N: 710 ± 12 kg), lesser step count (Y: 3,137 ± 121 vs. N: 3,685 ± 72 steps/d), lesser neck activity (Y: 359 ± 13 vs. N: 407 ± 16 units of movement/d), lesser rumination time (Y: 471 ± 34 vs. N: 520 ± 40 min/d), and lesser milk yield (Y: 31.4 ± 3.8 vs. N: 37.8 ± 4.3 kg/d). For days with significant differences ($P < 0.05$), CAL cows experienced greater lying time (Y: 9.4 ± 1.0 vs. N: 8.2 ± 1.1 h/d), greater fat:protein (Y: 1.37 ± 0.05 vs. N: 1.25 ± 0.05 fat:protein), lesser step count (Y: 2,490 ± 1,097 vs. N: 2,856 ± 1,180 steps/d), lesser neck activity (Y: 376 ± 19 vs. N: 447 ± 15 units of movement/d), lesser rumination time (Y: 485 ± 37 vs. N: 531 ± 31 min/d), lesser milk yield for primiparous cows (Y: 22.6 ± 4.0 vs. N: 26.3 ± 4.1 h/d), and lesser milk yield for multiparous cows (Y: 32.8 ± 5.4 vs. N: 37.3 ± 4.7 kg/d). Dairy producers could use PDM variables to identify transition cows for closer examination or treatment of MET, KET, and CAL.

Key words: transition cow, precision dairy monitoring (PDM), metabolic disease, hyperketonemia, hypocalcemia, metritis

INTRODUCTION

The transition period is defined as the three weeks before and three weeks after the cow calves. Transition cow diseases are considered production diseases. Metabolic disease, a specific type of production disease, reflects a cow' inability to meet metabolic demands. Negative energy balance (**NEB**) occurs in the early stages of lactation, when cows tend to mobilize body fat reserves to balance insufficient energy (Ingvartsen and Andersen, 2000, Drackley et al., 2001). The metabolic, immune, and endocrine systems dramatically change which makes cows more susceptible to disease (Bernabucci et al., 2005, Sordillo et al., 2009, Ospina et al., 2010).

Adaptations in energy, protein, and mineral metabolism are keys to a successful transition into a new lactation (Bell, 1995, Grummer, 1995, Horst et al., 1997, Drackley, 1999, Drackley et al., 2001). Maintaining proper nutrition and management improves dairy cow health, fertility, and productivity, which allows producers to save on labor and increase profitability (Mulligan and Doherty, 2008). Systematic observations may provide accurate and efficient indicators of transition diseases.

Precision dairy monitoring (**PDM**) technologies measure physiological, behavioral, production variables on individual animals. The technology allows dairy farmers to improve management strategies and overall efficiency (Bewley, 2010). De Koning (2010) reported that producers who used PDM could save 29% on labor; especially on large dairies. Sensors have been developed with the capability to measure variables for individual cows (Rutten et al., 2013). Variables include: daily milk yield, lying time, number of steps, body temperature, milk components, milk electrical conductivity, milk color sensors (Grummer, 1995), acceleration sensors (Bertics et al., 1992, Rukkwamsuk et al., 1999a, Sato et al., 1999), pH sensors (Adewuyi et al., 2005), and body weight (Bewley, 2010).

Behavioral signs could be used in the detection of various health problems. These signs could include inconsistent feeding, drinking, and activity. Easy access to frequently recorded data could help to understand a cow's health status. Increased resting time may be indicative of disease, as ill cows prioritize rest over other activities such as eating in order to conserve energy for the fever response (Hart, 1988, Dantzer, 2004). Cows' reactions and behaviors are crucial indicators of their energy expenditure (Hart, 1988). Decreased rumination (Calamari et al., 2014), activity (Titler et al., 2015), and feeding behavior (Bikker et al., 2014), and increased temperature, rumen temperature (AlZahal et al., 2009), number of steps, and lying time (Sepulveda-Varas et al., 2014a) may be signs that aid in the detection of metabolic diseases.

The objective of this study was to assess different commercial PDM that measured variables potentially affected by hypocalcemia, hyperketonemia, and metritis. Understanding and assessing how these variables change relative to disease may help determine how PDM measured variables could be applied as disease indicators.

MATERIALS AND METHODS

This experiment was part of a larger study designed to quantify physiological and behavioral changes associated with mastitis, lameness, estrus, and postpartum diseases, using multiple PDM. All studies were performed with the approval of the University of Kentucky Institutional Animal Care and Use Committee (IACUC protocol number: 2013-1199).

Animal, Feeding, and Housing

One hundred and thirty-eight lactating Holstein cows at the University of Kentucky Coldstream Dairy (Lexington, KY, USA) were enrolled in this study from June 2014 to October 2015. Cows were enrolled in the protocol after they calved. Lactating cows were housed in two freestall barns, one barn with 54 dual chamber waterbeds (Advanced Comfort technology, Inc.,

Reedsburg, WI) and the other equipped with 54 rubber-filled mattresses, both surfaces covered with sawdust. Prepartum cattle were housed in a 9.15 x 21.34 m straw bedded-pack with constant access to 3.64 hectares of pasture. A total mixed ration was delivered once daily to dry cows. Before and throughout the study, cows were balanced between barns by DIM and parity. Calving dates, breeding dates, and DIM were obtained from PCDART management software (Dairy Records Management Systems, Raleigh, NC). Parity ranged from 1 to 7. The mean parity for the herd was 2.10 ± 1.27. Percent of cows in parities 1, 2, 3, 4, 5, 6, and 7 were 37%, 37%, 10%, 10%, 2%, 2%, and 2%, respectively. A weather station (HOBO U23 Pro v2 External Temperature/Relative Humidity Data Logger - U23-002, Onset, Bourne, MA) was located inside each freestall barn that measured relative humidity and temperature every 15 minutes. Temperature humidity index (**THI**) was computed using the following formula (NOAA and Administration, 1976): THI = temperature (^{0}F) - [0.55 – (0.55 × relative humidity/100)] × [temperature (^{0}F) – 58.8].

Cows were provided ad libitum access to water in each barn and shared a feedbunk between barns. Lactating cows were fed the same ration at 0600 and 1330 daily. Dry cows were fed a different ration at 0600 once daily. The lactating diet consisted of forage, alfalfa hay, mineral and vitamin supplement, concentrate mix, whole cottonseed, and alfalfa haylage. Dry cow diet consisted of Orchard grass hay, cotton seed, mineral mix, wheat straw, biochlor, and hay. Cows were milked two times per d at 0430 and 1530.

Fresh cow exam

Cows were monitored every day after morning milking from 0700 to 0900 for the first 21 d of lactation. Rectal temperature and behavioral score were monitored daily for the first 21 DIM (Figure 2.1). Rectal temperature was measured with a GLA thermometer (GLA Agricultural

Electronics, San Luis Obispo, CA). Cows were measured while standing still in the freestall barn. A MetriCheck (Simcro Tech Ltd, Hamilton, New Zealand) device (50- cm-long stainless steel rod with a 4-cm hemisphere of silicon at the end for vaginal insertion) was used to obtain a uterine discharge sample and scored on 3, 5, 7, 9, 11, 14, 17, 19, and 21 DIM (Figure 2.1). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on visual appearance of sample; score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥2 were classified as clinical metritis cases.

Blood samples

β-carotene level from blood plasma was collected once from a range of 15 ± 5 d before calving, and at 3 DIM (Figure 2.1). β-carotene was measured using iCheck (ROVIMIX® β-Carotene, Heerlen, Netherlands) which is a spectrophotometer that interpreted color absorbency. Blood samples were obtained by caudal venipuncture on days 3 and 7 DIM. One 10 ml EDTA purple-top Vacutainer® (Becton, Dickinson and Company, New Jersey) for β-carotene, retinol and biochemical analysis and sterile 10 ml tubes containing 200 µl stabilizer solution (0.3 m EDTA, 1% acetyl salicylic acid, pH 7.4) for hormonal analysis were used. The sample was centrifuged for 20 min at 2500 RPM to obtain the plasma from the purple top tube, and plasma was used to mix with the solution that the company provided into cuvettes. The measurement was described previously by Schweigert et al. (2007). Ca level from blood serum and ketone level from blood was collected on 3, 7, 14, and 21 DIM (Figure 2.1). One 10 ml red-top Vacutainer® (Becton, Dickinson and Company, New Jersey) tube containing no anticoagulant was required for Ca diagnosis test. Samples were spun down in a centrifuge for 20 min at 2500

RPM to obtain the serum, and samples were split into 3 tube. The first subsample of serum was sent to the University of Kentucky Veterinary Diagnostic Laboratory within 1 d. Calcium was analyzed using a Calcium-Arsenazo assay (ACE Alera, Alfa Wassermann Diagnostic Technologies, LLC, West Caldwell NJ). Hypocalcemia was defined as a serum Ca level < 8.6 mg/dL (Chapinal et al., 2011). The second serum sample was sent to the University of Wisconsin-Madison: Wisconsin, Dr. Heather White (1675 Observatory Drive, Rm 934B) and analyzed by Wako (Wako pure Chemical Industries Ltd, Japan) NEFA-C test (ACS-ACOD method) to evaluate NEFA. The third vial of serum was used in Konelab™ 20XT Clinical Chemistry Analyzer (Thermo Electron Oy, Finland) to analyze cholesterol level. On days 3, 7, and 14, BHBA concentration was measured in a whole-blood sample left over from the blood drawn for the Ca test (Figure 2.1). A Precision Xtra electronic handheld device (Abbott Laboratories, Chicago, IL, USA), validated by Iwersen et al. (2009), was used with ketone test strips and 1.5 μL of blood drawn into a sample well. Cows with BHBA ≥ 1.2 mmol/L were classified as having hyperketonemia (Geishauser et al., 1998, McArt et al., 2012c, Kaufman et al., 2016).

Milk samples

Milk haptoglobin was measured on 3 and 7 DIM (Figure 2.1) by eProCheck (Frim Tes, Germany) which is based on enzyme-linked immunosorbent assay (ELISA). Composite milk samples were collected into clear, 90 ml polypropylene resin vials (Capitol Vial, Thermo Fisher Scientific, Hudson, New Hampshire) from each cow at both 3 and 7 DIM. A 5μl composite milk sample was used as described in Blödow et al. (1988). The rest of the milk sample was used with the PortaBHB^{TM} Milk Ketone Test (PortaCheck Inc., Moorestown, NJ). One drop of milk from the milk sampler was deposited on the end of a ketone test strip for PortaBHB^{TM} Milk Ketone

Test (PortaCheck, Moorestown, NJ). The semi-quantitative dipstick changed color after one drop of milk was added and the result was compared to the color chart. The level of BHB concentration in milk was categorized as follows: normal (-) 0-99 μmol/L, questionable (+/-) 100 to199 μmol/L, positive (+) 200 to 499 μmol/L, and positive (++) 500+ μmol/L.

PDM

Each cow was equipped with each PDM before being enrolled in the study to allow for an adjustment period of at least two weeks. The AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel) sensors recorded total lying time. This device was validated for dairy cattle use by Mattachini et al. (2013), the lying time ($R^2 > 0.94$) and lying bouts ($R^2 > 0.71$) were highly related with HOBO Pendant G logger. DVM Bolus (DVM Systems, LLC, Greeley, CO) recorded reticulorumen temperature. HR Tag (SCR Engineers Ltd, Netanya, Israel) sensors recorded total rumination time which was validated for dairy cattle use by Schirmann et al. (2009b), and high correlation ($R^2 = 0.87$) with human observation was found. CowManager SensoOr (Agis Autimatisering, Harmelen, Netherlands) sensors recorded total active, time not active, eating and rumination. IceQube (IceRobotics Ltd, Edinburgh, Scotland) sensors recorded total daily lying time and lying time per bouts which was validated for daily cattle use by McGowan et al. (2007). SmartBow (Smartbow GmbH, Jutogasse, Austria) recorded rumination time, lying time, time active, and time not active. Track a))) cow (ENGS, Hampshire, UK) recorded time around the feed bunk, number of steps, lying time and lying bouts, which was validated for dairy cattle use by Wolfger et al. (2015). The result of comparison of Track a))) cow and HOBO Pendant G logger, the moderately concordance correlation coefficients (CCC) of lying bouts (CCC =0.71) and the highly correlated lying time (CCC = 0.98) were found. However, Borchers et al. (2016) found visually recorded rumination behavior was strongly

correlated with Smartbow (r = 0.97, CCC = 0.96), and weakly correlated with CowManager SensoOr (r = 0.69, CCC=0.59). In addition, visually recorded lying behaviors were strongly correlated with AfiAct Pedometer Plus (r > 0.99, CCC > 0.99), IceQube (r > 0.99, CCC > 0.99), and Track a))) cow (r > 0.99, CCC > 0.99).

Leg devices were placed on the legs, and each cow received an individual tag. Time around the feed bunk was measured by Track a))) cow that records how long does cow spend around the feed bunk. DVM boluses, which were activated before insertion in the rumen, and inserted into the reticulorumen orally, using a bolus gun. Ear tags were positioned using an ear tagger, provided by each technology company to fit the respective device. Ear tags that measured time not active means that cows were doing nothing, which could happen either standing or lying.

The AfiMilk MPC Milk Meter (Afimilk, Kibbutz Afikim, Israel) was used to collect individual milk yield and milking time for each milking. Body weights were recorded by AfiWeigh (Afimilk, Kibbutz Afikim, Israel), placed in a common exit alley. Cows were sorted into their respective groups using AfiSort (Afimilk, Kibbutz, Afikim, Israel) after each milking. All computer clocks were set to synchronize with NIST Internet Time Service (NIST, Gaithersburg, MD, USA) automatically, and time was checked on all computers manually on a weekly basis. The software recorded raw data, including measurements and recordings of behavioral and physiological parameters, daily.

Statistical Analyses

Data Editing and Analyses

Statistical analyses were conducted using SAS Version 9.3 (SAS Institute Inc., Cary, NC). Milk yields < or > 4 standard deviations from the previous week's average milk yield were removed, presumably caused by technology error. To account for decreased reticulorumen temperature caused by water bouts, DVM reticulorumen temperatures were removed if < 38.3ºC or if they were less than 4 standard deviations from the previous week's average temperature. Milk yield was sum (milked twice per day) and body weight was averaged (weight twice per day) to create one value per variable per cow per day. IceQube bout duration was each averaged to create one value per variable per cow per day. IceQube lying bouts, IceQube standing time, IceQube motion, IceQube lying time, HR rumination, HR activity, CowManager SensoOr no active, CowManager SensoOr rumination, CowManager SensoOr feeding time, CowManager SensoOr active, CowManager SensoOr high active, SmartBow lying time, SmartBow inactive, SmartBow high active, SmartBow rumination, Track a))) cow lying time, Track a))) cow time around feed bunk, and Track a))) cow feed buck visit were each summed to create one value per variable per cow per day. If the measurement for any variable was 0 for the day, that variable was set as missing for that cow on that day. Cow days were removed if < 90% of each day's data was recorded, but if a cow generated > 99% of each day's data, that linear interpolation was used to include the missing 1% from that day. Cow days were between 90% and 99% were stay the same. And the cows day 90 % was selected, because the less impact on influence the entire data. In cases where less than 24 hours of data were available, the percentage lying for that period was used to calculate the percentage lying within 24 hours.

Blood Ca levels ≤ 8.6 mg/dL were classified as hypocalcemia (Chapinal et al., 2011). Blood ketone levels ≥ 1.2 mmol/l were classified as hyperketonemia (McArt et al., 2012b). Metritis scores ≥ 2 was classified as metritis (Sterrett et al., 2014). The numbers of clinical

diseases cases were combined with the numbers of subclinical disease cases because of the small number of clinical cases. The MEANS procedure was used to calculate the mean and standard deviation of each variable. The FREQ procedure was used to calculate the number of disease cases. Cows were classified as having hypocalcemia, metritis, hyperketonemia, and any combination of the three. The MIXED procedure was used to determine the significance ($P <$ 0.0.5) among the cows with disease and the variable measured throughout the experiment's duration. The MIXED procedure of SAS was comparing the disease or combinations with other diseases throughout the 21 DIM, and the interaction between cows with and without the disease. The $P < 0.05$ was considered as a significant difference between cows with and without the disease.

RESULTS AND DISCUSSION

Variables: Changes by diseases

The description and summary of each PDM are reported in Table 2.1. Means for each PDM variable are displayed in Table 2.2 and appendix Tables 2.1 to 2.2. Appendix Table 2.1 to 2.2 include the variables of the whole herd average, cows without any disease, cows with only one disease (hypocalcemia and metritis), cows with two different diseases (hyperketonemia and hypocalcemia, hypocalcemia and metritis, and hyperketonemia and metritis), and cows all three diseases. Cows in this study were housed in outdated freestall facilities, which may have altered lying times (Wadsworth, 2014). Table 2.3 is the overall variable changed by different disease, the plus and minus sign represents the positive or negative affect by different diseases. The number of cows with diseases was displayed in Table 2.4. Cows were categorized with only one disease, with two different diseases, and with all diseases. The total number of cows enrolled in the study 138, but during the study, data for some cows was missing because of lightning, snow, human error, and power outages. So, not all the 138 cows have fully recorded data. No cows

were found with only hyperketonemia in the study. The percentage of cows having hyperketonemia and hypocalcemia in 3, 7, 14, or 21 DIM is displayed in appendix Table2.3.

Hyperketonemia: lying time and lying bouts

Dairy cattle lying time has been reported between 10.5 and 11 hours per cow/d (10.7 ± 0.7 h/d in BC, 10.6 ± 0.9 h/d in the US) (Ito et al., 2010, von Keyserlingk et al., 2012), but individual cows lying times vary from 4.2 to 19.5 h/d and 2.8 to 20.5 h/d in BC and US (von Keyserlingk et al., 2012). Previous study results were greater than the mean of the lying time in this study (IceQube lying time was 9.03 ± 1.73 h/d, Track a))) cow lying time was 8.94 ± 2.1 h/d, and AfiAct Pedometer Plus was 8.42 ± 1.94h/d) in this study. Cows diagnosed with hyperketonemia had lying times greater than the cows without the disease (Figure 2.2). Cows without hyperketonemia laid down 9.8 h/d, and cows with hyperketonemia lied 10.9h/d ($P<$ 0.05) (Appendix Table 2.2). The average lying time of the herd was less than 10 h/d and number of lying bout was around 14.6 time/d from 1 to 21 DIM (Appendix Table 2.2). Itle et al. (2015) suggested that cows with subclinical hyperketonemia had decreased lying time after calving, but this was contradictory with the result in this paper. Greater lying ti,e was possible when disease occurred because cows diagnosed with NEB also suffered from lesser blood glucose level (Duffield et al., 1997a). With insufficient glucose, and decrease of dry matter intake, less energy was generated. Thus, greater lying time was possible when disease occurs. This concept was mentioned by Herdt (1988), who reported that an increase in lying time was an energy conserving response to the sickness. Sepúlveda-Varas et al. (2014b) stated that cows with multiple diseases (metabolic diseases and lameness) exhibited a greater increase in lying time than cows with only one disease. In this study, most cows had more than one disease, so cows in the analysis often had multiple diseases. The average lying bouts measurements varied among

technologies likely due to differences in proprietary algorithms (Figure 2.3) (AfiAct : 11 ± 4 bouts/d, IceQube: 19 ± 7 bouts/d, and Track a))) cow: 14 ± 5 bouts/d). Further, Calderon and Cook (2011b) reported that cows increase lying bouts on the day before calving (11.2 to peak 17.7 time/d) and decreased in the duration of each lying bout. Although cows diagnosed with hyperketonemia experienced greater number of lying bouts (cow with hyperketonemia, AfiAct: 9 ± 4 bouts/d, IceQube: 17 ± 6 bouts/d, and Track a))) cow: 11 ± 7 bouts/d; cow without hyperketonemia, AfiAct: 10 ± 3 bouts/d, IceQube: 15 ± 5 bouts/d, and Track a))) cow: 11 ± 2 bouts/d) than cows without hyperketonemia but no numerical difference was recorded. In addition, Hart (1988) found cows diagnosed as ill that exhibited an increase in lying time were considered to be showing energy conserving behaviors . The results of this study agree with Sepúlveda-Varas et al. (2014a) that lying behavior could be an indicator of detection common transition disease in dairy cows.

Hyperketonemia: steps and activity

The number of steps and the activity varied based on the different technologies and the locations of each technology on the cow's body (Figure 2.4). In cows with hyperketonemia, the average number of steps was 3137 ± 121 steps/d, and cows without hyperketonemia was 3685 ± 72 steps/d ($P< 0.05$). In cows with hyperketonemia, the average neck activity was 359 ± 13 unit motion/d, and cows without hyperketonemia was 407 ± 16 unit motion/d ($P< 0.05$). Activity value varied because of the position of the tags on the cows. Ear, leg and neck tags were used in this study. Although steps were significantly different ($P< 0.05$) in cows diagnosed with hyperketonemia when measured with AfiAct Pedometer Plus leg tag (3137 ± 121 steps/d vs 3685 ± 72 steps/d , $P < 0.05$), no difference was measured with the IceRobotics IceQube (1114 ± 343 steps/d vs 1142 ± 357 steps/d) and ENGS Track a))) cow (1948 ± 480 steps/d vs 2011 ± 557

steps/d) leg tag for number of steps. Cows that were diagnosed with hyperketonemia recorded less neck activity (cows with hyperketonemia were 359 ± 13; cows without hyperketonemia was 407 ± 16 units of movement/d, $P < 0.05$). Edwards and Tozer (2004b) found cows with the metabolic disorder would exhibit less activity than healthy cows on DIM 10 ± 8.2 ($P < 0.05$). Cows in this study with hyperketonemia may also suffer from other metabolic disorders. No cows with only hyperketonemia were found in this study, so cows with hyperketonemia were affected by other metabolic diseases.

Hyperketonemia: rumination, feeding time, eating time, and rumen temperature

Cows with hyperketonemia had lesser rumination time than cows without hyperketonemia (Figure 2.5) (cows with hyperketonemia were 471 ± 34 min/d; cows without hyperketonemia were 520 ± 40 min/d, $P < 0.05$). However, both cows with and without hyperketonemia experienced less rumination in the first 7 days (cows with hyperketonemia were 423 ± 107; cows without hyperketonemia were 468 ± 103 min/d). Cows with hyperketonemia were 469.7 ± 126; cows without hyperketonemia were 506.8 ± 108.8 min/d in the first 7 DIM ($P < 0.05$). Overall herd rumination time was 560 ± 66 min/d. One possible reason for the decreased rumination at the beginning of the lactation was that cows changed groups on the day of calving. Cows experience environmental, calving, and social change during this period. But rumination time slowly increased after 7 DIM (cows diagnosed as sick 313 min/d v.s cows not sick 368 min/d, $P < 0.01$), which was as suggested by Liboreiro et al. (2015b). Huzzey et al. (2007) suggested that cows that were defined as ill during the transition period spent less time eating and at the feed bunk during the first week after calving. The results of the previous studies and the present study agreed that rumination time decreased when cows were diagnosed with diseases.

Previous studies demonstrated that cows with hyperketonemia spent less time at the feed bunk during the first week after calving, up to 28% less when cows were diagnosed with hyperketonemia ($P < 0.05$) (Goldhawk et al., 2009, Itle et al., 2015). Also, cows diagnosed with hyperketonemia spend more time standing and waiting (cows with hyperketonemia 14.3 ± 0.6, and cows without hyperketonemia 12.0 ± 0.7 h/d, P=0.06). Although, the decrease of eating time and time around the feed bunk did show in the result, there are no differences between cows with and without hyperketonemia (Figure 2.6) (eating time: 198 ± 93 min/d vs 224 ± 106 min/d and time around the feed bunk: 149.1 ± 80.6 min/d, and cows without hyperketonemia 168.1 ± 73.3 min/d, $P > 0.05$). No significant difference ($P > 0.05$) was found in reticulorumen temperature between cows with and without hyperketonemia (Figure 2.7) (39.5 ± 0.3 ºC/d vs 39.6 ± 0.4 ºC/d).

Hyperketonemia: milk components

The average milk fat was significantly greater when cows were diagnosed with hyperketonemia (Figure 2.7) (cows with hyperketonemia 4.09 ± 0.81% vs cows without hyperketonemia 3.88 ± 0.42%). The milk fat: protein was also significantly greater in cows with hyperketonemia than without (1.42 ± 0.23 vs 1.29 ± 0.18) ($P < 0.01$). Duffield et al. (1997a) reported that cows were at greater risk for having hyperketonemia if their milk fat increased and milk protein deceased. Milk protein and milk fat in early lactation were used as markers for measuring nutritional status (Duffield et al., 1997b). In this study, the same result was reported. Cows with hyperketonemia produced milk with a greater milk fat content less milk protein (3.05 ± 0.27% vs 3.12 ± 0.21%). Further, in research conducted by Richardt (2004), a value of fat:protein (above 1.5), was associated with a high incidence of hyperketonemia (3.5 times)

compared with cows without. Routine recording of milk fat and protein could provide new insight into metabolic diseases

Hyperketonemia: milk yield and body weight

For analysis of milk yield and body weight, cows were classified as primiparous and multiparous. First lactation cows would have less milk and bodyweight than the second or higher lactation cows. Thus, categorize cows with primiparous and multiparous to separate the difference. In primiparous cows, there is no significant differences in milk yield between cows with and without hyperketonemia ($P > 0.05$). However, the milk yield was significant different within 21 DIM in multiparous cows between cows with and without hyperketonemia (cows with hyperketonemia 31.4 ± 3.8, cows without hyperketonemia 37.8 ± 4.3 kg/d, $P<0.05$). Also, the body weight was significant different within 21 DIM in multiparous cows between cows with and without hyperketonemia (cows with hyperketonemia 750 ± 18, cows without hyperketonemia 710 ± 12 kg, $P<0.05$). The result in this study matches the results of Edwards and Tozer (2004b), which concluded that sick cows recorded lesser milk yield than heathy cows (15kg/d less than healthy cows). And Rajala-Schultz et al. (1999) reported that the milk loss varied, from 3 kg/d to 5.3 kg/d, and depended on the parity.

As a good indicator of body reserve, body weight alone was not enough (Roche et al., 2013). In early lactation, body tissue mobilized while feed intake increased (Roche et al., 2007, Roche et al., 2013), but the weight of the tissue decrease which cannot be detected because the rumen is filled (Stockdale, 2001, Berry et al., 2006b). This weight change does not accurately reflect the change of adipose and weight of lean tissue (Roche et al., 2013). Thus, to measure the accurate adipose and lean tissue, measuring body condition is needed. Body condition is the ratio of body fat to non-fat components in the body as defined by (Murray, 1919b). In cows with BCS

> 3.5 around calving, the risk of developing hyperketonemia was 2 times more than in cows with BCS 3.25 (Gillund et al., 2001). Wright and Russel (1984) and Otto et al. (1991) reported the highly correlate between BCS and body fat (r=0.83), and the correlation between BCS and body weight were 0.62 in US Holstein cows (Otto et al., 1991). Further, with one unit change in BCS, the corresponding body weight changed from 21 to 110 kg (Otto et al., 1991, Berry et al., 2006a). In a recent study, Roche et al. (2015) found that cows with greater body weight have a greater chance of liver fat infiltration, increased risk of having metabolic diseases, and greater loss of BCS.

Hypocalcemia: lying time and lying bouts

Lying time and not active time are displayed in Figure 2.9. Not active time was an ear tag variable which measured cows when the cows' heads were not moving, which could occur while standing or lying. Cows with hypocalcemia experienced greater lying time (9.4 ± 1 h/d) than cows without hypocalcemia (8.2 ± 1 h/d) (P>0.01). Jawor et al. (2012a) found that cows with hypocalcemia spent more time lying down on the first week after calving (16.5 h/d, P=0.03). However, Huzzey et al. (2005) indicated that lying time decreased 1.1 h/d during the transition period. But Jawor et al. (2012b) indicated that cows with subclinical hypocalcemia would standing 3h longer during the 24h period before calving, this could suggest that cows experienced the discomfort. Jawor et al. (2012b) showed no lying bout difference between the 7d before and the 7d after cow calved (prepartum: 12.2 vs postpartum 10.7, P=0.9). Cows with hypocalcemia spent more time lying down to save energy, so lying time increased. Inadequate blood Ca would cause cows reduce the ability to walk and impaired muscle function. In addition, hypocalcemia reduce muscle contraction, which lead to the downer cow syndrome. Although different PDM were used in this study and recorded different times, overall lying time increased

when cows suffered from hypocalcemia (AfiAct: 517.2 ± 113.3 min/d vs 480 ± 119.1 min/d; IceQube: 563.9 ± 95.9 min/d vs 498.3 ± 103.7 min/d; Track a))) cow: 551.8 ± 120.8 min/d vs 502.9 ± 129 min/d). However, no difference was observed in lying bouts for cows with and without hypocalcemia (Figure2.10). Sepúlveda-Varas et al. (2014b) also reported no recordable difference existed in lying bouts between cows with and without metabolic diseases. Because of the lack of change on lying bouts, lying time could be used instead as a useful indicator of hypocalcemia.

Hypocalcemia: steps and activity

Steps and activity are displayed in Figure 2.11. Only AfiAct Pedometer Plus and SCR HR tags could detect the difference between cows with and without hypocalcemia in steps and activity. Cows with hypocalcemia took 2490 ± 1180 steps/d and cows without hypocalcemia took 2856 ± 1180 steps/d ($P < 0.05$) in AfiAct Pedometer Plus. The neck activity was 376 ± 19 when cows had hypocalcemia, and 447 ± 15 in cows without hypocalcemia ($P < 0.05$). No difference was found in IceQube and Track a))) cow. Overall, activity was affected by the disease, and cows with metabolic diseases was showed less active in Edwards and Tozer (2004b). The position of the tags, the algorithm used to calculate the steps or activity had affected on the results. Leg tags needed to be faced out, but when cows were lying down or walking, tags could shift to a different side, which could influence the data. A study by Stangaferro et al. (2016b) linked activity and rumination time with metabolic detection (sensitivity 93%, 95%CI: 89, 98). Whether or not cows suffered from hypocalcemia did affect activity and rumination in this study.

Although six technologies, which can detect activity or steps, were used in this study, few of them can detect the change caused by disease. This was due to missing data, which missing

during this study because of lightning, snow, human error, and power outages. Thus, some PDM technologies had more fully recorded data than others. In Edwards and Tozer (2004a), Afikim computerized dairy management system (Kibbutz Afikim, Israel) was used, and in this study, the updated version was used. Technologies that updated their system and tags often provided more information and accurate data. Therefore, activity could be an indicator of hypocalcemia.

Hypocalcemia: rumination time, feeding time, eating time, and rumen temperature

No differences were identified in reticulorumen temperature and feeding time during the transition period (Figure 2.12 and 2.13). But rumination time decreased when a cow was diagnosed with hypocalcemia (485 ± 37 vs.531 ± 31 min/d, $P < 0.05$). The result matched the previous study Liboreiro et al. (2015b), which showed that cows diagnosed with hypocalcemia had decreased rumination time after calving from 1 to 3 DIM ($P < 0.01$). Depending on the Ca levels, the ability of smooth muscle and skeletal contraction changed (Murray, 2008). Minimizing the usage of Ca circulation from the blood reserves could increase absorption from the rumen or intestines, and most importantly, the Ca reserves from bone (DeGaris and Lean, 2008).

No difference was recorded between eating time and time around the feed bunk for cows with and without hypocalcemia. Jawor et al. (2012a) concluded that cows with hypocalcemia increased intake during the 2 weeks after calving. However, Huzzey et al. (2005) mentioned that cows spent less time on eating after calving. In the Huzzey et al. (2005) study, the decrease of eating time from pre-calving to post-calving was 87 to 62 min/d. According to the result and contradicting evidence, the relationship between feeding time and disease was unknown, and more research is needed. In this study, no difference in feeding time was recorded for cows with

and without hypocalcemia. However, rumination time could be an indicator useful in the detection of hypocalcemia.

Hypocalcemia: *milk component*

Milk component is displayed in Figure 2.14. A significant difference was displayed in cows with and without hypocalcemia in milk conductivity, fat, lactose and fat: protein ($P < 0.05$). Cows with hypocalcemia had greater milk fat: protein (1.37 ± 0.05 vs. 1.25 ± 0.05, $P < 0.05$). Cows with hypocalcemia had greater milk conductivity (8.12 ± 0.27 vs. 7.64 ± 0.17 %, $P < 0.05$). Cows with hypocalcemia had greater milk fat (4.5 ± 0.1 vs. 4.05 ± 0.07 %, $P < 0.05$). Cows with hypocalcemia had lesser milk lactose (4.34 ± 0.55 vs. 4.52 ± 0.48 %, $P < 0.05$). A previous study showed no difference between milk fat in cows with hypocalcemia (Chamberlin et al., 2013). However, cows with hypocalcemia also had other metabolic diseases, which means hypocalcemia may not have a direct effect on the milk component.

Hypocalcemia: milk yield and body weight

Milk yield and body weight were separated by parity, primiparous and multiparous cows and display in Table 2.15. First lactation cows have less milk and bodyweight than the second or higher lactation cows. Thus, categorize cows from primiparous and multiparous to separate the difference. In primiparous and multiparous cows, there is a significant different in milk yield between cows with and without hypocalcemia from 1 to 21 DIM ($P < 0.05$). Cows with hypocalcemia produced less milk yield (primiparous: 23.89 ± 4.63 kg/d vs 27.18 ± 4.13 kg/d; multiparous: 33.72 ± 9.56 kg/d vs 39.9 ± 8.56 kg/d, $P < 0.05$). But, Gröhn et al. (1995) suggested that cows with hypocalcemia had a greater milk lactation in previous lactation. However, during this study, PDM measured daily milk yield, which was different than the previous study results. And Deluyker et al. (1991b) indicated that milk yield would temporarily or continuously drop

because of having hypocalcemia. Also, multiparous cows' milk loss could be a risk factor for other diseases (Erb and Grohn, 1988a, Klerx and Smolders, 1997). In this study, results showed cows with hypocalcemia exhibited lesser milk yield. However, less milk yield was expected during the transition period because feed intake affects production and feed intake was low during the transition period. No numerical difference in body weight was recorded. Østergaard and Gröhn (1999) suggested that multiparous cows with a greater body weight would have an increased risk of developing hypocalcemia during the first week after calving. The same study explained that the body weight was not different between healthy cows and cows with hypocalcemia. The results of this study matched those from Østergaard and Gröhn (1999) in that multiparous cows recorded greater body weights, but no difference was recorded in cows with and without hypocalcemia.

Metritis: lying time and lying bouts

Lying time and lying bouts are displayed in Figure 2.16. No difference in lying time and lying bouts were found between cows with and without metritis. Huzzey et al. (2007) indicated that cows with metritis would change their behavior, lying bouts, and time spent at the feed bunk. Huzzey et al. (2007) and Liboreiro et al. (2015b) mentioned that cow behavior would change after the cow was diagnosed with metabolic diseases. And Titler et al. (2013) pointed out that less rumination time, steps, activity, and lying bout could be found 1 to 3 d before cows were diagnosed with metritis. Therefore, the change is should be detectable using PDM. Liboreiro et al. (2015a) mentioned that less activity and rumination would be found when cows were diagnosed with metritis. But the results of this study cannot confirm the results from the previous studies.

Metritis: steps and activity

Figure 2.18 shows the significant difference ($P > 0.01$) in the decrease of steps and activity for cows with and without metritis. Cows with metritis recorded activity than the cows without metritis (2125 ± 1215 steps/d vs 2689 ± 1637 steps/d). Although the decrease of steps and activity vary, change can be detected between cows with and without metritis. Previous studies suggested that cows with metritis may have longer standing time, which could correlate to more steps (Huzzey et al., 2005). But in this study, less steps were found, this pointed that cow might experience illness, and not willing to walk or be active. Also, cows with metritis, could have other metabolic disease at the same time, which could have affected the results.

Metritis: rumination time, feeding time, eating time, and rumen temperature

Less rumination was recorded for cows diagnosed with metritis (473 ± 29 vs. 537 ± 35 min/d). Liboreiro et al. (2015b) reported that cows with metritis had less rumination time 415.9 ± 101.1 min/d when cows had metritis and 441.0 ± 5.2 min/d when cows did not have metritis. Further, time around the feed bunk and eating time were not significantly different between cows with metritis and without (time around the feed bunk: 160.6 ± 60.4 vs 131.3 ± 57.6 min/d; eating time: 210.1 ± 102.4 vs 245.1± 100.9 min/d, $P > 0.1$). Urton et al. (2005b) found that cows with metritis spent less time around the feed bunk. In this study. cows with metritis visited the feed bunk more often, contrary to the previous studies. Although Liboreiro et al. (2015b) stated that feeding behavior was a useful measurement for the risk of metritis, and in this study no difference was recorded. In the Liboreiro et al. (2015b) study, the sample size was big, and the cows with metritis were only diagnosed with metritis, which contrasts the present study. Cows in the present study with metritis also were diagnose with other metabolic diseases. This could account for the difference in the result. Reticulum temperature is displayed in Figure 2.26, but no significant difference was found in cows with and without metritis ($P > 0.9$). However, several

studies demonstrated that rectal and reticular temperature was useful in the detection of sick cows (Edwards and Tozer, 2004a). Sheldon et al. (2006) pointed out that cows with temperatures greater than 39.5 ºC generated a greater risk of contracting metritis. Adams et al. (2013) and the present study reported that temperature would not be affected whether the cows had metritis or not.

Metritis: milk component

Milk composition is displayed in Figure 2.21. Fat and fat: protein was significantly different in cows with and without metritis ($P< 0.01$). Cows with metritis had greater fat: protein than the cows without metritis (1.35 ± 0.05 vs. 1.18 ± 0.09 fat:protein). Cows with metritis had greater milk fat percent than cows without metritis (4.42 ± 0.1 vs. 3.95 ± 0.1 %). Previous research pointed out that fat:protein could be a potential indicator of NEB, because of the lack of energy supply reflects on milk component (Duffield et al., 1997b, Heuer et al., 2000). If the fat:protein was greater than 1.5, energy insufficiency was reported (Duffield et al., 1997b). Also, if fat:protein was greater than 1.5, the chances of having a metabolic disease was greater (Heuer et al., 2000). Toni et al. (2011) found that if the fat:protein was greater than 2.0, the chance to develop metritis was great. However, protein and lactose were not affected by metritis status

Metritis: milk yield and body weight

Milk yield and body weight were separated by parity, primiparous and multiparous cows, and display in Table 2.22. The significant difference was found in multiparous cows' body weight. Multiparous cows with metritis have a lesser body weight ($P < 0.05$). Compared with the results from Østergaard and Gröhn (1999), metritis cows loss body weight (23 kg on primiparous, and 16 kg on multiparous) before diagnosis. Østergaard and Gröhn (1999) reported that the body weight of cows with RP, metritis, and other metabolic disease was lower after

diagnosis. However, milk yield was not found to be affected by a metritis diagnosis, which confirms the results of Rajala and Gröhn (1998). At the early stage of development, metritis was found associated with milk loss. Cows in first lactation with RP were associated with milk loss (1.4 kg/d during the first 2 week). For cows in different stages of lactation and parity, milk was reduce because of metritis or other metabolic diseases, but no significant difference was found in this study or the previous studies (Lucey et al., 1986, Rowlands and Lucey, 1986, Rajala and Gröhn, 1998).

Serum concentration of Cholesterol, NEFA, milk BHBA, and milk Haptoglobin

Cholesterol

Blood cholesterol concentration is displayed in Figure 2.26a). Cows having varying disease as well as a varying number of disease affected blood cholesterol concentration. A lower level of cholesterol (167 ± 5.3 mg/dl) was associated with a greater loss of BCS during the first month of lactation ($P < 0.05$) (Kim and Suh, 2003). The relation between of low cholesterol and illness after calving is not certain, but researchers suggested that the relation could be related to DMI and energy balance after calving (Cavestany et al., 2005, Guretzky et al., 2006). Kessler et al. (2014b) found the milk cholesterol in milk fat decreased from the first week (248.33 ± 18.27 mg of cholesterol / 100g of fat) to fourth week (171.55 ± 14.67 mg of cholesterol / 100g of fat) after calving. Ruegg et al. (1992) and Kim and Suh (2003) linked BCS loss with a decrease in cholesterol, and concluded that lower cholesterol and greater BCS loss may be associated with greater mobilization of body reserves during early lactation. Also, Quiroz-Rocha et al. (2010b) found that NEFA and cholesterol were related to the risk of developing RP. Sepúlveda-Varas et al. (2015) indicated that cows with a low concentration of cholesterol would have an increased risk of experiencing fatty liver. Cows with multiple diseases and that experienced NEB recorded

a lesser cholesterol level. Cows with a greater cholesterol level suffered from NEB less often. Sepúlveda-Varas et al. (2015) reported that for every 0.4 mmol/L decrease in cholesterol level cows were twice as likely to develop metritis or other metabolic disease. In the same study, Sepúlveda-Varas et al. (2015) found cholesterol level was less in cows with severe metritis during the 2 weeks after calving ($P < 0.001$).

NEFA

Blood serum NEFA is displayed in Figure 2.26 b). Because of budget constraints, NEFA concentration was only measured on 3 DIM. But, a greater NEFA concentration was produced when cows exhibited multiple diseases. The result reflected previous study results in that NEFA concentration increased after calving. The results also matched with research that stated NEFA concentration could be used as a marker of NEB (Chapinal et al., 2011). Large amounts of fat mobilization in cows was linked with clinical endometritis and immunosuppression (Ospina et al., 2010). Ospina et al. (2010) reported that if NEFA concentration was greater than 0.7 mEq/L, then the chance of developing the metabolic disease was great. The greater concentration of NEFA during the last week before calving could be a risk indicator of metabolic diseases(Bicalho et al., 2017). But in the Qu et al. (2014) study, plasma NEFA was no different in cows with and without RP ($P = 0.48$). Although the standard value of NEFA is still being debated, in this study high NEFA indicated disease to an existing.

Milk BHBA

Milk BHBA is displayed in Figure 2.26 c). Most the previous research used blood BHBA to detect hyperketonemia. Geishauser et al. (1998) used a milk ketone test, and compared the results with 50 and 100 μmol of BHBA/L in milk with the milk ketone test. The 92% sensitivity and 72% specificity was found for the detection of hyperketonemia in Geishauser et al. (1998)

research. In this study, hyperketonemia is not separated from other diseases, because hyperketonemia was highly related to other metabolic diseases. But the results of this study indicated that high milk BHBA detected metabolic diseases. More research is needed with milk BHBA to detect only hyperketonemia.

Milk haptoglobin

Milk haptoglobin is displayed in Figure 2.26 d). No difference was found between milk haptoglobin concentration and metabolic diseases. In a previous study, a greater blood concentration of haptoglobin was found when cows were diagnosed with clinical metritis ($P < .001$) (Chan et al., 2010). The acute puerperal metritis was defined in the previous study, which was when a cow had fetid watery red-brown uterine discharge associated with signs of systemic illness and fever > 39.51C within 3 days after calving (Chan et al., 2010). Also, Huzzey et al. (2009) found cows with ≥ 1 g/L blood Hp 3d after calving were 6.7 times more likely to develop severe or milk metritis, with 50% sensitivity and 87% specificity. However, milk haptoglobin was used in this study and could be different from the previous study. And Humblet et al. (2006) found Hp could be a marker of inflammation in the week after calving, but this was stated with caution because more works need to be done. Hiss et al. (2009) mentioned that little information linked serum haptoglobin and metabolic stress. But greater milk Hp could be associated with greater NEFA level (Hiss et al., 2009). The greater concentration of haptoglobin could be caused by the circulating haptoglobin in milk (Thielen et al., 2007). During this study, cows always had multiple diseases, which created difficulty defining if milk haptoglobin was increased because of metritis or not. Also, during the study, milk samples were only collected on 3 and 7 DIM, and 25% of the milk samples were missing. Thus, the missing samples could affect the result. Also, this study was not looking at cow's comparison, not the level between cows. Cows naturally

have different levels of haptoglobin in their system, and that could have influenced the results. he relationship between metabolic and haptoglobin was not clear, and more research is needed.

Future studies

The following are potential opportunities for improvements for future studies. Learning from experiences during the study, there are many errors. Human error, maintenance and study design are the three main areas. People training is an important part of having fully recorded data. Before using technology, people should be trained and understand who to go to and how to troubleshot the problem. People who are responsible for taking care of the technology should double-check the system every week at least to make sure is well functioning. The system should be backed up the system every month, as this could make sure the company technicians have a resource to check the system if there is something wrong. Beside the PDM, during the fresh cow exam, training people could also affect the result. People who were trained to do fresh cow everyday need a reminder, in case of the missing data. No one is perfect, but with an effective reminder system, the chance of missing data could be reduced.

Second is maintenance the maintenance when the system was damaged by natural factors that cause system malfunction. The system was not housed inside but exposed out in the field. When the receiver was placed outside, under the severe weather, the receiver could be damaged. Natural factors include lightning, snow, and raccoons. The tag was designed to fit on the dairy cows' leg, neck or ear, but the data receiver needed to fit in with the natural environment. Thus, the location of the technology's receiver was crucial. Wild animals were the other natural factor, with the open feeding space for cows; raccoons were attracted to the feed. Thus, raccoons showed up on the farm and cheed the cable. During the study, raccoons damaged a few PDM receivers and wiring.

Next, change could be made in the study design. When intensively monitored dairy cows from 1 to 21 DIM, more samples could be taken. For blood BHBA, Ca, and NEFA, more samples could be taken. Instead of taking samples on DIM 3, 7, 14, and 21, the blood sample should be taken the intensively during first 7d, because daily fresh cow exams were already conducted, blood samples could also be taken simultaneously. Also, milk samples of BHBA and haptoglobin could be taken more often.

CONCLUSION

In this study, PDM provided the possibility of finding how change in physical activity, rumination time and temperature could indicate diseases. These variables provide producers the opportunity to implement the technology in their operations. Decreasing rumination, eating time, activity, body weight, and increasing lying time, milk fat could indicate the development of disease. Technology manufacturers should continue to seek ways to monitor multiple variables at once and to improve upon the variables they already monitor. The PDM used in this study have progressed from the time of this study and may be better able to predict disease than they were at this time. Beyond refinements in what information is collected within each technology, actually collecting that data consistently is very important. Missing data from both technology and human error required variables to be excluded from models, which may have provided better results if those variables had been included. Using PDM to predict hypocalcemia, hyperketonemia, and metritis is promising, but needs additional comparative work is needed.

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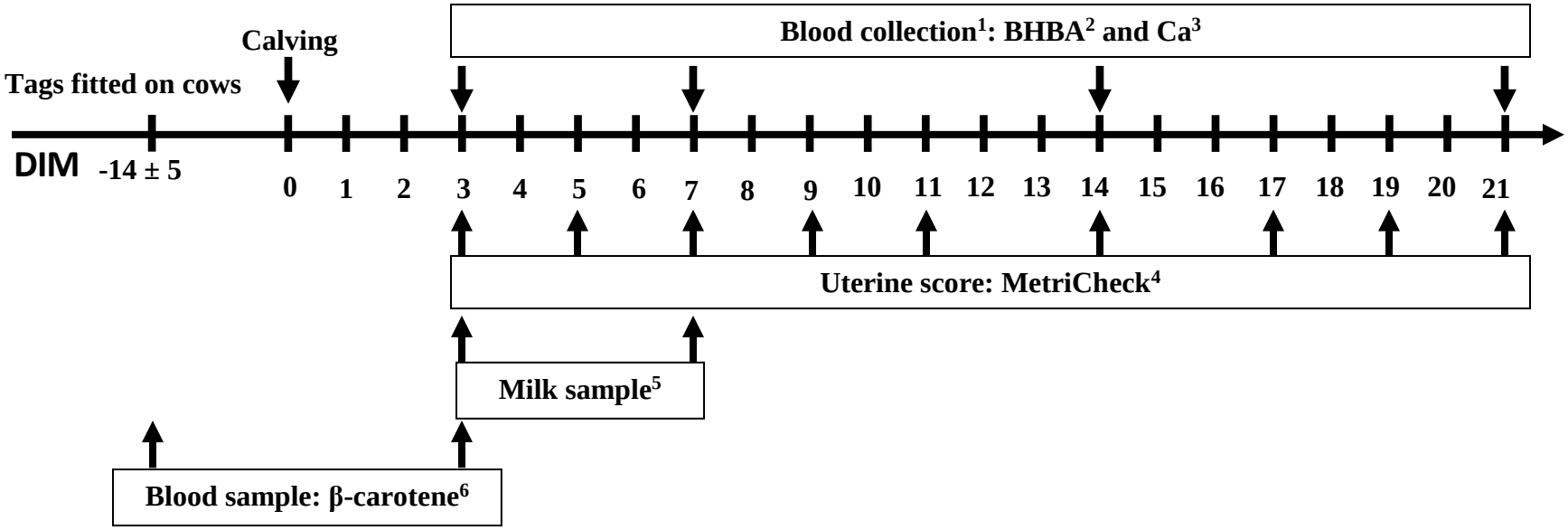
Table 2.1. Precision dairy monitoring technologies, variables measured, measurement frequency, and technology abbreviations used in evaluation of hyperketonemia, hypocalcaemia, and metritis.

Precision dairy monitoring technology	Variables measured	Frequency of measurements/ reporting data
AfiAct Pedometer Plus, Afimilk, Kibbutz Afikim, Israel	Activity (steps/d) Lying time (min/d) Lying bouts (bouts/d)	Continuously/ per hour
AfiLab Milk Analyzer, Afimilk, Kibbutz Afikim, Israel	Protein (%) Fat (%) Lactose (%)	Each milking/ End of milking
AfiMilk MPC Milk Meter Afimilk, Kibbutz Afikim, Israel	Milk yield (kg/d) Milk conductivity (%)	Each milking/ End of milking
AfiWeigh, Afimilk, Kibbutz Afikim, Israel	Body weight (kg/d)	Each milking/ End of milking
CowManager SensoOr, Agis Automatisering, Harmelen, Netherlands	Rumination time (min/d) Eating time (min/d) Time not active (min/d) Time active (min/d) Time high active (min/d)	Every minute/ Every hour
DVM bolus, DVM System, LLC, Greeley, CO	Reticulorumen temperature (ºC)	Every 5 minutes/ Hourly
HR Tag, SCR Engineers Ltd., Netanya, Israel	Neck activity (units/d) Rumination time (min/d)	Continuously / Every 2 hours
IceQube, IceRobotics Ltd., Edinburgh, Scotland	Lying time (min) Steps (number/d) Motion index Lying bouts (bouts/d) Bout duration (unit/d)	Continuously/ 15 minute intervals
Track a))) Cow, ENGS System Innovative Dairy Solutions, Israel	Steps (number/d) Lying time (min) Lying bouts (bouts/d) Time spent at feed bunk (min/d) Feed bunk visit time (number/d)	Continuously/ Every 5 minutes
SmartBow, Smartbow GmbH, Jutogasse, Austria	Rumination time (min/d) Lying time (min/d) Time not active (min/d) Time active (min/d) Time high active (min/d)	Continuously/15 minute intervals

Figure 2.1 Depiction of the timing for taking blood samples and uterine score.



[1]Blood was collected from coccygeal vein while cow was standing still in the freestall.
[2]BHBA level was measured by Precision Xtra (Abbott Laboratories, Chicago, IL, USA).
[3]Ca was measured by the University of Kentucky Veterinary Diagnostic Laboratory.
[4]Metricheck device was used to score vaginal discharge on a scale of 1 to 3 with 1 being no metritis and >1 being metritis (Sterrett et al., 2014).
[5]Milk sample was taken for measuring milk haptoglobin by eProCheck (Frim Tes, Germany) and milk BHBA PortaBHB^{TM} Milk Ketone Test (PortaCheck Inc., Moorestown, NJ).
[6] β-carotene level was measured by iCheck (ROVIMIX® β-Carotene, Heerlen, Netherlands).

Table 2.2. Means of variables[1] measured by precision dairy monitoring technologies[2] for dairy cows from 1 to 21 DIM for all cows (healthy or with disease) and cows with any transition cow disease[3].

Variable[1]	Technology[2]	Mean ± SD			
		Overall herd	N[4]	Disease[3]	N[4]
Activity (steps/d)	AfiAct pedometer Plus	3593 ± 850	131	3347 ± 713	34
Activity (steps/d)	Track a)) Cow	1988 ± 534	114	1948 ± 487	29
Activity (steps/d)	IceQube	1133 ± 354	135	1085 ± 350	34
Motion index	IceQube	3877 ± 1243	135	3616 ± 1231	34
Active time (min/d)	SensoOr	68 ± 19	90	62 ± 20	23
High activity (min/d)	SensoOr	71 ± 42	90	66 ± 44	23
Neck activity (unit/d)	HR Tag	396 ± 113	106	344 ± 92	28
Active time (min/d)	Smartbow	924 ± 87	90	876 ± 92	22
High activity (min/d)	Smartbow	138 ± 79	90	116 ± 63	22
Lying time (min/d)	AfiAct pedometer Plus	506 ± 117	131	539 ± 120	34
Lying bouts (#/d)	AfiAct pedometer Plus	11 ± 4	131	12 ± 5	34
Lying time (min/d)	IceQube	542 ± 104	135	597 ± 94	34
Lying bouts (#/d)	IceQube	19 ± 7	135	21 ± 8	34
Bout duration (min/bout)	IceQube	542 ± 104	135	597 ± 95	34
Time not active (min/d)	SensoOr	507 ± 161	90	577 ± 199	23
Lying time (min/d)	Track a)) Cow	536 ± 126	114	595 ± 104	29
Lying bouts (#/d)	Track a)) Cow	14 ± 5	114	15 ± 5	29
Time not active (min/d)	Smartbow	378 ± 95	90	449 ± 106	22
Lying time (min/d)	Smartbow	727 ± 127	90	770 ± 101	22
Rumination time (min/d)	SensoOr	583 ± 118	90	538 ± 157	23
Rumination time (min/d)	HR Tag	479 ± 95	106	442 ± 112	28
Rumination time (min/d)	Smartbow	535 ± 79	90	492 ± 87	22
Eating time (min/d)	SensoOr	215 ± 103	90	201 ± 96	23
Intake visits (#/d)	Track a)) Cow	8 ± 2	114	8 ± 2	29
Time at feedbunk (min/d)	Track a)) Cow	157 ± 61	114	144 ± 70	29
Mean rectal temperature (ºC)	GLA thermometer	38.6 ± 0.2	138	38.6 ± 0.2	36
Reticulorumen temperature (ºC)	DVM bolus	39.6 ± 0.4	97	39.6 ± 0.3	20
Milk yield (kg/d)	AfiMilk MPC Milk Meter	31.6 ± 9.6	131	27.3 ± 9.2	34
Milk fat (%)	AfiLab Milk Analyzer	4.1 ± 0.6	131	4.4 ± 0.7	34
Milk protein (%)	AfiLab Milk Analyzer	3.1 ± 0.2	131	3.0 ± 0.3	34
Milk fat protein ratio	AfiLab Milk Analyzer	1.3 ± 0.2	131	1.5 ± 0.2	34
Milk lactose (%)	AfiLab Milk Analyzer	4.7 ± 0.2	131	4.6 ± 0.3	34
Milk conductivity (%)	AfiMilk MPC Milk Meter	8.0 ± 0.8	131	8.2 ± 0.6	34
Body weight (kg)	AfiWeigh	695 ± 84	131	717 ± 87	34

[1]Variables were measured from the corresponding precision dairy monitoring technology. For example, AfiAct Pedometer Plus recorded activity (steps/d), lying time (min/d), and lying bouts (#/d).
[2]Precision dairy monitoring technologies included: AfiAct Pedometer Plus, Afimilk, AfiLab, AfiWeigh (Kibbutz Afikim, Israel); Track a))) cow (ENGS System Innovative Dairy Solutions, Israel); DVM bolus (DVM System, LLC, Greeley, CO); IceQube **(**IceRobotics Ltd., Edinburgh, Scotland); HR Tag, SCR (Engineers Ltd., Netanya, Israel); SmartBow (Smartbow GmbH, Jutogasse, Austria); and CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands).
[3]Disease included any animals with hyperketonemia, hypocalcaemia, metritis, or any combination of diseases.
[4]N referred to the total number of cows in each row and column.

Table 2.3. With the MIXED[1] procedure of SAS 9.3 analysis the change of variables (positively[2], negatively[3] change, or NS[4]) that affected by cows with and without hyperketonemia[4], hypocalcemia[5], and metritis[6] during DIM 21

	Disease		
Variables	Hyperketonemia	Hypocalcemia	Metritis
Milk yield (kg)	**-**	**-**	**NS**
Steps	**-**	**-**	**-**
Lying time	**+**	**+**	**+**
Lying bouts	**+**	**+**	**NS**
Body Weight	**+**	**NS**	**NS**
Fat: protein	**+**	**+**	**+**
Fat (%)	**+**	**+**	**+**
Temperature	**-**	**-**	**+**
Rumination (min)	**-**	**-**	**-**
Time around the feed bunk (min)	**-**	**NS**	**NS**

[1]MIXED procedure of SAS was compared the average of cow from cows with and without disease from 1 to 21 DIM.

[2]Positively change, after MIXED procedure of SAS, the variable was increased because of having disease, would mark as "+" in the column.

[3]Negatively change, after MIXED procedure of SAS, the variable was decrease because of having disease, would mark as "-" in the column.

[4]NS, after MIXED procedure of SAS, the variable was not change because of having disease, would mark as "NS" (Not significant) in the column.

[3]Hyperketonemia was identified on 3, 7, 14, or 21 DIM by using Precision Xtra (Abbott Laboratories, Chicago, IL, USA) with coccygeal vein blood. N referred to cows without subclinical or clinical hyperketonemia at each DIM.

[4]Hypocalcaemia was identified on 3, 7, 14, or 21 DIM by University of Kentucky Veterinary Diagnostic Laboratory using coccygeal vein blood serum. N referred to cows without subclinical or clinical hypocalcaemia at each DIM.

[5]Metricheck device was used to score vaginal discharge on a scale of 1 to 3 with 1 being no metritis and >1 being metritis (Sterrett et al., 2014).

Table 2.4. Hyperketonemia[1], hypocalcaemia[2], and metritis[3] detection cut-points for individual diseases and disease combinations for transition cows (1 to 21 DIM) from January 2013 to October 2015.

Disease	Cut point	Numbers of cows
Only hyperketonemia[1]	≥ 1.2 mmol/L	0
Only hypocalcaemia[2]	≤ 8.6 mg/dL	5
Only metritis[3]	MetriCheck	26
Combination 1		
Hypocalcaemia[2]+ Metritis[3]		48
Combination 2		
Hyperketonemia[1]+ Hypocalcaemia[2]		4
Combination 3		
Hyperketonemia[1]+ Metritis[3]		9
Combination 4		
Hyperketonemia[1]+ Hypocalcaemia[2]+ Metritis[3]		36
No diseases		10
Total individual cases[5,6]		138

[1]Hyperketonemia was identified on 3, 7, 14, or 21 DIM by using Precision Xtra (Abbott Laboratories, Chicago, IL, USA) with coccygeal vein blood.

[2]Hypocalcaemia was identified on 3, 7, 14, or 21 DIM by University of Kentucky Veterinary Diagnostic Laboratory using coccygeal vein blood serum.

[3]Metricheck device was used to score vaginal discharge on a scale of 1 to 3 with 1 being no metritis and >1 being metritis (Sterrett et al., 2014).

[4]No hyperketonemia cases occurred without a case of either metritis, hypocalcaemia, or both.

[5]Only 10 animals of the 138 animals on the study did not have metritis, hypocalcaemia, hyperketonemia, or a combination of diseases from January 2013 to October 2015.

[6]Although 138 animals were on the study, and 128 animals were positive for a case of metritis, hypocalcaemia, hyperketonemia, or combination. Multiple diseases were possible for an individual cow, resulting in a greater total individual disease incidence than the number of individual cows.

Table 2.5. Mean ± S.D of variables[1] from PDM[2] affected by different diseases (Hyperketonemia[3], Hypocalcaemia[4]and Metritis[5])

	Disease					
Variable[1]	Non Hyperketonemia[6]	Hyperketonemia[3]	Non Hypocalcaemia[7]	Hypocalcaemia[4]	Non metritis[8]	Metritis[5]
Lying time (h)	9.8 ± 1.6	10.9 ± 1.7	8.22 ± 1.0	9.4 ± 1.0	--	--
Milk fat (%)	4.1 ± 0.2	4.4 ± 0.2	4.1 ± 0.1	4.5 ± 0	3.9 ± 0.1	4.4 ± 0.1
BW (parity > 2) (kg)	710 ± 12	750 ± 18	--	--	--	--
Activity (steps)	3685 ± 72	3137 ± 121	2856 ± 1180	2490 ± 1097	2689 ± 1637	2125 ± 1215
Activity (neck)	407 ± 16	359 ± 13	447 ± 15	376 ± 19	--	--
Rumination time (min)	520 ± 40	471 ± 34	531 ± 31	485 ± 37	537 ± 35	473 ± 29
Milk yield (parity > 2) (kg)	37.8 ± 4.3	31.4 ± 3.8	26.3 ± 4.1	22.6 ± 4.0	--	--

[1]Variables, same variables that detected from different technology, in this table would be lying time (AfiAct Pedometer Plus, Track a))) cow, IceQube), milk fat (AfiLab), body weight (AfiWeigh), activity (AfiAct Pedometer Plus, Track a))) cow, IceQube, SmartBow, CowManager SensoOr and HR Tag, SCR), rumination time (SmartBow, CowManager SensoOr and HR Tag, SCR) and milk yield (AfiLab).

[2]Precision dairy monitoring (PDM) technologies included: AfiAct Pedometer Plus, Afimilk, AfiLab, AfiWeigh (Kibbutz Afikim, Israel); Track a))) cow (ENGS System Innovative Dairy Solutions, Israel); IceQube (IceRobotics Ltd., Edinburgh, Scotland); HR Tag, SCR (Engineers Ltd., Netanya, Israel); SmartBow (Smartbow GmbH, Jutogasse, Austria); and CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands).

[3]Hyperketonemia was identified on 3, 7, 14, or 21 DIM by using Precision Xtra (Abbott Laboratories, Chicago, IL, USA) with coccygeal vein blood. N referred to cows without subclinical or clinical hyperketonemia at each DIM.

[4]Hypocalcaemia was identified on 3, 7, 14, or 21 DIM by University of Kentucky Veterinary Diagnostic Laboratory using coccygeal vein blood serum. N referred to cows without subclinical or clinical hypocalcaemia at each DIM.

[5]Metricheck device was used to score vaginal discharge on a scale of 1 to 3 with 1 being no metritis and >1 being metritis (Sterrett et al., 2014).

[6]Non Hyperketonemia was the cows that considered not having hyperketonemia during 1 to 21 DIM.

[7]Non Hypocalcaemia was the cows that considered not having hypocalcaemia during 1 to 21 DIM.

[8]Non Metritis was the cows that considered not having metritis during 1 to 21 DIM.

Figure 2.2. Compare lying/resting time and time not active changed by average all the cows from DIM 1 to DIM 21 with and without hyperketonemia[1] by in MIXED procedure of SAS 9.3.

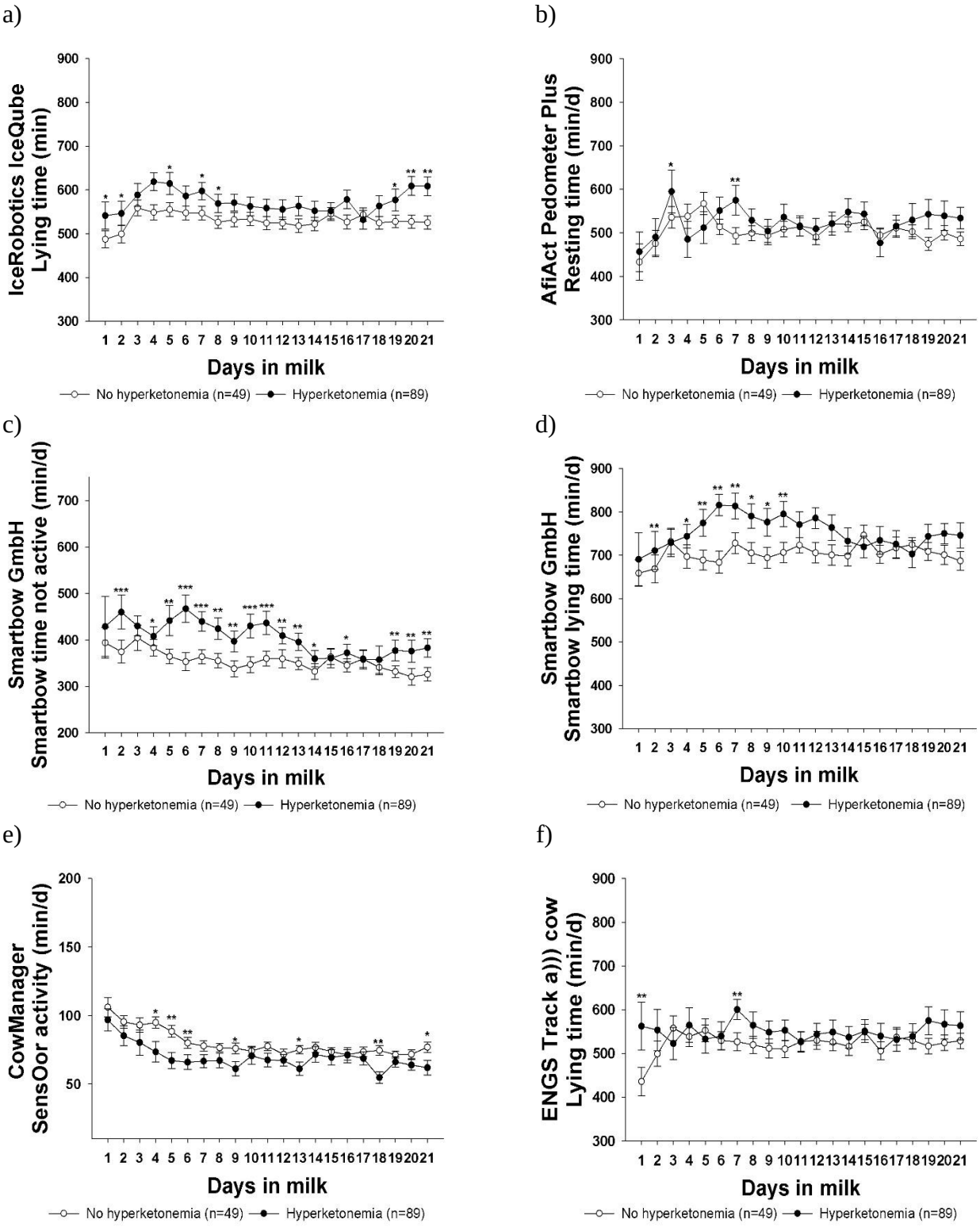
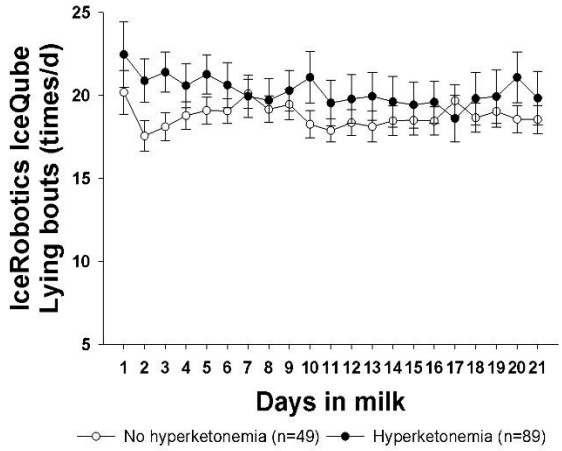


Figure 2.2. (cont.)

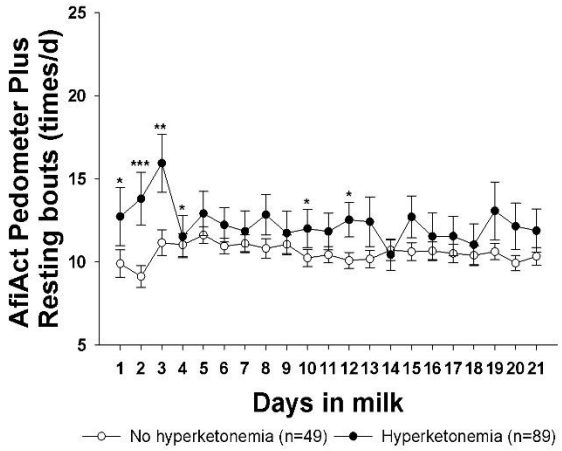
[1]Hyperkeonemia was detected by Precision Xtra (Abbott Laboratories, Chicago, IL, USA) BHBA, when blood BHBA was ≥ 1.2 mmol/L at 3, 7, 14, or 21 DIM.
[2]a) AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel, b) IceQube (IceRobotics Ltd., Edinburgh, Scotland), c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel), d) and e) SmartBow (Smartbow GmbH, Jutogasse, Austria), and f) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands)
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.3. Compare lying /resting bouts changed by average all the cows from DIM 1 to DIM 21 with and without hyperketonemia[1] by in MIXED procedure of SAS 9.3.

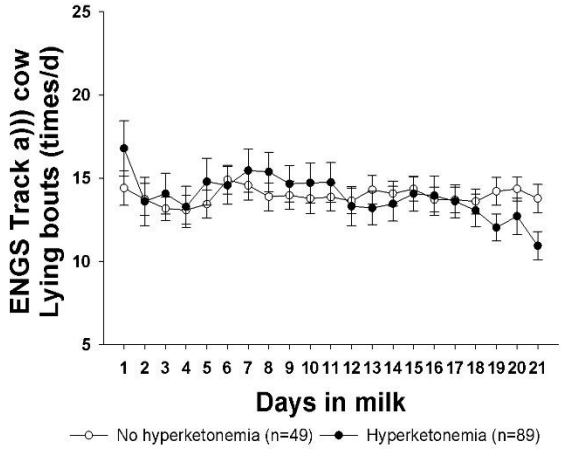
a)



b)



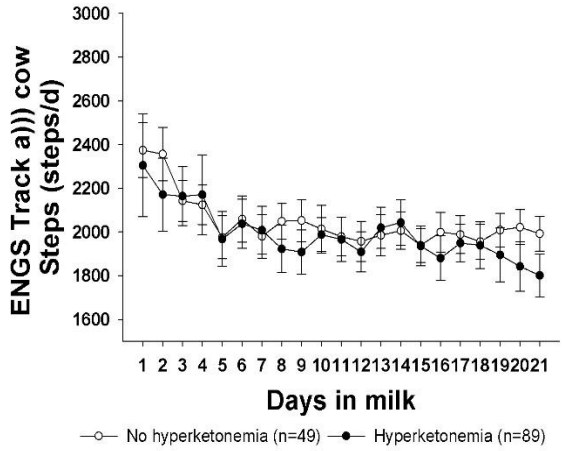
c)



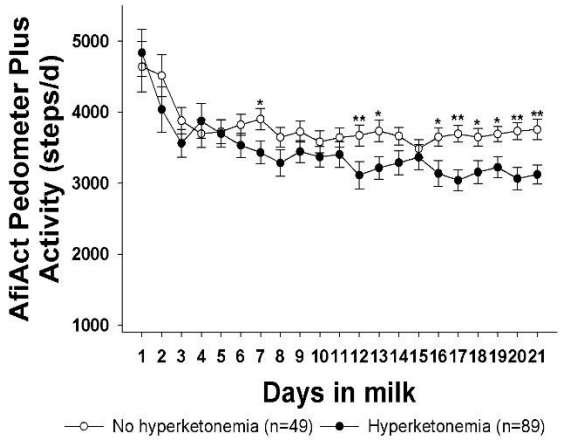
[1]Hyperkeonemia was detected by Precision Xtra (Abbott Laboratories, Chicago, IL, USA) BHBA, when blood BHBA was ≥ 1.2 mmol/L at 3, 7, 14, or 21 DIM.
[2]a) AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), b) IceQube (IceRobotics Ltd., Edinburgh, Scotland), c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel)
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.4. Compare activity/ steps/ motion changed by average all the cows from DIM 1 to DIM 21 with and without hyperketonemia[1] by in MIXED procedure of SAS 9.3.

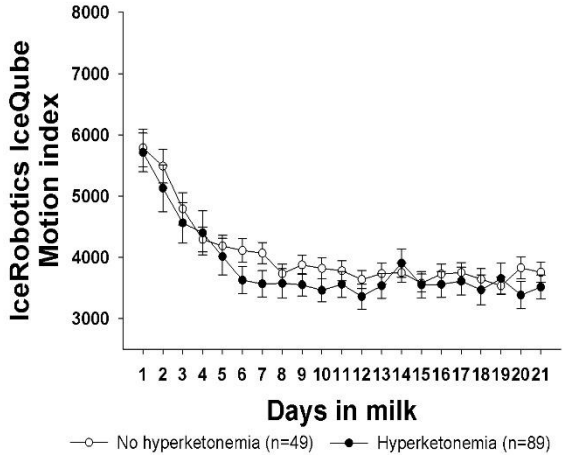
a)



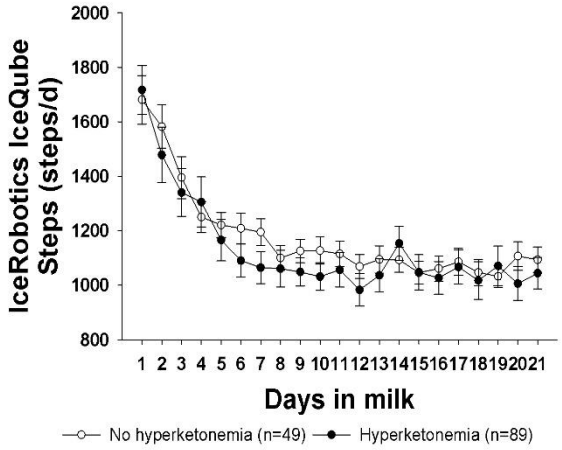
b)



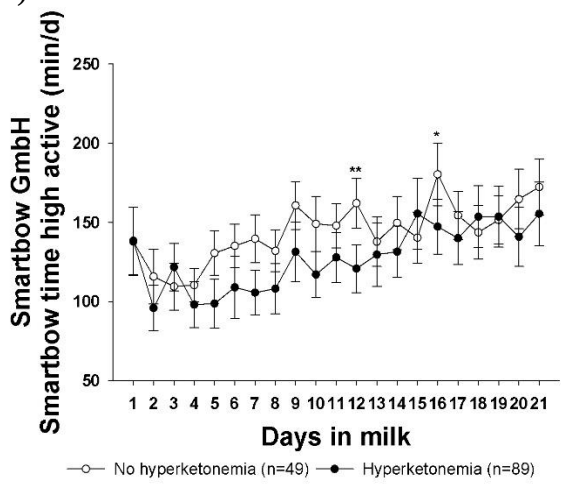
c)



d)



e)



f)

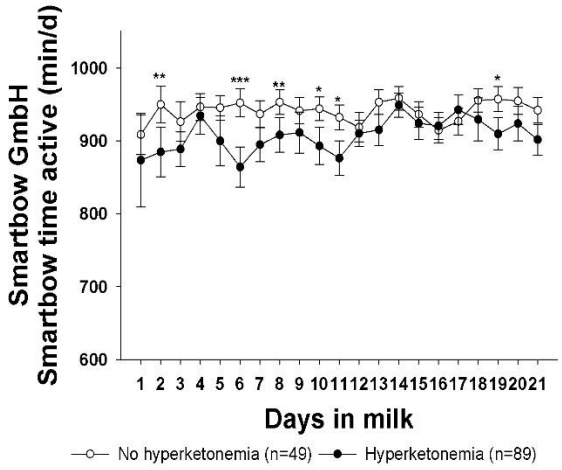
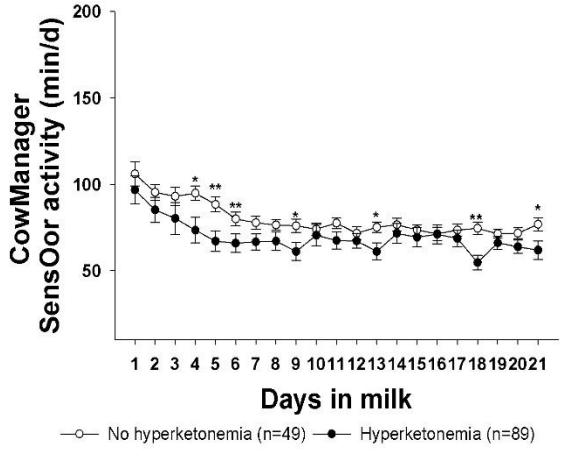
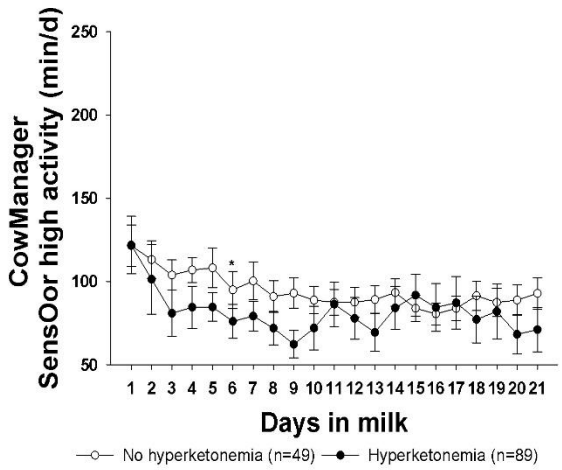


Figure 2.4. (cont.)

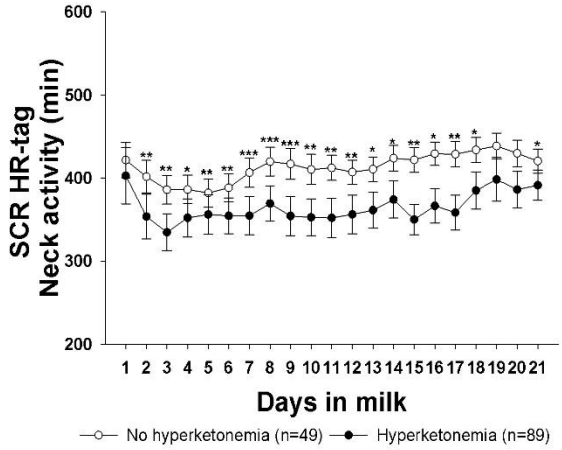
g)



h)



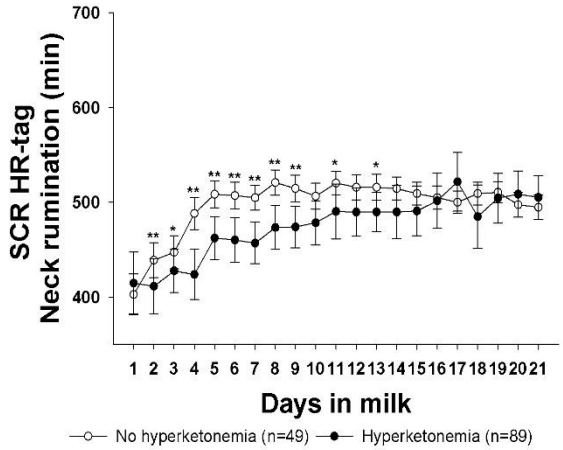
i)



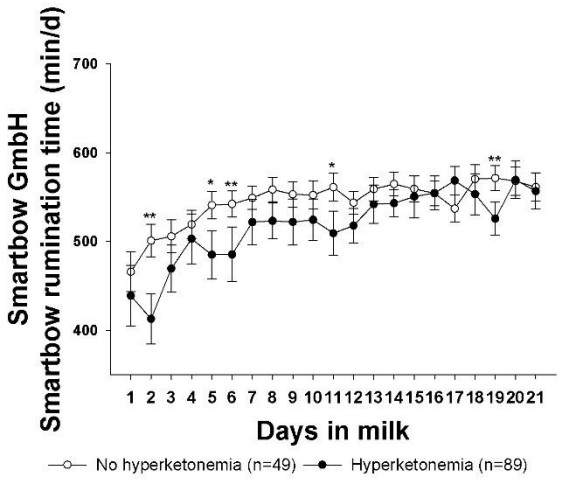
[1]Hyperkeonemia was detected by Precision Xtra (Abbott Laboratories, Chicago, IL, USA) BHBA, when blood BHBA was greater than 1.2 mmol/L at 3, 7, 14, or 21 DIM.
[2]a) AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), b) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel), c) and d) IceQube (IceRobotics Ltd., Edinburgh, Scotland), e) and f) SmartBow (Smartbow GmbH, Jutogasse, Austria), g) and h) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands), i) HR Tag (SCR Engineers Ltd., Netanya, Israel).
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.5. Compare rumination changed by average all the cows from DIM 1 to DIM 21 with and without hyperketonemia[1] by in MIXED procedure of SAS 9.3.

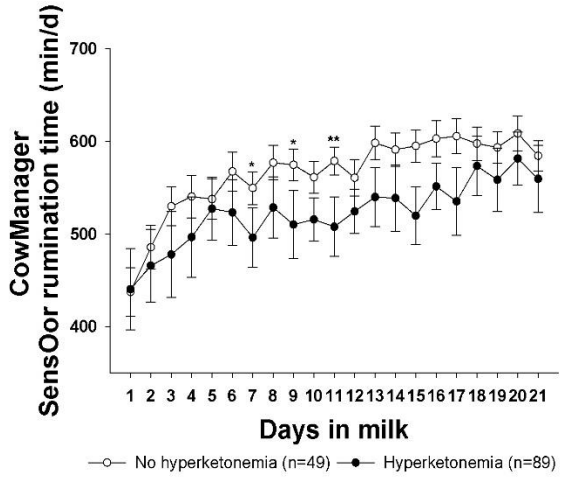
a)



b)



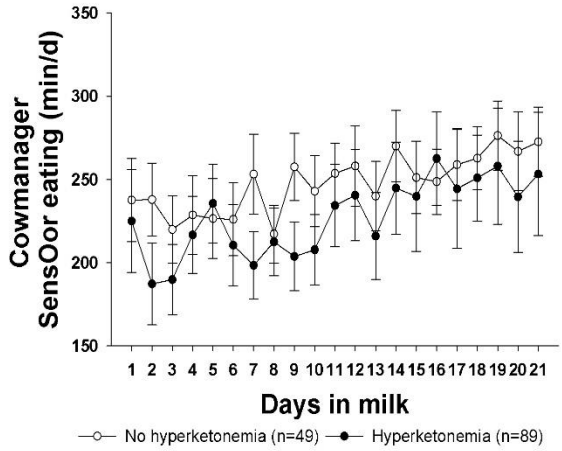
c)



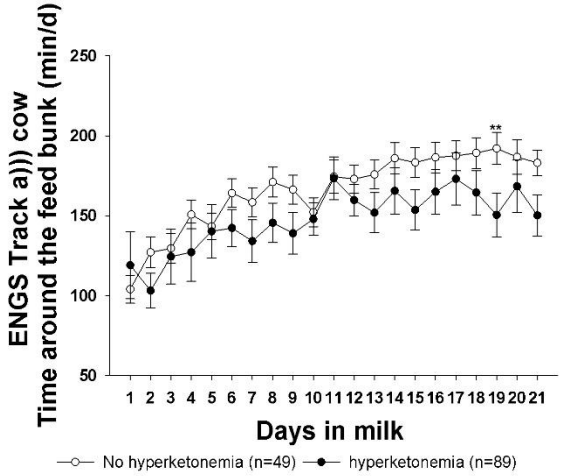
[1]Hyperkeonemia was detected by Precision Xtra (Abbott Laboratories, Chicago, IL, USA) BHBA, when blood BHBA was ≥ 1.2 mmol/L at 3, 7, 14, or 21 DIM.
[2]a) HR Tag (SCR Engineers Ltd., Netanya, Israel), b) SmartBow (Smartbow GmbH, Jutogasse, Austria), c) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands).
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.6. Compare eating time/time around the feed bunk changed by average all the cows from DIM 1 to DIM 21 with and without hyperketonemia[1] by in MIXED procedure of SAS 9.3.

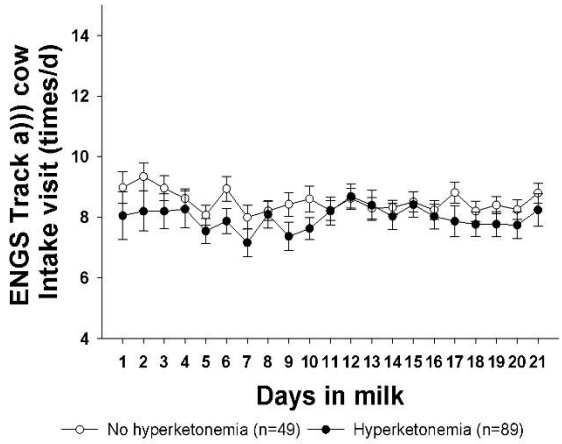
a)



b)



c)



[1]Hyperketonemia was detected by Precision Xtra (Abbott Laboratories, Chicago, IL, USA) BHBA, when blood BHBA was ≥ 1.2 mmol/L at 3, 7, 14, or 21 DIM.
[2]a) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands), b) and c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel)
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.7. Compare milk component changed by average all the cows from DIM 1 to DIM 21 with and without hyperketonemia[1] by in MIXED procedure of SAS 9.3.

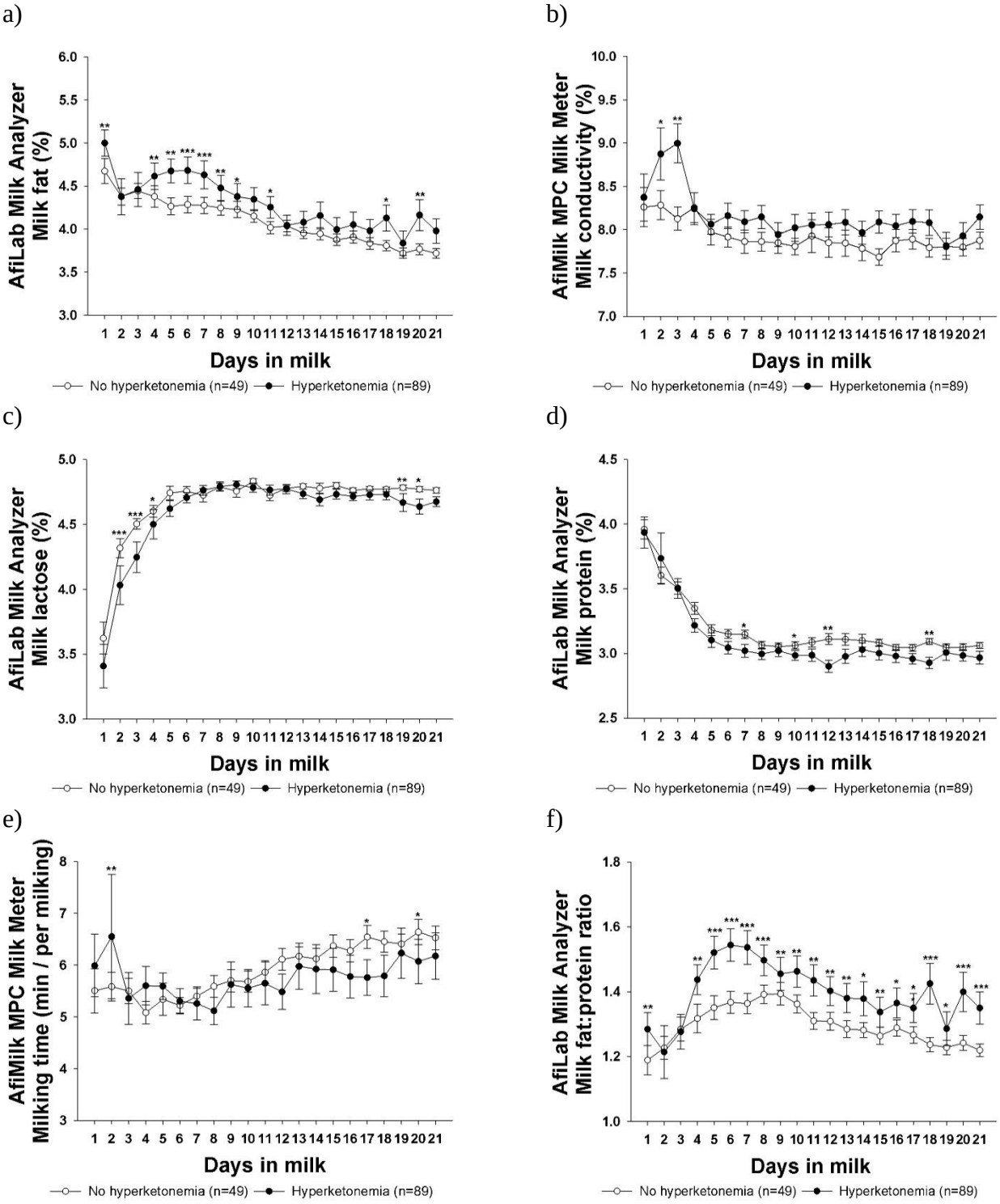
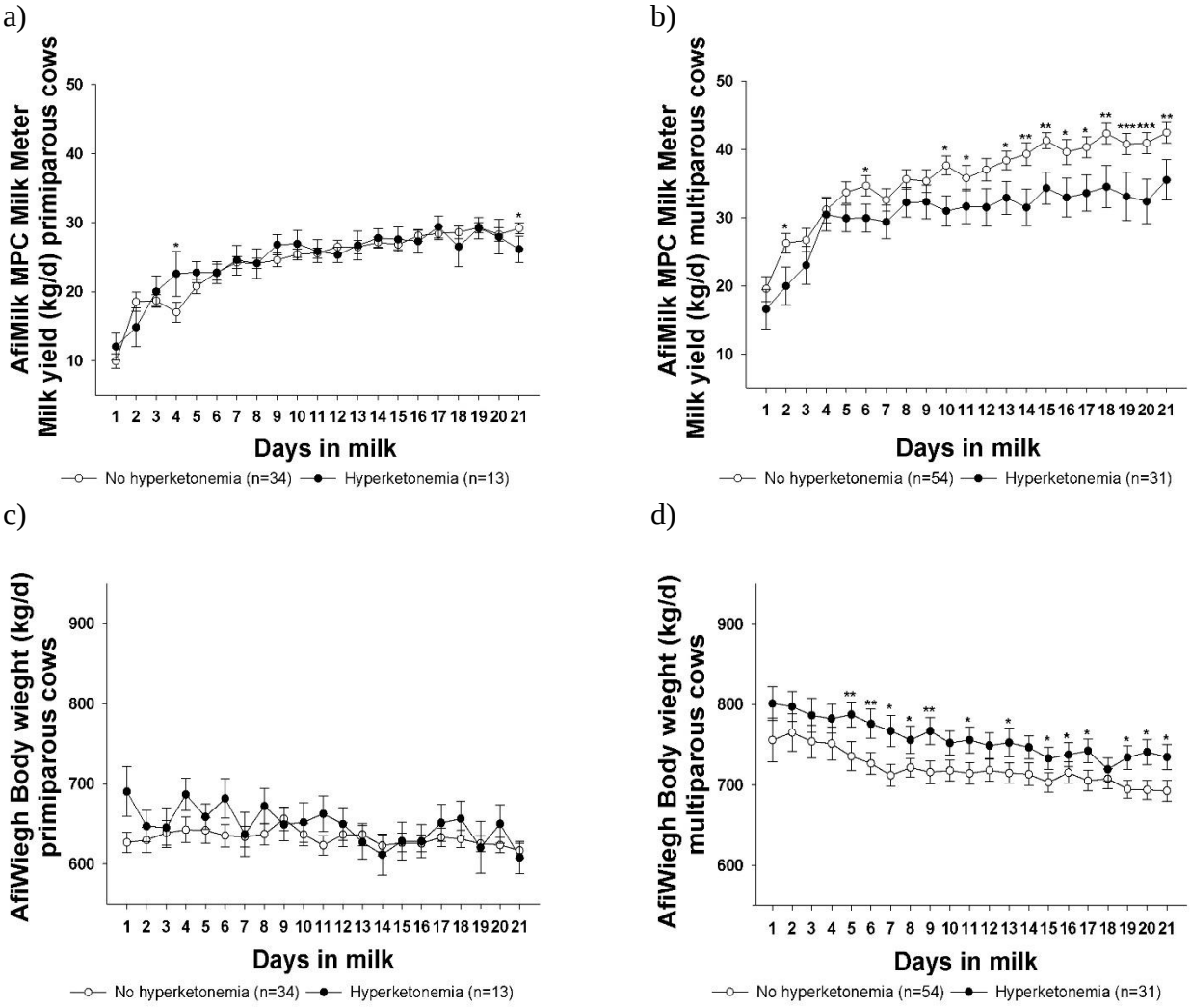


Figure 2.7. (cont.)

[1]Hyperketonemia was detected by Precision Xtra (Abbott Laboratories, Chicago, IL, USA) BHBA, when blood BHBA was ≥ 1.2 mmol/L at 3, 7, 14, or 21 DIM.
[2]AfiLab Milk Analyzer, AfiMilk MPC Milk Meter (Afimilk, Kibbutz Afikim, Israel)
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.8. Compare milk yield / body weight changed by average all the cows from DIM 1 to DIM 21 with and without hyperketonemia[1] by in MIXED procedure of SAS 9.3.



[1]Hyperketonemia was detected by Precision Xtra (Abbott Laboratories, Chicago, IL, USA) BHBA, when blood BHBA was ≥ 1.2 mmol/L at 3, 7, 14, or 21 DIM.
[2] a) and b)AfiLab Milk Analyzer, AfiMilk MPC Milk Meter (Afimilk, Kibbutz Afikim, Israel), c) and d) AfiWeigh (Afimilk, Kibbutz Afikim, Israel).
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.9. Compare lying/resting time and time not active changed by average all the cows from DIM 1 to DIM 21 with and without hypocalcemina[1] by in MIXED procedure of SAS 9.3.

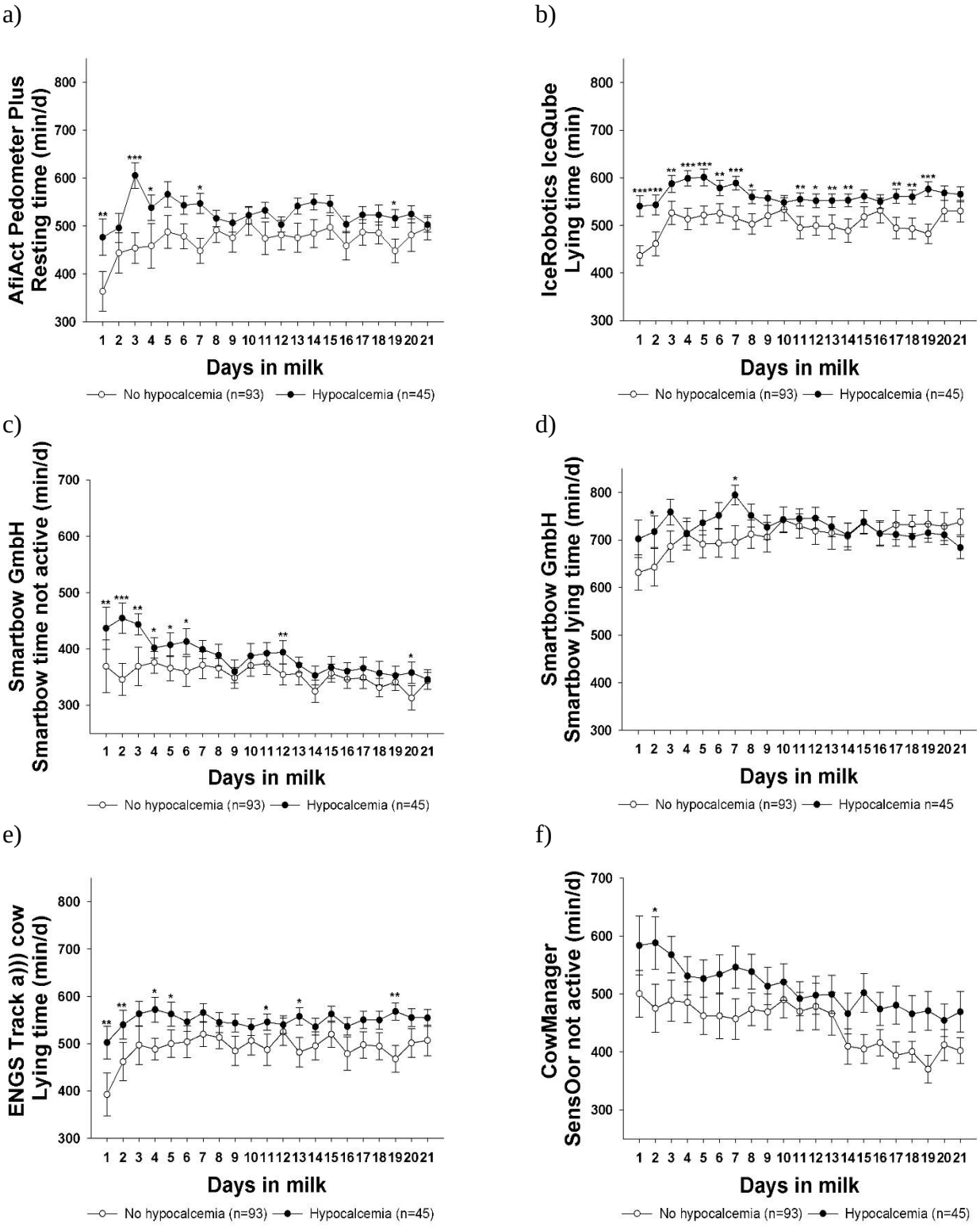
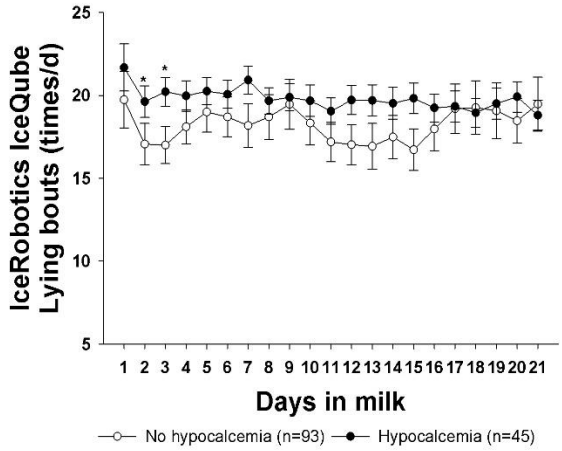


Figure 2.9. (cont.)

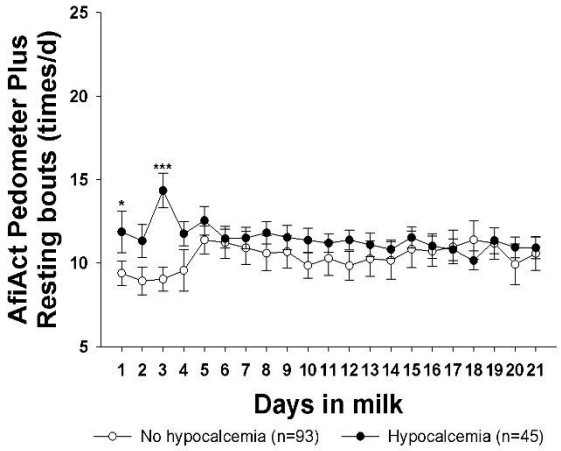
[1]Hypocalcaemia was defined as any blood serum concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[2]a) AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), b) IceQube (IceRobotics Ltd., Edinburgh, Scotland), c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel), d) and e) SmartBow (Smartbow GmbH, Jutogasse, Austria), and f) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands)
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.10. Compare lying/resting bouts changed by average all the cows from DIM 1 to DIM 21 with and without hypocalcemina[1] by in MIXED procedure of SAS 9.3.

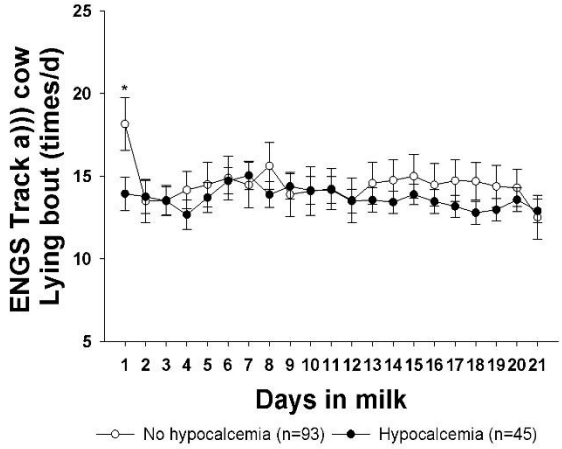
a)



b)



c)



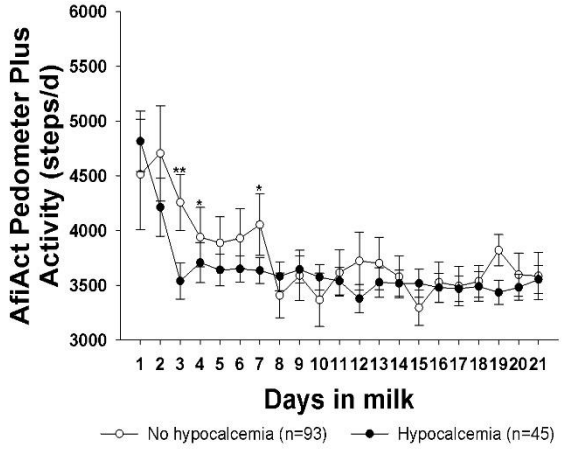
[1]Hyocalcaemia was defined as any blood serum concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[2]a) AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), b) IceQube (IceRobotics Ltd., Edinburgh, Scotland), c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel)

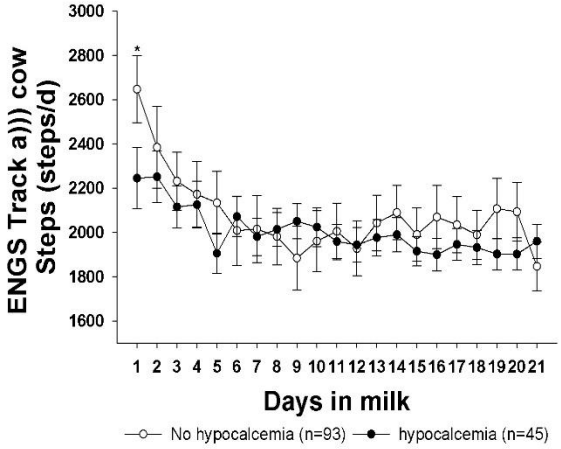
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.11. Compare activity/ steps/ motion changed by average all the cows from DIM 1 to DIM 21 with and without hypocalcemina[1] by in MIXED procedure of SAS 9.3.

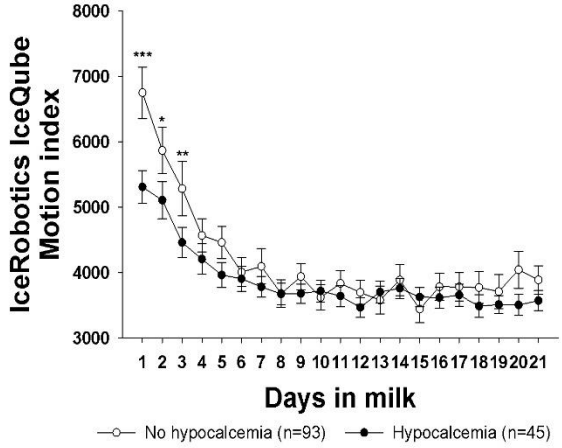
a)



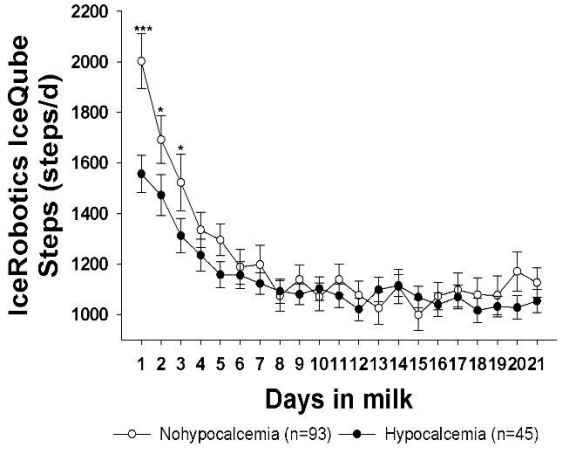
b)



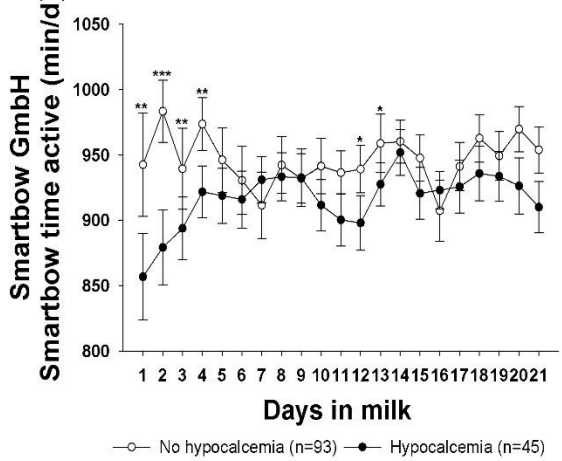
c)



d)



e)



f)

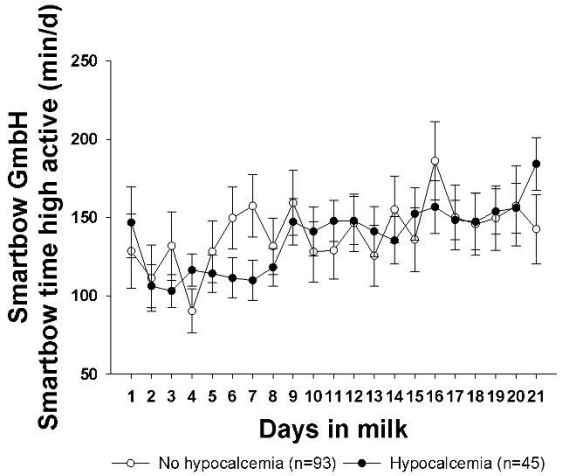
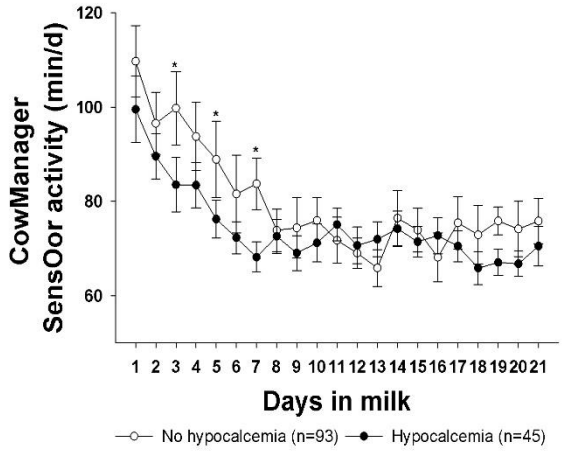
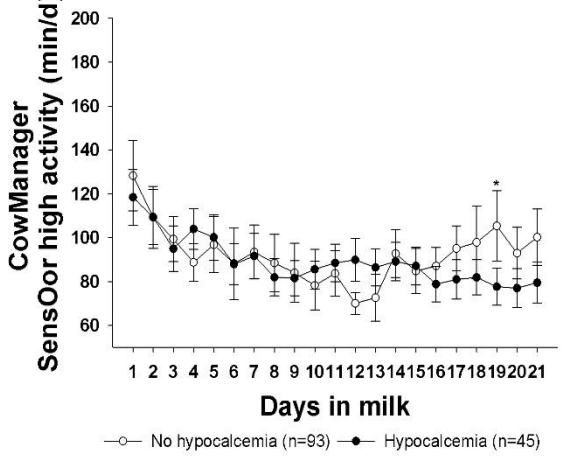


Figure 2.11. (cont.)

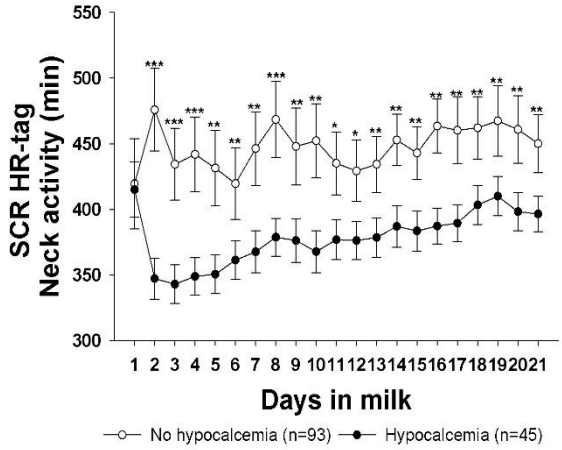
g)



h)



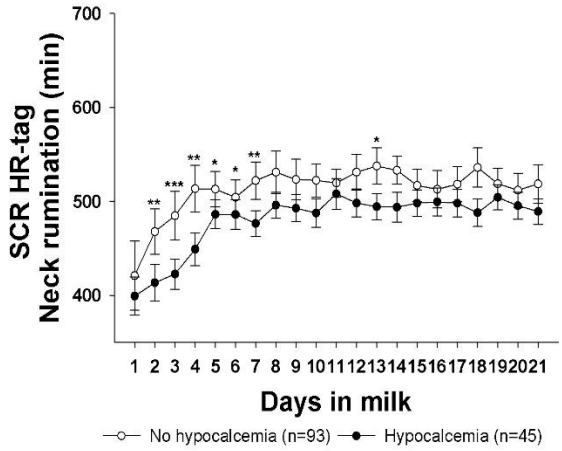
i)



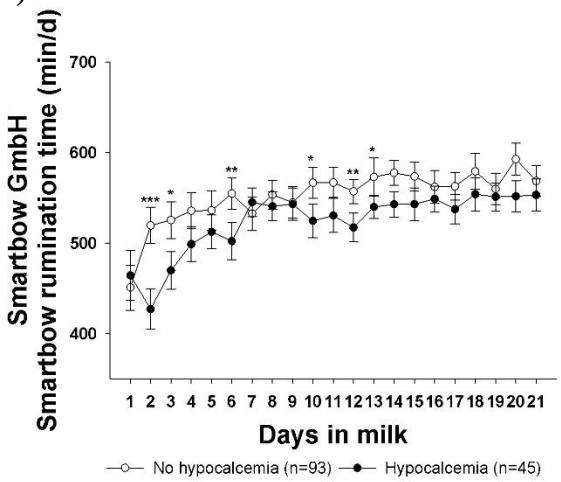
[1]Hypocalcemia was defined as any blood serum concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[2]a) AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), b) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel), c) and d) IceQube (IceRobotics Ltd., Edinburgh, Scotland), e) and f) SmartBow (Smartbow GmbH, Jutogasse, Austria), g) and h) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands), i) HR tag (SCR Engineers Ltd., Netanya, Israel)
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.12. Compare rumination changed by average all the cows from DIM 1 to DIM 21 with and without hypocalcemina[1] by in MIXED procedure of SAS 9.3.

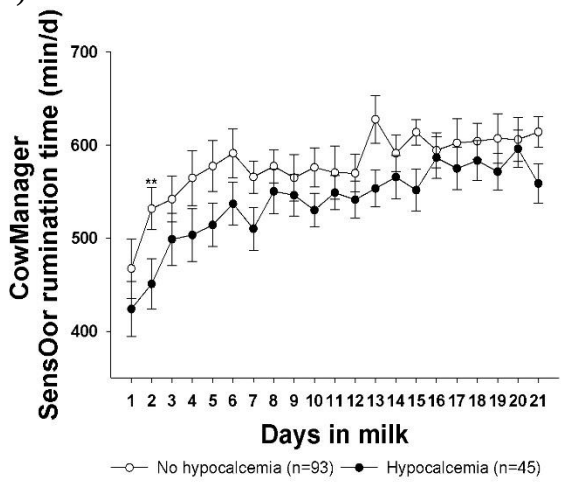
a)



b)



c)



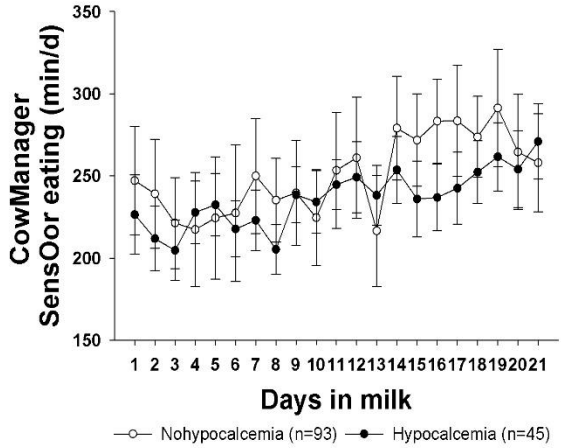
[1]Hypocalcemia was defined as any blood serum concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[2]a) HR tag (SCR Engineers Ltd., Netanya, Israel), b) SmartBow (Smartbow GmbH, Jutogasse, Austria), c) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands)

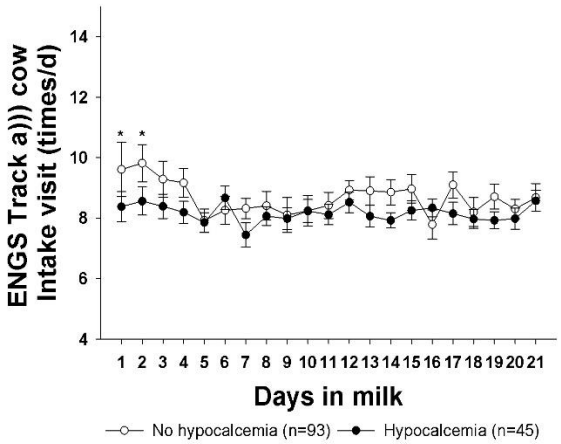
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.13. Compare eating time/ time around the feed bunk changed by average all the cows from DIM 1 to DIM 21 with and without hypocalcemina[1] by in MIXED procedure of SAS 9.3.

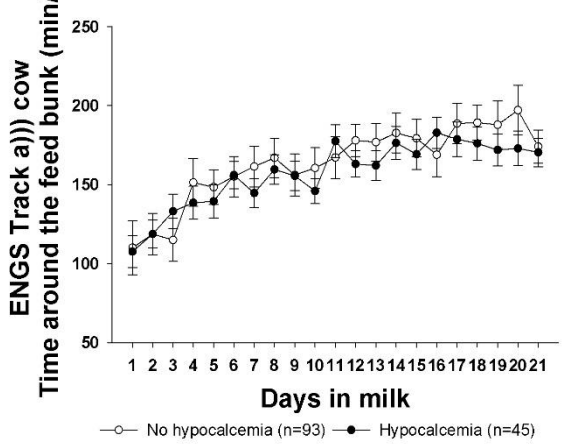
a)



b)



c)



[1]Hypocalcemia was defined as any blood serum concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[2]a) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands), b) and c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel)

[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.14. Compare milk component changed by average all the cows from DIM 1 to DIM 21 with and without hypocalcemina[1] by in MIXED procedure of SAS 9.3.

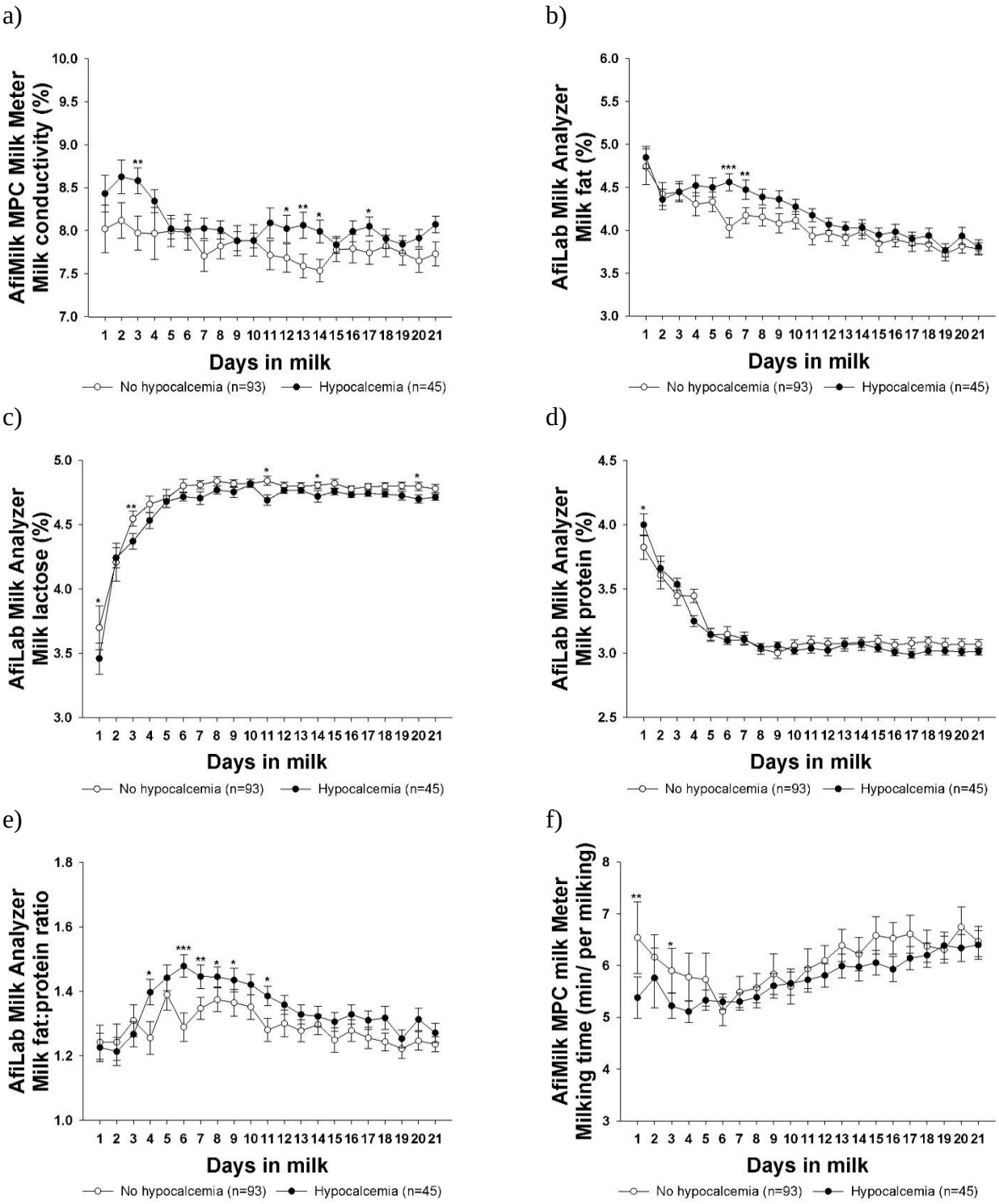
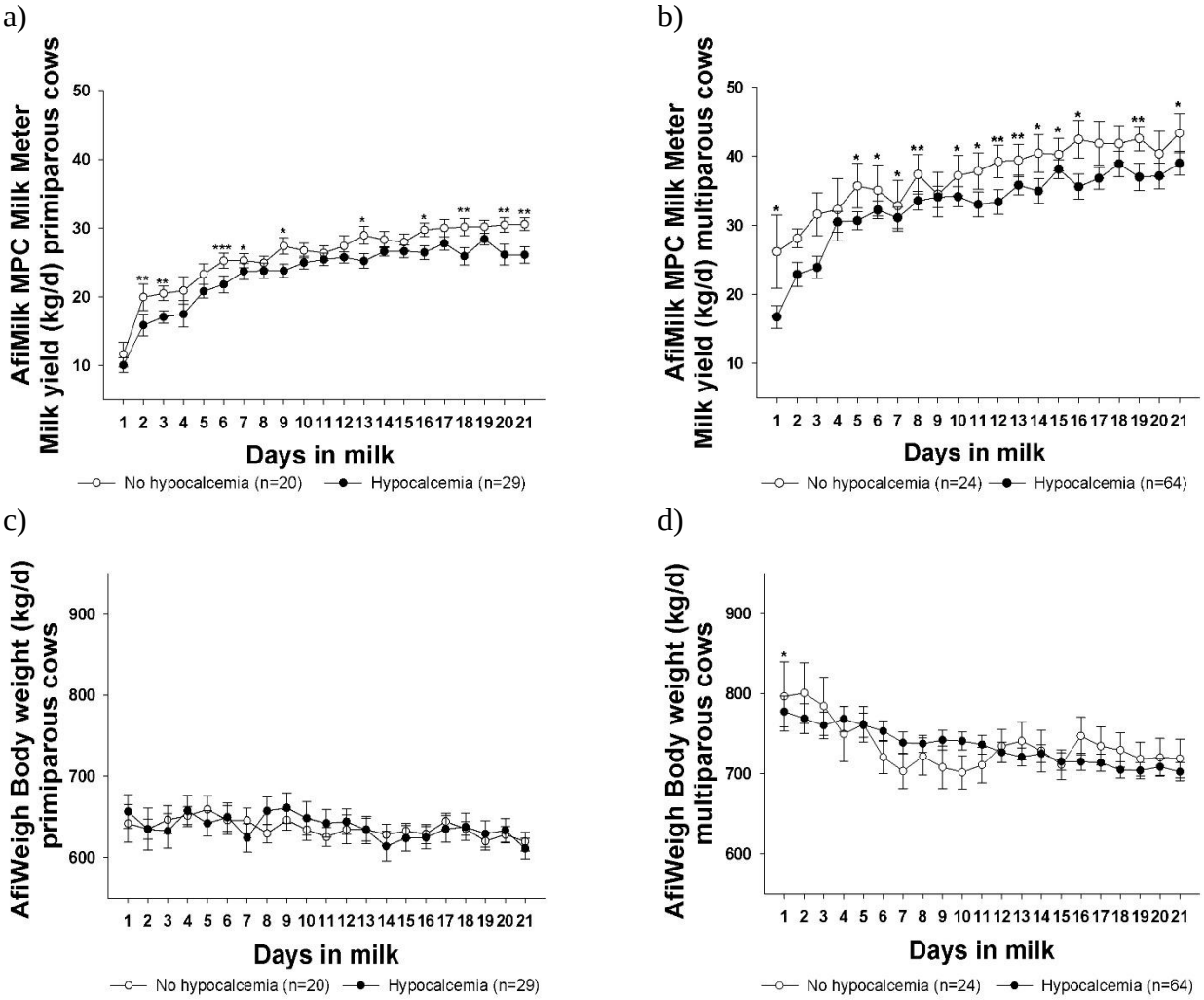


Figure 2.14. (cont.)

[1]Hypocalcemia was defined as any blood serum concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[2]AfiLab Milk Analyzer, AfiMilk MPC Milk Meter (Afimilk, Kibbutz Afikim, Israel)
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.15. Compare milk yield / body weight changed by average all the cows from DIM 1 to DIM 21 with and without hypocalcemina[1] by in MIXED procedure of SAS 9.3.



[1]Hypocalcemia was defined as any blood serum concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[2] a) and b)AfiLab Milk Analyzer, AfiMilk MPC Milk Meter (Afimilk, Kibbutz Afikim, Israel), c) and d) AfiWeigh (Afimilk, Kibbutz Afikim, Israel)

[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.16. Compare lying/resting time and time not active changed by average all the cows from DIM 1 to DIM 21 with and without metritis[1] by in MIXED procedure of SAS 9.3.

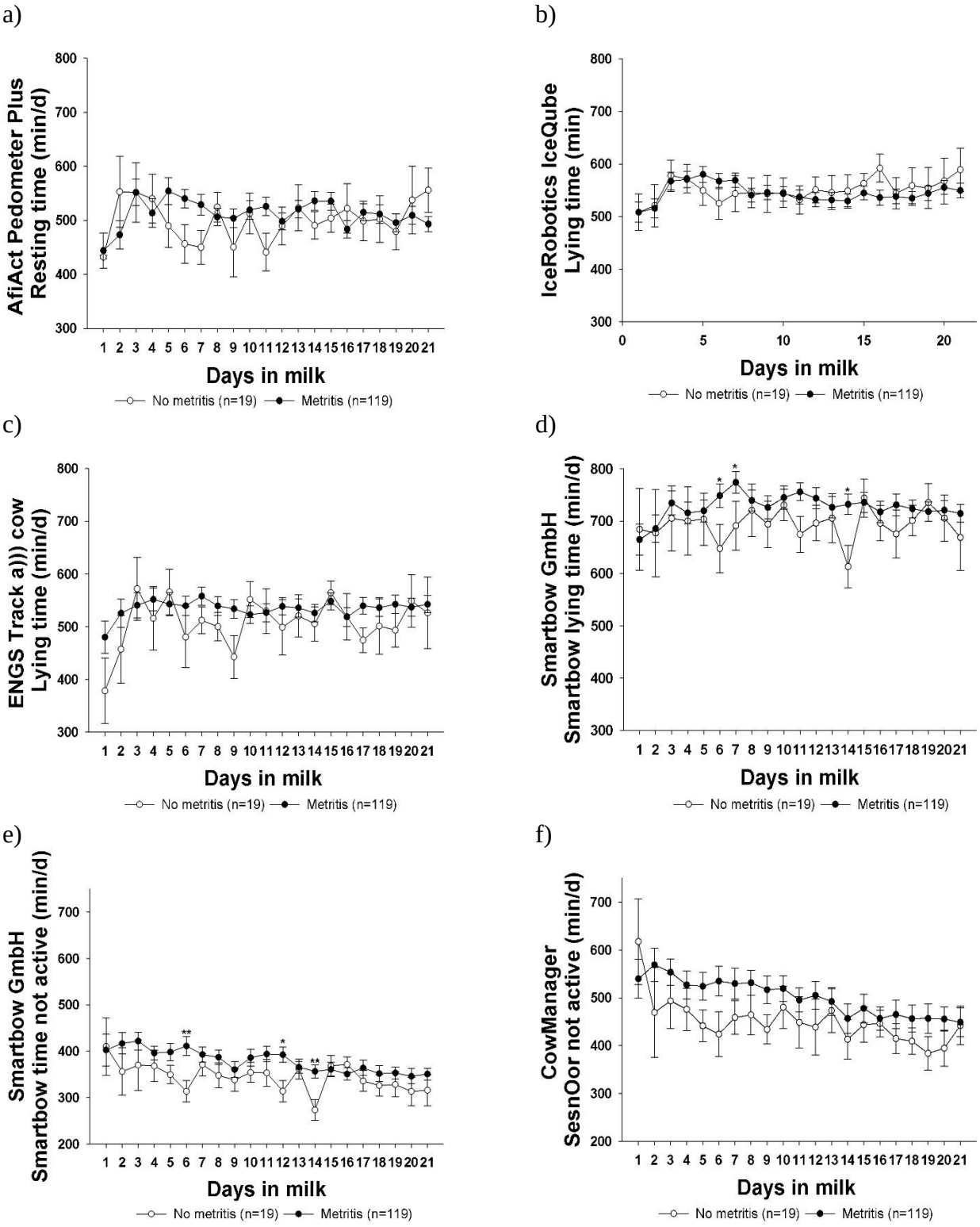
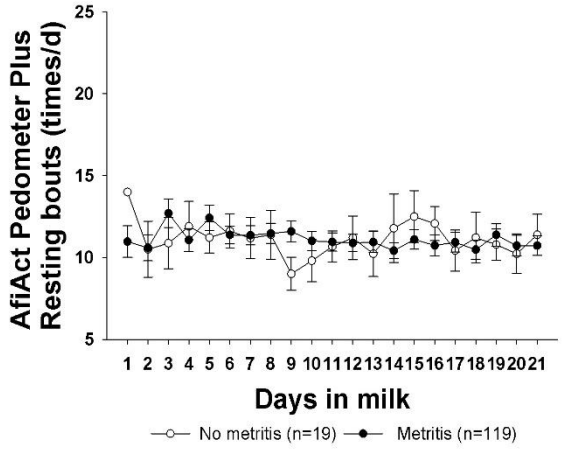


Figure 2.16. (cont.)

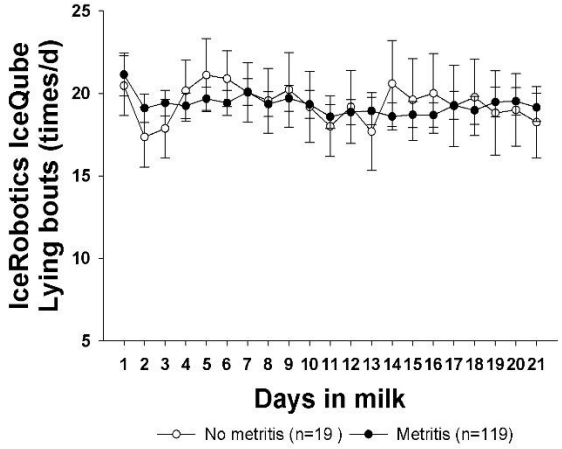
[1]Metritis was diagnosed by vaginal discharge evaluation with the MetriCheck device (Simcro Tech Ltd, Hamilton, New Zealand). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on discharge visual appearance. Score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥ 2 were classified as clinical metritis cases.
[2]a) AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), b) IceQube (IceRobotics Ltd., Edinburgh, Scotland), c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel), d) and e) SmartBow (Smartbow GmbH, Jutogasse, Austria), and f) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands).
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.17. Compare lying/resting bouts changed by average all the cows from DIM 1 to DIM 21 with and without metritis[1] by in MIXED procedure of SAS 9.3.

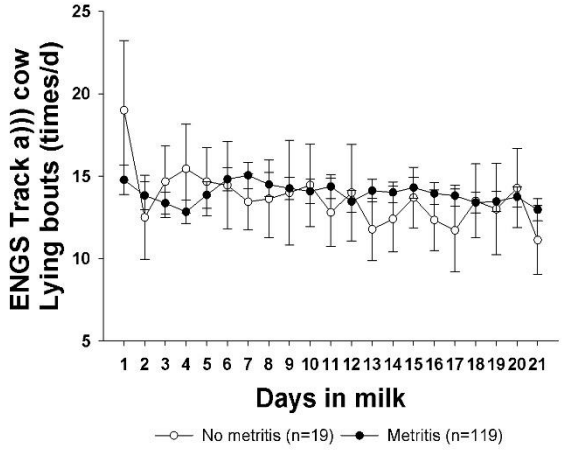
a)



b)



c)



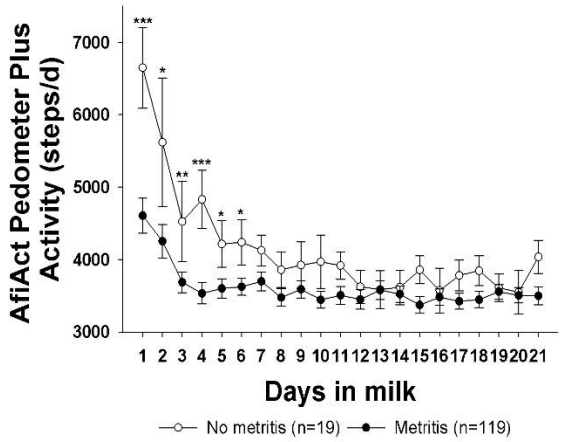
[1] Metritis was diagnosed by vaginal discharge evaluation with the MetriCheck device (Simcro Tech Ltd, Hamilton, New Zealand). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on discharge visual appearance. Score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥ 2 were classified as clinical metritis cases.

[2]a) AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), b) IceQube (IceRobotics Ltd., Edinburgh, Scotland), c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel)

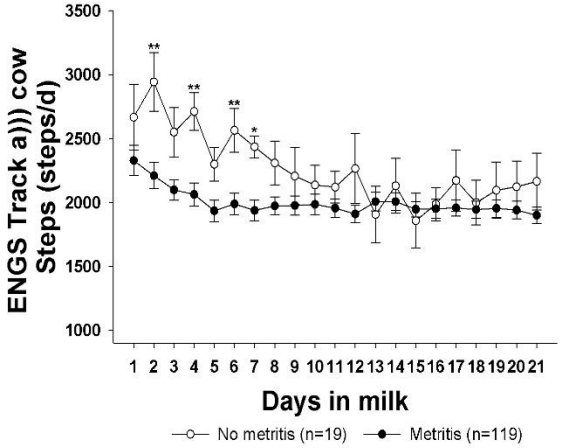
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.18. Compare activity/ steps/ motion changed by average all the cows from DIM 1 to DIM 21 with and without metritis[1] by in MIXED procedure of SAS 9.3.

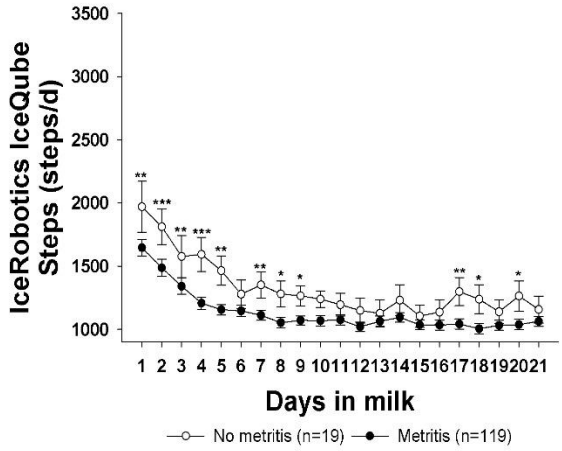
a)



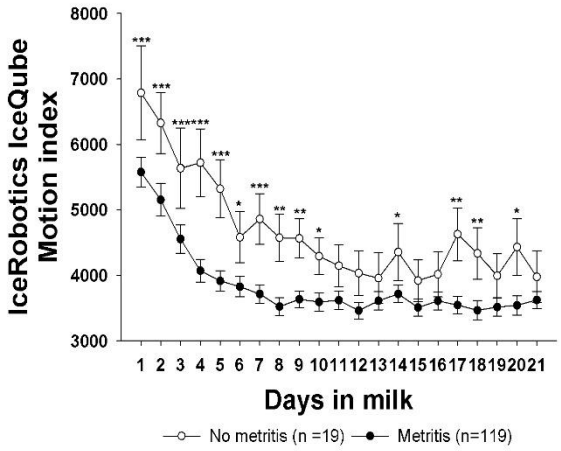
b)



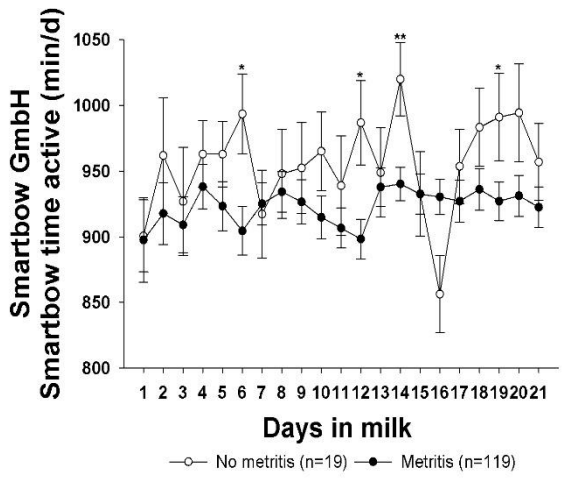
c)



d)



e)



f)

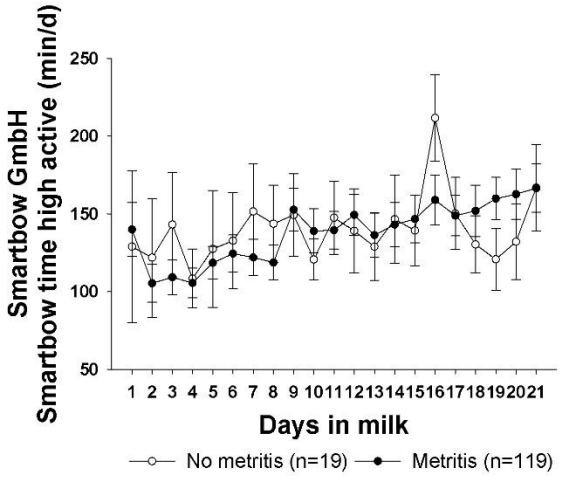
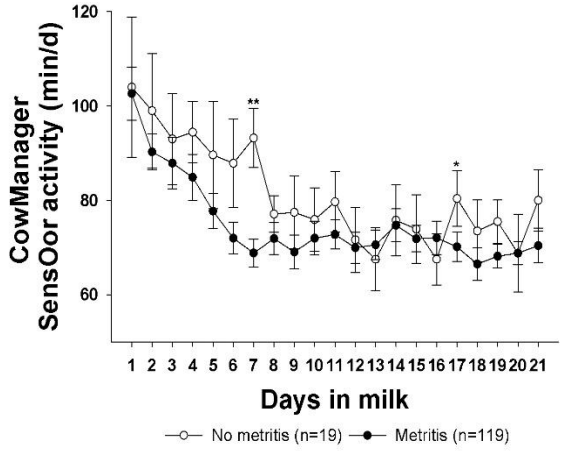
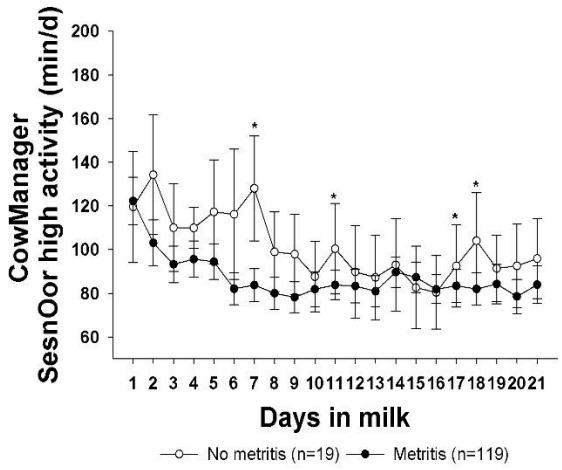


Figure 2.18. (cont.)

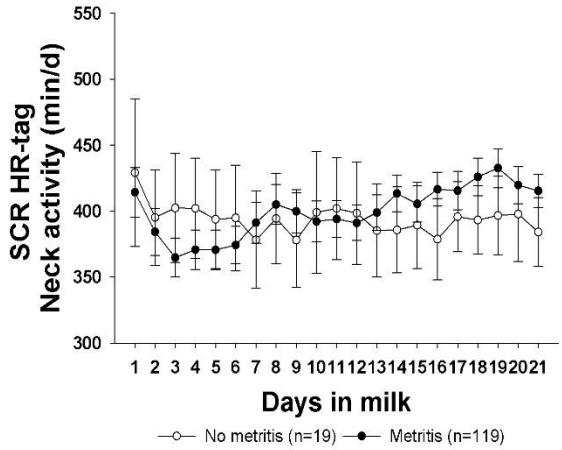
g)



h)



i)



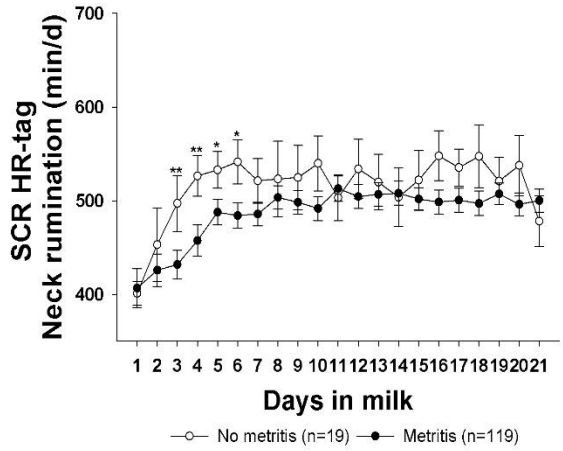
[1]Metritis was diagnosed by vaginal discharge evaluation with the MetriCheck device (Simcro Tech Ltd, Hamilton, New Zealand). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on discharge visual appearance. Score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥ 2 were classified as clinical metritis cases.

[2]AfiAct Pedometer Plus (Afimilk, Kibbutz Afikim, Israel), b) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel), c) and d) IceQube (IceRobotics Ltd., Edinburgh, Scotland), e) and f) SmartBow (Smartbow GmbH, Jutogasse, Austria), g) and h) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands), i) HR tag (SCR Engineers Ltd., Netanya, Israel)

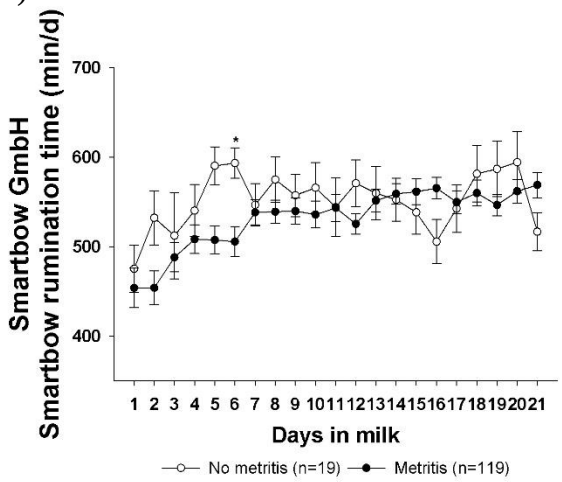
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.19. Compare rumination changed by average all the cows from DIM 1 to DIM 21 with and without metritis[1] by in MIXED procedure of SAS 9.3.

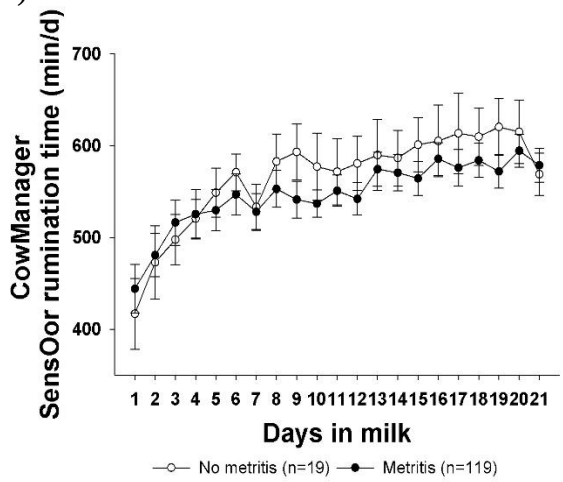
a)



b)



c)



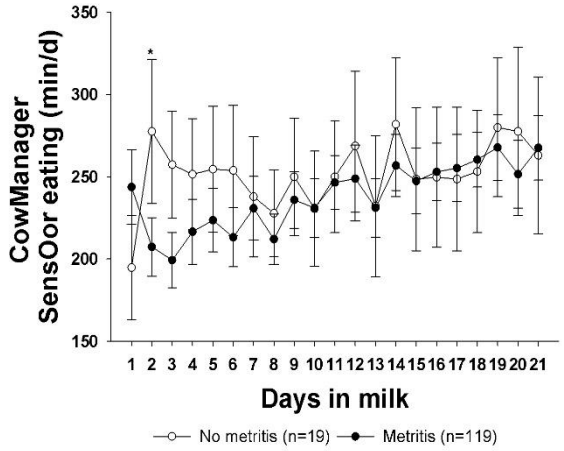
[1]Metritis was diagnosed by vaginal discharge evaluation with the MetriCheck device (Simcro Tech Ltd, Hamilton, New Zealand). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on discharge visual appearance. Score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥ 2 were classified as clinical metritis cases.

[2]a) HR tag (SCR Engineers Ltd., Netanya, Israel), b) SmartBow (Smartbow GmbH, Jutogasse, Austria), c) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands)

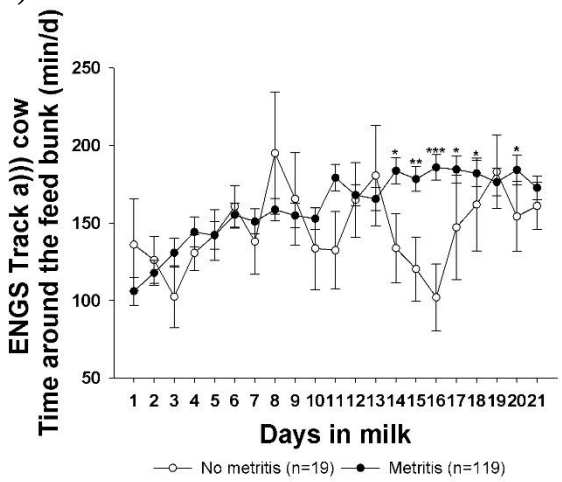
[3]† $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.20. Compare eating time/ time around the feed bunk changed by average all the cows from DIM 1 to DIM 21 with and without metritis[1] by in MIXED procedure of SAS 9.3.

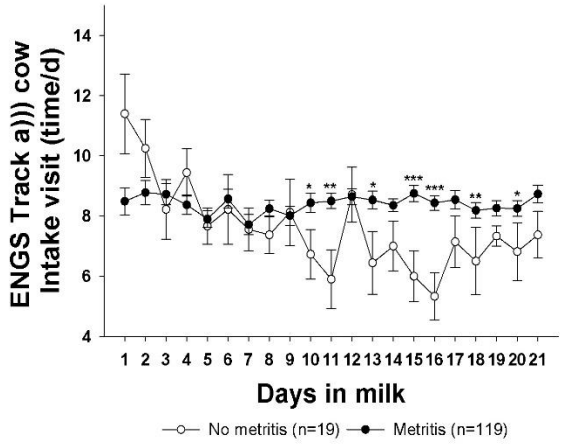
a)



b)



c)



[1]Metritis was diagnosed by vaginal discharge evaluation with the MetriCheck device (Simcro Tech Ltd, Hamilton, New Zealand). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on discharge visual appearance. Score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥ 2 were classified as clinical metritis cases.

[2]a) CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands), b) and c) Track a))) cow (ENGS System Innovative Dairy Solutions, Israel)

[3]† $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.21. Compare milk component changed by average all the cows from DIM 1 to DIM 21 with and without metritis[1] by in MIXED procedure of SAS 9.3.

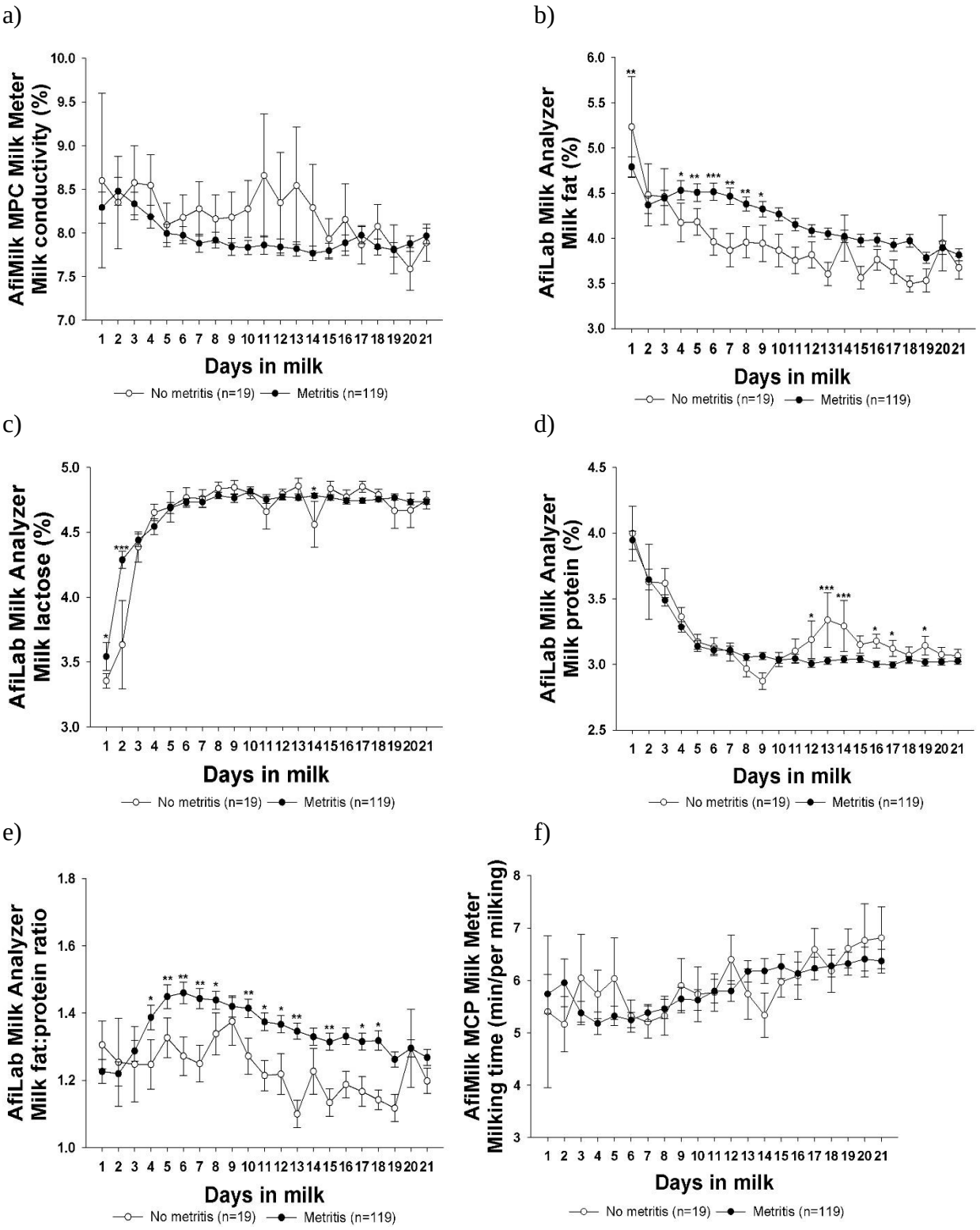
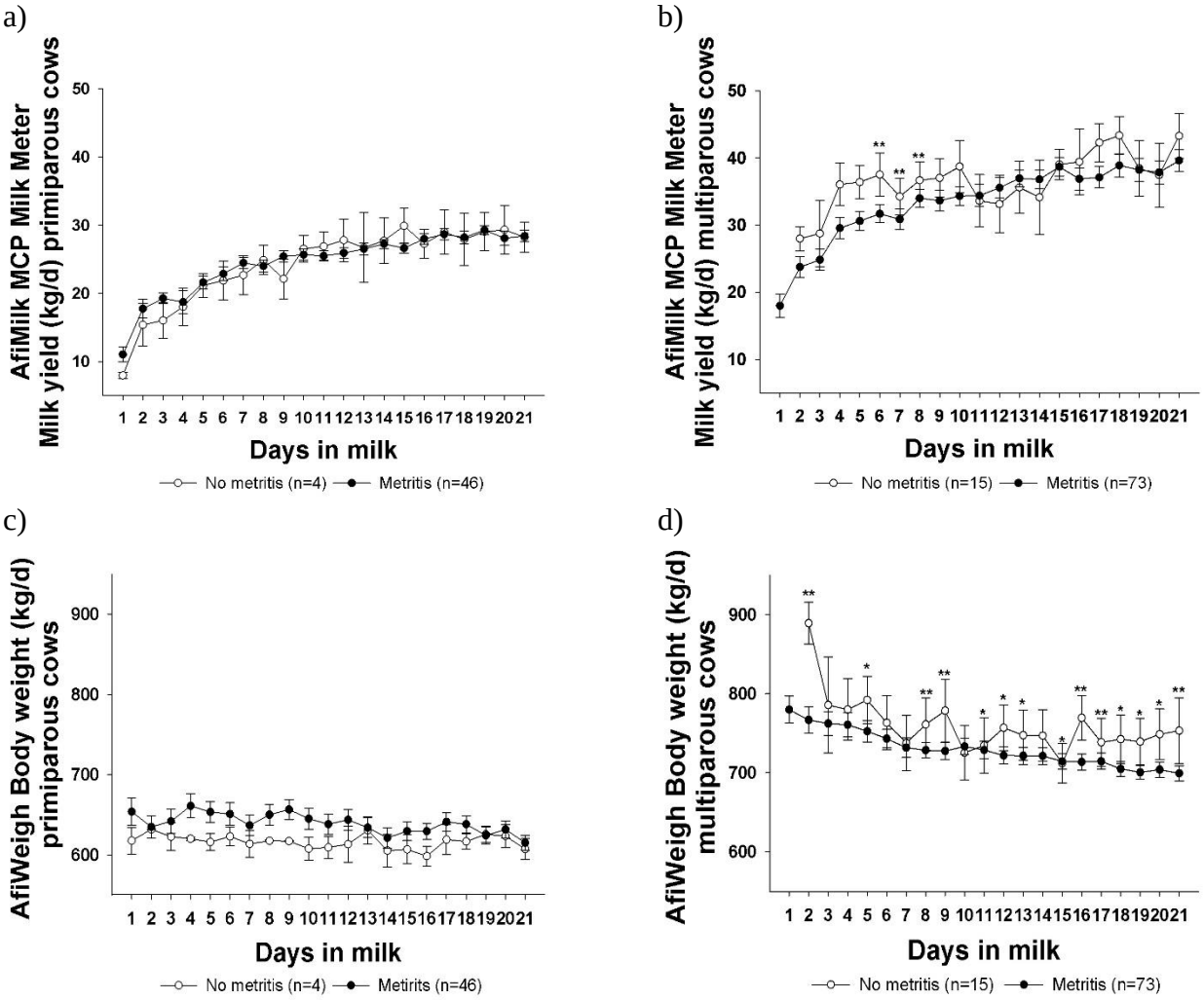


Figure 2.21. (cont.)

[1]Metritis was diagnosed by vaginal discharge evaluation with the MetriCheck device (Simcro Tech Ltd, Hamilton, New Zealand). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on discharge visual appearance. Score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥ 2 were classified as clinical metritis cases.
[2]AfiLab Milk Analyzer, AfiMilk MPC Milk Meter (Afimilk, Kibbutz Afikim, Israel)
[3]† $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.22. Compare milk yield / body weight changed by average all the cows from DIM 1 to DIM 21 with and without metritis[1] by in MIXED procedure of SAS 9.3.



[1]Metritis was diagnosed by vaginal discharge evaluation with the MetriCheck device (Simcro Tech Ltd, Hamilton, New Zealand). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on discharge visual appearance. Score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥ 2 were classified as clinical metritis cases.

[2] a) and b)AfiLab Milk Analyzer, AfiMilk MPC Milk Meter (Afimilk, Kibbutz Afikim, Israel), c) and d) AfiWeigh (Afimilk, Kibbutz Afikim, Israel)

[3]† $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.23. Overall disease incidence for 138 transition cows from Jane 2014 to October 2015 in relation to a) blood serum cholesterol concentration (mmol/L), b) blood serum non-esterified fatty acid (NEFA) concentration (mmol/L), c) milk β-hydroxybutyrate (BHBA; Porta BHB strip score[1]) concentration, and d) milk haptoglobin concentration (mmol/L).

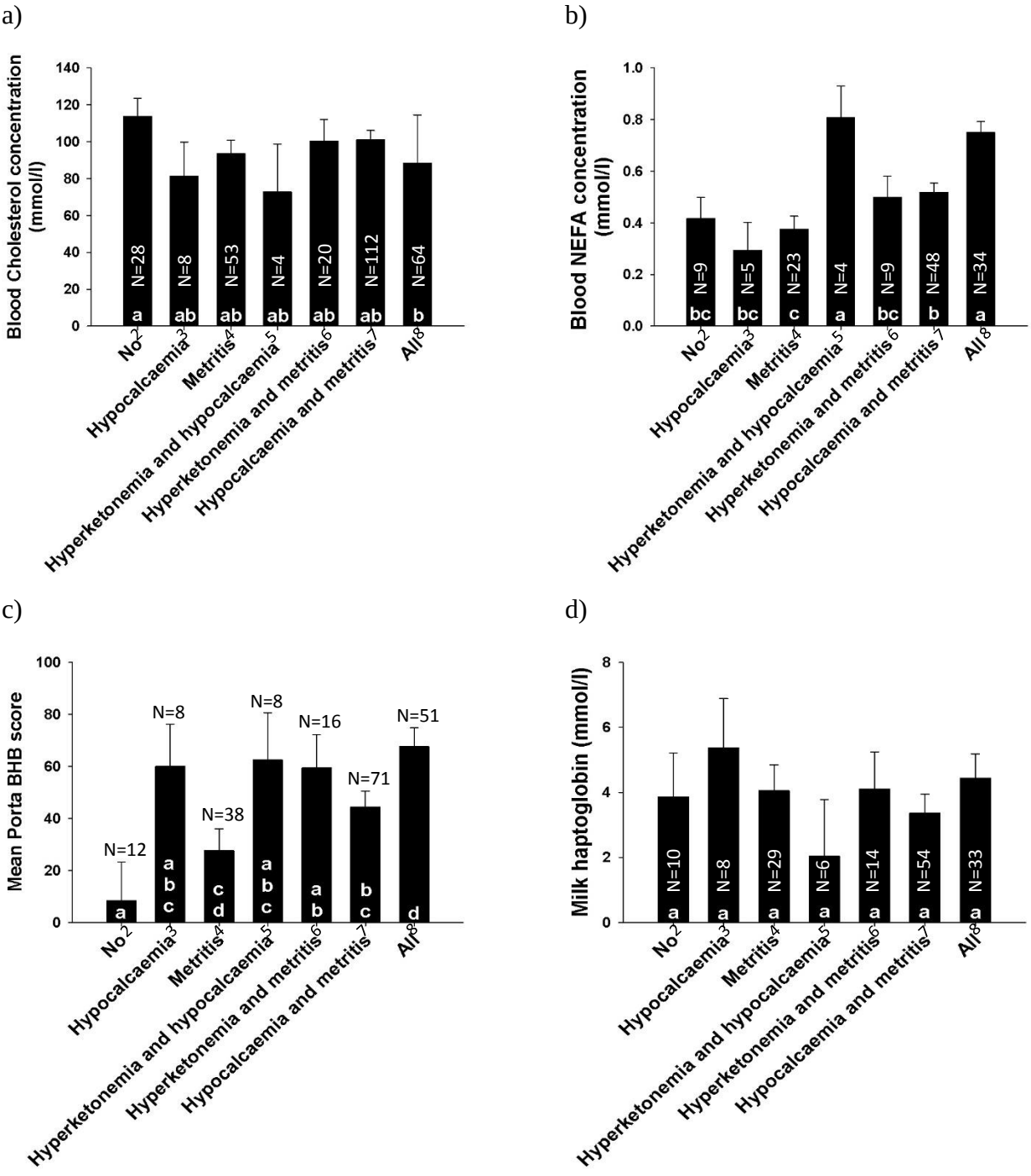


Figure 2.23. (cont.)

[1]Porta BHB strip score: The semi-quantitative dipstick changed color after one drop of milk was added, and compared the result with the color chart. The level of BHB concentration in milk is separated into four catalogs, normal (-) 0-99 μmol/L, questionable (+/-) 100 to199 μmol/L, positive (+) 200 to 499 μmol/L, and positive (++) 500+ μmol/L.
[2]No, cows during 21 DIM were diagnosed without any diseases.
[3]Hypocalcaemia, referred to the cows with hypocalcaemia.
[4]Metritis, referred to the cows with metritis.
[5]Hyperketonemia and hypocalcaemia referred to the cows with hyperketonemia and hypocalcaemia.
[6]Hyperketonemia and metritis referred to the cows with hyperketonemia and metritis.
[7] Hypocalcaemia and metritis referred to the cows with hypocalcaemia and metritis.
[8]All referred to cows with all three all three possible types of diseases (hyperketonemia, hypocalcaemia, and metritis).

CHAPTER THREE

Postpartum disease detection potential using precision dairy monitoring technologies

I.C. Tsai[*], L.M. Mayo[*], B.W. Jones[*], A.E. Stone[*], D.L. Ray[*], J.D. Clark[*], H.M. White[†], S.A. Janse[‡], Y.M. Chang[§], and J.M. Bewley[*]

[*]University of Kentucky, Lexington, Kentucky 40546, Department of Animal and Food Sciences

[†]University of Wisconsin-Madison Department of Dairy Science

[‡]Department of Statistics, University of Kentucky, Lexington, 40546

[§]Research Support Office, The Royal Veterinary College, London, United Kingdom

ABSTRACT

Precision dairy monitoring (**PDM**) technologies are used to measure physiological or behavioral, and production variables on individual animals to improve management strategies and farm performance (Bewley, 2010). Seven different commercial PDM devices were used to monitor cows from 1 to 21 DIM. The UNIVARIATE and GENMOD procedures of SAS 9.3 (SAS Inc., Raleigh, NC) were used and compared the 5d (**5D**) moving range of actual disease occurrence (metritis, hyperketonemia, and hypocalcemia) with the alert that analysis generated from PDM variable changes. Three metabolic diseases (metritis, hyperketonemia, and hypocalcemia) and the combination of the three diseases (**DIS**) were covered in this study. An odds ratios analysis of developing transition cow diseases was also included in this study. Base on one standard deviation (**SD**) different from the whole herd as the unit. Overall disease detection performance varied by PDM technology, ranging from 62 to 90% sensitivity, 66 to 85% specificity, and 73 to 83% accuracy. The 5D moving range combined with each PDM improved sensitivity, specificity, and accuracy compared to other PDM studies (Stangaferro et al., 2016b). One SD increase in milk fat: protein (0.2) increased the odds of developing DIS by 1.48 to 1.75 ($P < 0.01$). If lying time increased one SD (137 to 164 min/d), the odds of developing DIS increased by 1.27 to 1.32 ($P < 0.01$). One SD decrease in rumination time (96 to 110 unit/d) increased the odds of developing DIS by 1.38 to 1.54 ($P < 0.01$). These results demonstrate the possibility of detecting disorders by monitoring physical activity, eating behavior, and temperature. Incorporating PDM into a management system could be a useful tool for identifying cows with metabolic disorders, and increasing producer's profitability and animal's well-being.

Keywords: Precision dairy monitoring (PDM), transition cow disease, sensitivity

INTRODUCTION

The transition period is defined as the three weeks before and after calving. Transition cow diseases are considered to be production diseases. Metabolic disease, a specific type of production disease, reflects cows' inability to maintain metabolic demands. Insufficient energy supply increases the incidence rate of metabolic diseases such as milk fever, endometritis, ketosis, displaced abomasum, and retained placenta (Drackley, 1999, Duffield, 2000). Around 30% to 50% of dairy cows developed metabolic diseases or infections around calving (LeBlanc, 2010). McArt et al. (2012a) showed the incidence rate of subclinical hyperketonemia was between 26 to 56% (Drackley et al., 2001, Gilbert et al., 2005, Ingvartsen, 2006), and the cost was $67 per case. Lean et al. (2006) indicated that the mean incidence of hypocalcemia was 21% and the cost was $335 per case (Liang, 2013). Sheldon and Dobson (2004) pointed out that dairy cows had a 10 to 20% chance of developing metritis after calving, and the cost ranged from $146 to $176 per case (Mahnani et al., 2015). Thus, closely monitoring cows during this critical period is imperative to cow longevity. Systematic observations could provide accurate and efficient early detection for hyperketonemia, hypocalcemia, and metritis.

Precision dairy monitoring (**PDM**) technologies measure physiological, behavioral, production variables on individual animals which can help dairy farmers improve management strategies and overall efficiency (Bewley, 2010). With PDM, producers could improve farm performance, management, efficiency (El-Osta and Morehart, 2000), and reduce labor and costs. This is especially true in the large dairy operations, where producers could save 29% on labor (De Koning, 2010). Recently, technologies have been improved, thus monitoring systems could measure more variables than systems on the market than in the past. Variables included: daily milk yield, step number, temperature, milk electrical conductivity, milk color sensors (Grummer,

1995), accelerometer sensors (Bertics et al., 1992, Rukkwamsuk et al., 1999, Sato et al., 1999), rumen pH (Adewuyi et al., 2005), and body weight which could help producers monitor individual cows (Bewley, 2010).

Behavior monitoring with PDM of dairy cows has been used to understand health status, management, and cows' welfare (Mattachini et al., 2013). Changes in standing and lying behavior could also be useful for the detection of health problems in the transition period, such as lameness (Proudfoot et al., 2010, Calderon and Cook, 2011), dystocia (Proudfoot et al., 2009), and subclinical hypocalcemia (Jawor et al., 2012). Precision dairy monitoring also had the potential to detect disease early, maximizing individual animal performance. Disease detection has relied on producers observing clinical signs, but once clinical signs have been displayed, it is often too late to act effectively. Clinical signs were often preceded by physiological changes that were undetectable with human senses, but may be observable with PDM and could allow producers to intervene sooner (Bewley, 2012). With early detection, producers could decrease culling rates and increase animal well-being. With an alert provided by the system, producers could identify cows with disorders. Improved sensor performance to increase the detection accuracy is needed. One major concern with technologies is the large number of false positive alerts (Hogeveen et al., 2010). With improved detection models and sensors, PDM could flag cows with disorders and producers could react much faster. For producers, easy access to PDM data and a reliable alert system could greatly assist in understanding the herd status.

To the authors' knowledge, no study using multiple commercial PDM for early detection of metabolic diseases has been published. The objective of this study was to use variables from multiple commercially available PDM to exam alert performance generated from different analyses and define the odds ratio of having a disease. The first analysis examined behavioral

changes with the UNIVARIATE procedure of SAS to generate alerts to compare with disease occurrence. The second analysis used the GENMOD procedure of SAS to generate disease probabilities and created alerts based on probability thresholds. Both analyses utilized the EXPAND procedure of SAS to create a 5d backward moving window for the alerts and disease occurrences.

MATERIALS AND METHODS

This experiment was part of a larger study designed to quantify physiological and behavioral changes associated with mastitis, lameness, estrus, and postpartum diseases, using multiple PDM. All studies were performed with the approval of the University of Kentucky Institutional Animal Care and Use Committee (IACUC protocol number: 2013-1199).

Animal, Feeding, and Housing

One hundred and thirty-eight lactating Holstein cows at the University of Kentucky Coldstream Dairy (Lexington, KY, USA) were enrolled in this study from June 2014 to October 2015. Cows were enrolled in the protocol after they calved. Lactating cows were housed in two freestall barns, one barn with 54 dual chamber waterbeds (Advanced Comfort technology, Inc., Reedsburg, WI) and the other equipped with 54 rubber-filled mattresses, both surfaces covered with sawdust. Prepartum cattle were housed in a 9.15 x 21.34 m straw bedded-pack with constant access to 3.64 hectares of pasture. A total mixed ration was delivered once daily to dry cows. Before and throughout the study, cows were balanced between barns by DIM and parity. Calving dates, breeding dates, and DIM were obtained from PCDART management software (Dairy Records Management Systems, Raleigh, NC). Parity ranged from 1 to 7. The mean parity for the herd was 2.10 ± 1.27. Percent of cows in parities 1, 2, 3, 4, 5, 6, and 7 were 37%, 37%, 10%, 10%, 2%, 2%, and 2%, respectively. A weather station (HOBO U23 Pro v2 External

Temperature/Relative Humidity Data Logger - U23-002, Onset, Bourne, MA) was located inside each freestall barn that measured relative humidity and temperature every 15 minutes. Temperature humidity index (**THI**) was computed using the following formula (NOAA and Administration, 1976): THI = temperature (^{0}F) - [0.55 – (0.55 × relative humidity/100)] × [temperature (^{0}F) – 58.8].

Cows were provided ad libitum access to water in each barn and shared a feedbunk between barns. Lactating cows were fed the same ration at 0600 and 1330 daily. Dry cows were fed a different ration at 0600 once daily. The diet consisted of corn silage, alfalfa hay, mineral and vitamin supplement, concentrate mix, whole cottonseed, and alfalfa haylage. Dry cow diet consisted of Orchard grass hay, cotton seed, mineral mix, wheat straw, biochlor, and hay. Cows were milked two times per d at 0430 and 1530.

Fresh cow exam

Cows were monitored every day after morning milking from 0700 to 0900 for the first 21 d of lactation. Rectal temperature and behavioral score were monitored daily for the first 21 DIM (Figure 2.1). Rectal temperature was measured with a GLA thermometer (GLA Agricultural Electronics, San Luis Obispo, CA). Cows were measured while standing still in the freestall barn. A MetriCheck (Simcro Tech Ltd, Hamilton, New Zealand) device (50- cm-long stainless steel rod with a 4-cm hemisphere of silicon at the end for vaginal insertion) was used to obtain a uterine discharge sample and scored on 3, 5, 7, 9, 11, 14, 17, 19, and 21 DIM (Figure 2.1). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on visual appearance of sample; score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score

3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥2 were classified as clinical metritis cases.

Blood samples

β-carotene level from blood plasma was collected once from a range of 15 ± 5 d before calving, and at 3 DIM (Figure 2.1). β-carotene was measured using iCheck (ROVIMIX® β-Carotene, Heerlen, Netherlands) which is a spectrophotometer that interpreted color absorbency. Blood samples were obtained by caudal venipuncture on days 3 and 7 DIM. One 10 ml EDTA purple-top Vacutainer® (Becton, Dickinson and Company, New Jersey) for β-carotene, retinol and biochemical analysis and sterile 10 ml tubes containing 200 µl stabilizer solution (0.3 m EDTA, 1% acetyl salicylic acid, pH 7.4) for hormonal analysis were used. The sample was centrifuged for 20 min at 2500 RPM to obtain the plasma from the purple top tube, and plasma was used to mix with the solution that the company provided into cuvettes. The measurement was described previously by Schweigert et al. (2007). Ca level from blood serum and ketone level from blood was collected on 3, 7, 14, and 21 DIM (Figure 2.1). One 10 ml red-top Vacutainer® (Becton, Dickinson and Company, New Jersey) tube containing no anticoagulant was required for Ca diagnosis test. Samples were spun down in a centrifuge for 20 min at 2500 RPM to obtain the serum, and samples were split into 3 tube. The first subsample of serum was sent to the University of Kentucky Veterinary Diagnostic Laboratory within 1 d. Calcium was analyzed using a Calcium-Arsenazo assay (ACE Alera, Alfa Wassermann Diagnostic Technologies, LLC, West Caldwell NJ). Hypocalcemia was defined as a serum Ca level < 8.6 mg/dL (Chapinal et al., 2011). The second serum sample was sent to the University of Wisconsin-Madison: Wisconsin, Dr. Heather White (1675 Observatory Drive, Rm 934B) and analyzed by Wako (Wako pure Chemical Industries Ltd, Japan) NEFA-C test (ACS-ACOD

method) to evaluate NEFA. The third vial of serum was used in Konelab™ 20XT Clinical Chemistry Analyzer (Thermo Electron Oy, Finland) to analyze cholesterol level. On days 3, 7, and 14, BHBA concentration was measured in a whole-blood sample left over from the blood drawn for the Ca test (Figure 2.1). A Precision Xtra electronic handheld device (Abbott Laboratories, Chicago, IL, USA), validated by Iwersen et al. (2009), was used with ketone test strips and 1.5 μL of blood drawn into a sample well. Cows with BHBA ≥ 1.2 mmol/L were classified as having hyperketonemia (Geishauser et al., 1998, McArt et al., 2012c, Kaufman et al., 2016).

PDM

Each cow was equipped with the PDM before being enrolled in the study to allow for an adjustment period of at least two weeks for cows to get used to the PDM with AfiAct pedometer Plus (Afimilk, Kibbutz Afikim, Israel) sensors recorded total lying time which was validated for dairy cattle use by Mattachini et al. (2013). DVM Bolus (DVM Systems, LLC, Greeley, CO) recorded reticulorumen temperature. HR Tag (SCR Engineers Ltd, Netanya, Israel) sensors recorded total rumination time which was validated for dairy cattle use by Schirmann et al. (2009b). CowManager SensoOr (Agis Autimatisering, Harmelen, Netherlands) sensors recorded total time active, time not active, eating and rumination which was validated for dairy cattle use by Wolfger et al. (2015). IceQube (IceRobotics Ltd, Edinburgh, Scotland) sensors recorded total daily lying time and lying time per bouts which was validated for daily cattle use by McGowan et al. (2007). SmartBow (Smartbow GmbH, Jutogasse, Austria) recorded rumination time, lying time, time active, and time not active. Track a))) cow (ENGS, Hampshire, UK) recorded time around the feed bunk, number of steps, lying time and lying bouts (Table2.1). The technologies were found correlated for dairy cattle by Borchers et al. (2016).

Leg devices were placed on the legs, and each cow received an individual tag. Resting time (or lying time) was measured by leg tags. Lying bouts, measured by leg tags, recorded the number of times that a cow lied down. Number of steps was measured by leg tags that recorded how many steps cows took per day. Time around the feed bunk was measured by leg tag that recorded how long cows spent around the feed bunk. DVM boluses, which were active before insertion in the rumen, were inserted into the reticulorumen orally, using a bolus gun. Ear tags were positioned using an ear tagger, provided by each technology company to fit the respective device. Ear tags that measured time not active recorded the time that cows were hanging their head in the air but doing nothing which could mean the cow was either standing or lying.

The AfiMilk MPC Milk Meter (Afimilk, Kibbutz Afikim, Israel) was used to collect individual milk yield and milking time for each milking. Body weights were recorded by AfiWeigh (Afimilk, Kibbutz Afikim, Israel), placed in a common exit alley. Cows were sorted into their respective groups using AfiSort (Afimilk, Kibbutz, Afikim, Israel) after each milking. All computer clocks were set to synchronize with NIST Internet Time Service (NIST, Gaithersburg, MD, USA) automatically, and time was checked on all computers manually on a weekly basis. The software recorded raw data, including measurements and recordings of behavioral and physiological parameters, daily.

Statistical Analyses

Data Editing and Analyses

Statistical analyses were conducted using SAS Version 9.3 (SAS Institute Inc., Cary, NC). Milk yields < or > 4 standard deviations from the previous week's average milk yield were removed, presumably caused by technology error. To account for decreased reticulorumen

temperature caused by water bouts, DVM reticulorumen temperatures were removed if < 38.3ºC or if they were less than 4 standard deviations from the previous week's average temperature. Milk yield was sum (milked twice per day) and body weight was averaged (weight twice per day) to create one value per variable per cow per day. IceQube bout duration was each avergaed to create one value per variable per cow per day. IceQube lying bouts, IceQube standing time, IceQube motion, IceQube lying time, HR rumination, HR activity, CowManager SensoOr no active, CowManager SensoOr rumination, CowManager SensoOr feeding time, CowManager SensoOr active, CowManager SensoOr high active, SmartBow lying time, SmartBow inactive, SmartBow high active, SmartBow rumination, Track a))) cow lying time, Track a))) cow time around feed bunk, and Track a))) cow feed buck visit were each summed to create one value per variable per cow per day. If the measurement for any variable was 0 for the day, that variable was set as missing for that cow on that day. Cow days were removed if < 90% of each day's data was recorded, but if a cow generated > 99% of each day's data, that linear interpolation was used to include the missing 1% from that day. Cow days were between 90% and 99% were stay the same. And the cows day 90 % was selected, because the less impact on influence the entire data. In cases where less than 24 hours of data were available, the percentage lying for that period was used to calculate the percentage lying within 24 hours.

The UNIVARIATE procedure was used on these variables and the 1st and 99th percentile of all variables were removed. In the analysis, disease referred to any occurrence of hyperketonemia, hypocalcemia, metritis, and any of their combinations. Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra at 3, 7, 14, or 21 DIM. Hypocalcemia was defined as any blood serum Ca concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM. Metritis was

defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.

Analysis 1: sensitivity, specificity and accuracy of disease detection based on the 10th or 90th percentiles of each technology variable.

The UNIVARIATE procedure was used on each variable from each technology to identify the overall 10th and 90th percentiles. The 10th and 90th percentiles was generate from Tsai et al. (2016) and display in Table 3.4. When examining Tsai et al., 2016 any individual variables that were decreased (or were elevated) due to hyperketonemia, metritis, or hypocalcaemia would be conducted value < 10th percentile (or > 90th percentile) and result in an alert (**Alert1**). For ecample, the 90th and 10th percentile for AfiAct pedometer plus lying time were 711 and 315 min/d (Table 3.4). Cows with hypocalcemia had greater lying time, so if cows' lying time was > 90th (711 min/d), then an alert was created as alert (1). If the lying time was < 711 min/d then an alert was not created (0). And all the Alert1s for each variable were added together for each technology into an overall alert (**Alert2**). For instance, AfiAct Pedometer Plus measures 3 variables activity, lying time and lying bouts. Individual variables generated an Alert1 for activity, lying time, and lying bouts were added together as one technology to create Alert2. The UNIVARIATE procedure was conducted twice after Alert2 was generated to create the final alert (**Alert3**). The 50th percentile or greater of Alert2 was used to create Alert3. Different percentile of the Alert3 were tried, and only the percentile higher than 50% showed the greater results. If Alert2 was > 50th percentile, Alert3 was generated (1); if Alert2 was < 50th then Alert3 was not generated (0). To increase alert robustness, Alert3 and disease occurrence were increased to a 5d backward moving maximum (**5D**) with the EXPAND procedure of SAS. This created a 5D detection window that allowed detection on Day 0 (day event identified), Day$_{-1}$,

Day_{-2}, Day_{-3}, or Day_{-4}. Different days of backward moving were tried, but only the 5D backward show the greater results.

Correctly identified disease events were considered true positives (**TP**), non-alerted events were false negatives (**FN**), non-alerted non-events were true negatives (**TN**), and alerted non-events were false positives (**FP;** Firk et al., 2002). True positives were identified when alerts and diseases occurred at the same time within the 5D window. True negatives were identified when no alerts or diseases occurred at the same time within the 5D window. False positives were identified when alerts and no diseases occurred at the same time within the 5D window. False negatives were identified when diseases and no alerts occurred at the same time within the 5D window.

Specificity is the probability that a negative sample is from a disease-negative cow. Sensitivity is the probability that a positive alert is a true indicator of a disease (Hamann and Zecconi, 1998, Sherlock et al., 2008, Hogeveen et al., 2010). Because sensitivity and specificity are interdependent, thresholds should be set to optimize both (Hogeveen et al., 2010). Accuracy can account for the prevalence of a disease whereas sensitivity and specificity cannot. Accuracy depends on how strongly and closely the measured parameters are associated with the event, how accurately the technology measures the parameters, and how well the manufacturer algorithm processes the data to create useful alerts (Dolecheck et al., 2015). Sensitivity, specificity, and accuracy for each final multivariate model were determined using Equation. 3.1, 3.2, and 3.3 (Sherlock et al., 2008, Hogeveen et al., 2010).

$$\text{Specificity} = TN / (TN + FP) \times 100 \qquad \textbf{Equation 3.1}$$

Sensitivity = TP / (TP + FN) x 100 **Equation 3.2**

Accuracy = [(TP + TN) / (TP + TN + FP + FN) X 100] **Equation 3.3**

Analysis 2: Association between technology and disease status

The previous day's data was used for each technologies' variables to account for the timing of data availability to producers (**d -1**). A moving baseline was created for each cow and each variable through a 5D backwards mean. The baseline used data from d -2 (yesterday), d -3, d -4, d -5, and d -6. The percent change for each day was calculated using Equation. 3.4 and that data was used in all models. Where d-1 was the "current" day and baseline was the 5 previous days.

Percent change = (d-1 – baseline) / baseline x 100 **Equation 3.4**

Models were analyzed with the GENMOD procedure with binomial distributions with cows as repeated subject and metabolic disease status as the dependent variable (yes or no for having hyperketonemia, hypocalcemia, or metritis). Metabolic disease status was expanded to a 5D rolling backward maximum to a wider window for compare. The single variable GENMOD procedure was used to screen all the variables to include in the multivariate models. Non-significant variables ($P \geq 0.05$) were not accounted for in any further analysis. The previous day's data (d -1) and percent change were examined independently for all variables. Variables significant in each of these individual models were then included in the multivariate models ($P < 0.05$).

Odds ratios were generated within GENMOD procedure of SAS, using one standard deviation different of variable's feature in the regression model. Standard deviation was

generated from the whole herd average and calculated. The odds ratios were from separate models to avoid highly related variables in the same model. The LOGISTIC procedure of SAS was used to calculate receiver operator characteristic (**ROC**) curves and determine probabilities of disease for each cow each day using all of the GENMOD identified variables. The ROC curves were created by sensitivity (y- axis) and 1- specificity (x-axis). Based on area under the curve (**AUC**), means the magnitude of the quantity that is obtained by the product of the quantities signified by the 1- specificity and the sensitivity axes. If AUC was > 0.7, the accurate performance of technology would be found (Swets, 1988). The GENMOD procedure of SAS was used to create probabilities for alert thresholds. Instead of using the threshold created from the AUC, probability was used to calculate the performance of PDM. Probability is the predicted value of the mean or the predicted probability that the response variable is less than or equal to the value in the model. In this study, probability was generated from GENMOD procedure, and represented the predicted value that response to the variables on cows with or without diseases. When the dataset probability for a particular cow on a particular day was greater than the GENMOD probability threshold, an alert was created for that cow on that day. All alerts and disease events were expanded to the 5D window using the EXPAND procedure of SAS. True positives, FN, TN, and FP were identified within the 5D window. Sensitivity (Equation 3.1), specificity (Equation. 3.2), and accuracy (Equation. 3.3) were calculated for each variable's probability threshold (Table 3.24 to Table 3.30).

RESULTS

A summary of all the tables is displayed in Table 3.1. Two main types of analysis were used, the UNIVARIATE and GENMOD procedures of SAS. The description of the EXPAND procedure 5D backward moving window is depicted in Figure 3.1. After an alert was created

from either UNIVARIATE or GENMOD, a 5D backward moving maximum was conducted. The EXPAND procedure with a 5D backward moving maximum was used to determine the timing of disease, hyperketonemia, hypocalcemia, and metritis diagnosis.

All variables were examined within the UNIVARIATE procedure (Figure 3.2) from each technology and individual variables were selected according to Tsai et al. (2016). Selected variables from the UNIVARIATE procedure were used in the GENMOD procedure (Figure 3.3). Data from the previous day was used as an indicator in both models. The percent change of the variables affected by the cows with and without disease is displayed in Table 3.3. In the GENMOD procedure, the percent change of each variable was considered as an indicator, and that percent was considered as a predicted value.

UNIVARIATE: performance

Overall PDM performance is displayed in Table 3.5. All the tables were separated by disease (disease, hyperketonemia, hypocalcemia or metritis). Disease catalog was created by cows with any kind of diseases (either hyperketonemia, hypocalcemia or metritis). Technologies were separated by leg tags, neck tags, ear tags, the parlor analyzer, and the body weight measurement. Table 3.6 to Table 3.16 were the performance of individual PDM within the UNIVARIATE procedure, and Table 3.16 was the performance of all the PDM combination.

Table 3.6 iS the performance of AfiAct Pedometer Plus within UNIVARIATE procedure. Activity, lying time and lying bouts were conducted in the model. The disease detection performance was 71% sensitivity, 82% specificity, and 78% accuracy. The hyperketonemia detection performance was 78% sensitivity, 68% specificity, and 67% accuracy. The hypocalcemia detection performance was 77% sensitivity, 71% specificity, and 72% accuracy. The metritis detection performance was 72% sensitivity, 77% specificity, and 76% accuracy.

In Table 3.7, the performance of AfiLab Milk Analyzer within UNIVARIATE procedure was displayed. Milk protein, fat, lactose, fat: protein, conductivity, milk yield, and milking time were conducted in the model for detection. The disease detection performance was 82% sensitivity, 78% specificity, and 80% accuracy. The hyperketonemia detection performance was 78% sensitivity, 84% specificity, and 84% accuracy. The hypocalcemia detection performance was 79% sensitivity, 82% specificity, and 81% accuracy. The metritis detection performance was 76% sensitivity, 79% specificity, and 78% accuracy.

Table 3.8 is the performance of the body weight (AfiWeigh). The disease detection performance was 33% sensitivity, 80% specificity, and 94% accuracy. The hyperketonemia detection performance was 61% sensitivity, 90% specificity, and 90% accuracy. The hypocalcemia detection performance was 49% sensitivity, 92% specificity, and 88% accuracy. The metritis detection performance was 28% sensitivity, 81% specificity, and 81% accuracy.

Table 3.9 is the combination of all the Afi systems, which included all the variables above. The disease detection performance was 78% sensitivity, 81% specificity, and 80% accuracy. The hyperketonemia detection performance was 74% sensitivity, 90% specificity, and 89% accuracy. The hypocalcemia detection performance was 71% sensitivity, 86% specificity, and 88% accuracy. The metritis detection performance was 70% sensitivity, 82% sensitivity, and 79% accuracy.

In Table 3.10, the performance of Track a))) cow within UNIVARIATE procedure was displayed. The measurement combined lying time, lying bout, steps, time around the feed bunk, and feed bunk visit time. The disease detection performance was 79% sensitivity, 79% specificity, and 79of accuracy. The hyperketonemia detection performance was 79% sensitivity, 74% specificity, and 74% accuracy. The hypocalcemia performance detection was 74%

sensitivity, 78% specificity, and 78% accuracy. The metritis detection performance was 75% sensitivity, 78% specificity, and 78% accuracy.

The performance of DVM bolus was displayed in Table 3.11. Reticulorumen temperature was the only variable included in the model. The disease detection performance was 35% sensitivity, 92% specificity, and 79% accuracy. The hyperketonemia detection performance was 32% sensitivity, 94% specificity, and 92% accuracy. The hypocalcemia detection performance was 31% sensitivity, 95% specificity, and 90% accuracy. The metritis detection performance was 41% sensitivity, 93% specificity, and 85% accuracy.

In Table 3.12, the performance of IceQube was evaluated base on the variables of lying time, number of lying bouts, number of steps, motion index, and lying bout duration. The disease detection performance was 71% sensitivity, 84% specificity, and 80% accuracy. The hyperketonemia detection performance was 70% sensitivity, 78% specificity, and 77% accuracy. The hypocalcemia detection performance was 70% sensitivity, 82% specificity, and 80% accuracy. The metritis detection performance was 72% sensitivity, 80% specificity, and 78% accuracy.

The performance of HR tag is displayed in Table 3.13. Only neck activity and rumination were evaluated in the model. The disease detection performance was 42% sensitivity, 96% specificity, and 82% accuracy. The hyperketonemia detection performance was 70% sensitivity, 83% specificity, and 82% accuracy. The hypocalcemia detection performance was 68% sensitivity, 87% specificity, and 84% accuracy. The metritis detection performance was 54% sensitivity, 88% specificity, and 81% accuracy.

The performance of Smartbow and CowManager SensoOr ear tags is displayed in Table 3.13 and Table 3.15. Smartbow included lying time, rumination, time not active, and activity in

the model. The disease detection performance was 53% sensitivity, 90% specificity, and 79% accuracy. The hyperketonemia detection performance was 70% sensitivity, 81% specificity, and 81% accuracy. The hypocalcemia detection performance was 64% sensitivity, 74% specificity, and 73% accuracy. The metritis detection performance was 61% sensitivity, 78% specificity, and 74% accuracy.

CowManager SensoOr included rumination, time not active, and active a eating time in the model. The disease detection performance was 56% sensitivity, 91% specificity, and 81% accuracy. The hyperketonemia detection performance was 71% sensitivity, 81% specificity, and 81% accuracy. The hypocalcemia detection performance was 62% sensitivity, 83% specificity, and 81% accuracy. The metritis detection performance was 57% sensitivity, 87% specificity, and 80% accuracy.

In Table 3.16, all the PDMs were combined in the model. The disease detection performance was 81% sensitivity, 83% specificity, and 82% accuracy. The hyperketonemia detection performance was 80% sensitivity, 83% specificity, and 83% accuracy. The hypocalcemia detection performance was 81% sensitivity, 81% specificity, and 81% accuracy. The metritis detection performance was 79% sensitivity, 77% specificity, and 78% accuracy. As more variables were included in the model, more indicators were counted. The combination of PDM produced a visibly greater performance.

GENMOD: Odds ratios

The GENMOD procedure of SAS was conducted from all the PDM individual variables to obtain significant variables ($P< 0.05$). The PDM variables were compared with cows with diseases or not to make sure the variable was significant affected by diseases. In this analysis, the variable that was significantly different would be the used as the odds ratio analysis. The odds

ratios were from separate models to avoid including highly related variables in the same model. Unit in the model was calculated with one standard deviation different from the herd average. Table 3.17 is selected after GENMOD, and only the variables from AfiLab Milk Analyzer had significant effects on having disease ($P < 0.05$). With every .7% milk fat increase, the odds of developing any disease increased 1.33 times. Every .3% milk protein decrease, the odds of developing any disease increased 1.20 times. With every .2 of milk fat: protein increase, the odds of developing disease increased 1.61 times. With every .3% of milk lactose increase, the odds of developing disease increased 1.22 times. With every 1.9 min of milking time decrease, the odds of developing disease increased 1.25 times. With every 10 kg of milk yield decrease, the odds of developing disease increased 1.25 times.

However, for hyperketonemia separate models were created and included milk fat, milk fat: protein, milk conductivity, and body weight. With every .7% of milk fat increase, the odds of developing hyperketonemia increased 1.76 times. With every .2 of milk fat: protein increase, the odds of developing hyperketonemia increased 1.75 times. With every .9% of milk conductivity increase, the odds of developing hyperketonemia increased 1.21 times. With every 87kg of body weight increase, the odds of developing hyperketonemia increased 1.21 times. The follow up disease was hypocalcemia, which included milk fat, milk protein, milk lactose, milk fat: protein, milk yield, milk conductivity, milking time, body weight, and resting time in the separate models. With every .7% of milk fat increase, the odds of developing hypocalcemia increased 1.87 times. With every .3% of milk protein increase, the odds of developing hypocalcemia increased 1.40 times. With every .3% of milk lactose decrease, the odds of developing hypocalcemia increased 1.28 times. With every .2 of milk fat: protein increase, the odds of developing hypocalcemia increased 1.48 times. With every 10 kg of milk yield decrease, the

odds of developing hypocalcemia increased 2.21 times. With every 1.9 min of milking time decrease, the odds of developing hypocalcemia increased 1.46 times. With every 87 kg of body weight decrease, the odds of developing hypocalcemia increased 2 times. With every 153 min of resting time increase, the odds of developing hypocalcemia increased 1.15 times.

Lastly, Afi system was used to detect metritis. Milk protein, milk lactose, milk fat: protein ratio and milk conductivity were including in the models. With every .3% of milk protein decrease, the odds of developing metritis increased 1.62 times. With every .3% of milk lactose increase, the odds of developing metritis increased 1.48 times. With every .2 of milk fat: protein ratio increase, the odds of developing metritis increased 1.48 times. With every .9% of milk conductivity increase, the odds of developing metritis increased 1.31 times.

The odds ratio of Track a))) cow variables that affected any diseases, hyperketonemia, hypocalcemia, and metritis are displayed in Table 3.18. Only significant variables were included in the final model ($P < 0.05$). In cows with any disease, every 76 min of time around the feed bunk decrease increased the odds of developing disease 1.19 times. Every 679 steps decrease increased the odds of developing disease 1.23 times. Every 164 min of lying time increase increased the odds of developing disease 1.16 times. No variables that are significantly different ($P < 0.05$) from Track a))) cow detected the variable changes between cows with and without hyperketonemia. One variable, time around the feed bunk, differed between cows with and without hypocalcemia. Every 76 min of time decrease around the feed bunk increased the odds of developing disease 1.65 times. Number of steps differed between cows with and without metritis ($P < 0.01$). Every 679 steps, decrease increased the odds of developing disease 1.24 times.

The odds ratio for DVM bolus reticulorumen temperature is displayed in Table 3.19. No significant difference was found with hyperketonemia, hypocalcemia, and metritis. In cows with 0.8ºC of reticulorumen temperature increase, the odds of developing disease increased by 1.18 times ($P = 0.04$).

Odds ratios of having any disease, hyperketonemia, hypocalcemia, and metritis from IceQube are reported in Table 3.20. Cows with the disease, recorded an affect in lying time and bout duration, respectively. With every 142 min of lying time increase, the odds of developing the disease increased 1.18 times ($P < 0.01$). And with every 142 min of bout duration increase, the odds of developing disease increased 1.18 times ($P < 0.01$). Cows with hyperketonemia had the same results as cows without the disease. With every 142 min increase in lying time, the odds of developing hyperketonemia increased by 1.27 times ($P = 0.02$). And with every 142 min increase of bout duration, the odds of developing hyperketonemia increased 1.27 times ($P = 0.02$). Cow with hypocalcemia could be detected by the changing of lying time, bout duration, and steps, respectively. With every 142 min increase of lying time, the odds of developing hypocalcemia increased 1.26 times ($P < 0.01$). With every 142 min increase of bout duration, the odds of developing hypocalcemia increased 1.26 times ($P < 0.01$). And with every 474 steps increase, the odds of developing hypocalcemia increased 1.17 times ($P = 0.04$). Last, cow with metritis could be detected by the changing of steps and motion. With every 474 steps decrease, the odds of developing metritis increased 1.29 times ($P < 0.01$). And with every 1667 motion decrease, the odds of developing metritis increased 1.32 times ($P < 0.01$).

Table 3.21 is displayed with odds ratios from HR tags. Neck activity reported a significant difference in disease detection ($P< 0.01$). For every 119 unit of neck activity decrease, the odds of developing the disease increased 1.39 times. Neck activity produced similar

results in cows with hyperketonemia as a significant difference was found in the model (P<.0.01). For every 119 neck activity decrease, the odds of developing hyperketonemia increased 2.72 times. Cows with hypocalcemia could be detected by both neck activity and rumination, respectively. For every 119 neck activity decrease, the odds of developing hypocalcemia increased 1.96 times and with every 110 min rumination decrease, the odds of developing hypocalcemia increased by 1.54. Last, rumination time was significantly different in the metritis model (P<.0.01). For every 110 min increase of rumination, the odds of developing metritis increased 1.31 times.

Odds ratios from Smartbow variables are displayed in Table 3.22. Cows with the disease could be detected with lying time and time not active. For every 107 min increase of time not active, the odds of developing disease increased 1.20 times (P = 0.03). And with every 137 min of lying time increase, the odds of developing disease increased 1.32 times (P < 0.01). When cows have hyperketonemia, time not active, lying time, and rumination were affected, respectively. With every 107 min increase of time not active, the odds of developing hyperketonemia increased by 1.64 times (P < 0.01). With every 137 min of lying time increase, the odds of developing hyperketonemia increased 1.51 times (P = 0.02). And with every 96 min of rumination decrease, the odds of developing hyperketonemia increased 1.62 times (P < 0.01). Cows with hypocalcemia could be identified by detecting time not active and rumination time. For every 107 min of time not active increase, the odds of developing hyperketonemia increased 1.42 times (P < 0.01). And with every 96 min of rumination decrease, the odds of developing hyperketonemia increased 1.38 times (P < 0.01).

Odds ratios of CowManager SensoOr are displayed in Table 3.23. Variables that were listed as significant were affected by any disease, hyperketonemia, hypocalcemia, and metritis

(P<0.05). A decrease of eating time was found in cows with the disease. For every 113 min decrease in eating time, the odds of developing disease increased 1.33 times (P = 0.02). A significant increase in time not active was recorded in cows with hypocalcemia (P<0.01). With every 172 min increase of time not active, the odds of developing hyperketonemia increased 1.58 times (P < 0.01). Hypocalcemia was detected by changes in time not active, rumination, and eating time. With every 172 min increase in time not active, the odds of developing hypocalcemia increased 1.47 times (P < 0.01). With every 120 min decrease in rumination time, the odds of developing hypocalcemia increased 1.30 times (P = 0.05). And with every 113 min decrease in eating time, the odds of developing hypocalcemia increased 1.43 times (P < 0.01). Cows with metritis were detected though the significant change was active time and rumination time (P<0.01). With every 23 min decrease of activity, the odds of developing metritis increased 1.21 times (P = 0.02). And with every 120 min of rumination increase, the odds of developing metritis increased 1.33 times (P < 0.01).

GENMOD: MULTIVARIABLE

According to the univariable above, any variables from each technology that were significantly different in GENMOD were added into the multivariable model (P < 0.05). Also, any significant value from percent change in GENMOD univariable was selected in the multivariable as well (P < 0.05). Table 3.24 to Table 3.30 were separated by disease, hyperketonemia, hypocalcemia, and metritis. Sensitivity, specificity, and accuracy were reported from 90% sensitivity, 90% specificity, and the equal value of sensitivity and specificity. Probability and ROC curve were generated from GENMOD procedure of SAS. Probability represents the predicted value of the mean of the response, or the predicted probability that the response from the data was used. Thus, the probability was used to set the threshold and

calculate the performance of the technologies. After the select cut-point of probability, an alert was created. The performance was generated from the comparison of the alert and the timing of disease diagnosed.

Table 3.24 reports the performance of AfiAct Pedometer Plus, Afimilk, AfiLab, and AfiWeigh in combination. In disease detection, if the probability was greater than 0.5, then cows were considered sick in the multivariable model of GENMOD. The performance of the disease detection was 80% sensitivity, 85% specificity, and 83% accuracy. In hyperketonemia detection, if the probability was greater than 0.05, then cows were considered to have hyperketonemia in the multivariable model of GENMOD. Sensitivity was 80%, specificity was 79%, and the accuracy was 79% in hyperketonemia detection. If the probability were greater than 0.16 in the multivariable model of GENMOD, cows would consider as having hypocalcemia. The performance of hypocalcemia detection was 82% sensitivity, 80% specificity, and 80% accuracy. If the probability of metritis was greater than 0.45, the cows were considered to have metritis in the multivariable model of GENMOD. The performance of detection metritis was 83% sensitivity, 80% specificity and 81% accuracy.

The performance of Track a))) cow with GENMOD procedure is displayed in Table 3.25. For disease detection, if the probability was greater than 0.59, the disease detection performance was 80% sensitivity, specificity was 81%, and the accuracy was 81%. In hyperketonemia detection, if the probability was greater than 0.81, then the performance was 77% sensitivity, 70% specificity, and 71% accuracy. For hypocalcemia were considered to have the disease if the probability was greater than 0.75, and the disease detection performance was 62% sensitivity, 66% specificity, and 65% accuracy. For metritis, cows were considered to have the disease if the

probability was greater than 0.48 and the disease detection performance was 73% sensitivity, 76% specificity, and 75% accuracy.

DVM bolus performance with GENMOD procedure is displayed in Table 3.26. To detect disease, if the probability was greater than 0.5, then the performance of sensitivity was 70%, specificity would be 77%, and accuracy would be 75%. In hyperketonemia detection, if the probability was greater than 0.02, then the performance was 69% sensitivity, 78% specificity, and 77% accuracy. In hypocalcemia detection, if the probability was greater than 0.21 than the performance of the detection was 70% sensitivity, 75% specificity, and 74% accuracy. Because only reticulorumen temperature was detected within DVM, only one variable could be modeled. Thus, in metritis detection, there were not enough variables to include in the model, so DVM cannot provide metritis detection performance within the GENMOD procedure.

The performance of IceQube within the GENMOD procedure is displayed in Table 3.27. In disease detection, if the probability was greater than 0.64, then the performance of the detection was 78% sensitivity, 82% specificity, and 80% accuracy. For hyperketonemia, cows were considered to have the disease if the probability was greater than 0.13 and the disease detection performance was 83% sensitivity, 79% specificity and 80% accuracy. In hypocalcemia detection, if the probability was greater than 0.29, then the performance of the detection was 77% sensitivity, 81% specificity, and 80% accuracy. Last, in metritis detection, if the probability was greater than 0.5, then the performance of detection metritis was 81% sensitivity, 75% specificity, and 77% accuracy.

Table 3.28 displays the performance of the SCR HR tags within the GENMOD procedure. For disease detection, if the probability was greater than 0.57, the performance of detection was 76% sensitivity, 80% specificity, and 78% accuracy. In hyperketonemia detection,

if the probability was greater than 0.10, then the performance of detection was 71% sensitivity, 78% specificity, and 78% accuracy. For hypocalcemia detection, if the probability was greater than 0.18, then the performance of detection was 69% sensitivity, 85% specificity, and 83% accuracy. For metritis detection, if the probability was greater than 0.48, the performance of detection was 74% sensitivity, 74% specificity, and 74% accuracy.

Table 3.29 displays the performance of the ear tag Smartbow within GENMOD procedure of SAS. If the probability was greater than 0.2, the performance of disease detection was 46% sensitivity, 88% specificity, and 77% accuracy. If the probability was greater than 0.02, the performance hyperketonemia detection was 45% sensitivity, 94% specificity, and 93% accuracy. If the probability was greater than 0.15, the performance of hypocalcemia detection was 54% sensitivity, 82% specificity, and 80% accuracy. If the probability was greater than 0.45, the performance of metritis detection was 70% sensitivity, 77% specificity, and 75% accuracy.

The performance of CowManager SensoOr within GENMOD procedure is displayed in Table 3.30. If the probability was greater than 0.40, the performance of disease detection was 60% sensitivity, 85% specificity, and 78% accuracy. To detect hyperketonemia, the probability was greater than 0.08 was selected. The performance of hyperketonemia detection was 59% sensitivity, 86% specificity, and 85% accuracy. If the probability was greater than 0.1, the performance of hypocalcemia detection was 74% sensitivity, 76% specificity, and 75% accuracy. Last, if the probability was greater than 0.2, the performance of metritis detection was 62% sensitivity, 77% specificity, and 73% accuracy.

DISCUSSION

Hyperketonemia

To detect hyperketonemia, increased milk fat, milk fat: protein ratio, milk conductivity, body weight, lying time and decreased activity and rumination indicate possible changes that were useful variables. The blood BHBA concentration was normally used for detection hyperketonemia, but taking blood samples either from the coccygeal vein or jugular vein would increase handling stress for cows. If milk could be a good indicator of detection hyperketonemia, this could reduce stress and labor. And Nielen et al. (1994) stated that the comparison between milk ketone test and serum BHB were 73% of sensitivity and 98% of specificity. Further, cows go through the milking process every day, so the process is low stress and routine for cows. During milking, the hyperketonemia detection could be hold at the same time. While the milking process, PDM could help to exam the milk BHB level. Thus, with the finding of this study, milk component could be an indicator for detection hyperketonemia.

In Duffield et al. (1997), the milk fat percent ranged from 3.5 to 4.4, and milk protein ranged from 2.6 to 3.2 and had a greater receiver operating characteristic (**ROC**) curve. Receiver operating characteristic is a plot that determines the performance from a logistic model. Further, when milk fat percent was greater or equal to 4.1%, the performance of detection of subclinical hyperketonemia was 54% of sensitivity and 72% of specificity (Duffield et al., 1997). In the previous study, finding both high sensitivity and specificity was difficult. Although ROC was high, different cut-point of variables were still needed. But in Grieve et al. (1986), if milk fat: protein was less than or equal to 0.75, there was a greater accuracy of detection than when using either milk fat or protein or in combination. In a recent study, Koeck et al. (2014a), pointed out that the less the milk BHBA, the less the milk fat: protein. So, using the milk component to detect metabolic disease could be profitable.

Soriani et al. (2012) found a negative relationship between rumination and blood BHBA concentration. Kaufman et al. (2016a) suggested that monitoring rumination during the transition period could identify cows developing hyperketonemia. Kaufman et al. (2016a) also indicated that cows with a 20 min/d decrease in rumination could be at 1.2 times greater risk of developing hyperketonemia or other metabolic diseases. The present study found similar results. With every 60 min decrease of rumination, the likelihood of having hyperketonemia increased 1.14 to 1.35 times. However, in Stangaferro et al. (2016b) study, a 91% of sensitivity was found based on rumination and activity. Although in this study, the intermediate sensitivity was found (70%), the different comparison between alert and disease timing was conducted. Compared with the previous study, 5D was used to compare alert and disease being diagnosed, but in Stangaferro et al. (2016b) study 5d before and after disease had been diagnosed was conducted. In this study, 1D (1 day before the disease was diagnosed), 3D (3 days before the disease was diagnosed), 5D (5 days before the disease was diagnosed) and 7D (7 days before the disease was diagnosed) moving backward were used, but 5D showed the best performance. By using different comparing windows and analysis methods, result differs. But overall, hyperketonemia could be detected with the changes of rumination and activity.

Daily body weight was measured in the present study. With an increase of body weight, the incidence of having hyperketonemia also increased. Koeck et al. (2014b) found that cows with a greater BCS would have a lesser incidence of having hyperketonemia. But in another study, Garro et al. (2014), mentioned that high BCS before calving was associated with the high incidence of having hyperketonemia during the first 19 DIM. Also in Oetzel (2007), fat cow syndrome and a greater BSC around calving was associated with hepatic lipidosis and hyperketonemia. Further, with one unit change in BCS, the corresponding body weight changed

21 to 110 kg (Otto et al., 1991, Berry et al., 2006). In a recent study, Roche et al. (2015), found that cows with a greater body weight would have a greater chance of liver fat infiltration, greater risk of having the metabolic disease, and greater loss of BCS. More research is required about the relationship between the incidence of hyperketonemia and body weight. Last, lying time increase could be another indicator in detecting the development of hyperketonemia. According to Kaufman et al. (2016b), with every 131 min/d increase in lying time during the first week after calving, there was a 1.8 times greater chance of having hyperketonemia. Further, research from Edwards and Tozer (2004), and Itle et al. (2015) found a decrease of activity when cows developed hyperketonemia in the first 14 DIM. Cows with hyperketonemia have been reported to develop metritis (McArt et al., 2012a). Cows with only hyperketonemia were not found in this study, but the result indicated that having hyperketonemia would increase the chance of having other metabolic diseases.

Hypocalcemia

For detecting hypocalcemia, the increase of milk fat, milk fat: protein, milk conductivity, milk protein, lying time and the decrease of activity, body weight, rumination, time around feed bunk, milking time, and milk yield could be useful variables. In a previous paper, lying time and lying bouts was linked with metabolic disease in that cows with metabolic disease tended to have increased lying time ($P = 0.04$) (Sepulveda-Varas et al., 2014). The result of the study was similar to the present study in that cows with hypocalcemia increased lying time. With an increase in lying time, activity decreased at the same time (Edwards and Tozer, 2004). Thus, lying time could be a predictor of hypocalcemia. However, little research has been conducted on lying time to calculate sensitivity and specificity. In this study, the sensitivity of detecting hypocalcemia ranged from 20% to 90%, and because different PDM and variables were included

in model. But with the leg tag, AfiAct Pedometer Plus, Track a))) cow, and IceQube, the overall performance was 82%, 62%, and 77% of sensitivity, respectively. Further, in the Stangaferro et al. (2016b) study, using a different window of alert and disease occurrence could generate different performance of PDM. Thus, because of evidence from this study combined with the previous studies, lying time and activity could be an indicator of hypocalcemia.

Østergaard and Gröhn (1999) found multiparous cows with a greater body weight had an increased risk of developing hypocalcemia during the first week after calving. In Caixeta et al. (2015), if cows had low Ca blood level in first 3 DIM and if parity was greater than 3, the incidence of having hypocalcemia increased. In this study, body weight was one of the variables that could detect hypocalcemia, and with other variables combine in the model would increase the detection performance.

Milk yield has been the most debated variable. Rajala-Schultz et al. (1999) reported that cows with hypocalcemia would produce more milk than healthy cows. But Østergaard and Gröhn (1999) found that milk yield was not affected by hypocalcemia. In this study, cows with hypocalcemia had less milk production. The result was related to decreased time around the feed bunk, which indicates cows spent less time eating. Without enough energy to produce milk, body weight, activity, and rumination decreased. Also, Goff (2008) research pointed out that intake decrease was caused by NEB and resulted in decreasing milk yield. The effect of NEB causes the vicious cycle in cows' bodies, thus increasing the incidence rate of having the metabolic disease and the culling rate. However, Jawor et al. (2012) had a result that contradicted the present study. Jawor et al. (2012) suggested that cows with subclinical hypocalcemia produced 5.7 kg/d more than the control cows during weeks 2, 3, and 4 after calving. Although results were different from the previous studies, different technologies and methods were used. To date, technologies

have changed to different versions and software systems. But the relationship between milk yield and hypocalcemia was not clear, and more research is needed.

Additionally, in this study the number of cows with only hypocalcemia was limited. Most of the cows had multiple metabolic diseases. And the same issue was found in the hypocalcemia detection that was found in hyperketonemia, cows with hypocalcemia have a greater risk of having other metabolic disease. So, variables which were included in the model could be associated with other metabolic diseases. In this result, milk fat and protein were affected when cows had hypocalcemia, which could also be because hyperketonemia occurred at the same time. Thus, the relationship between hypocalcemia and milk production, milk component, and intake requires further investigation.

Metritis

In metritis detection, increased milk fat: protein ratio, milk conductivity, lying time, rumination, and the decrease of milk protein and activity could be useful variables. Heuer et al. (2000) mentioned that a milk fat: protein greater than 1.5 was a sign of energy insufficiency. Further, Toni et al. (2011) found that with greater milk fat: protein, the risk of developing metritis increased, which was similar to the present study. In the same study, Toni et al. (2011) reported that first lactation cows had a greater incidence of developing metritis than second or greater lactation cows. If milk fat: protein was greater than 2, the risk of developing metritis increased (Toni et al., 2011). Similarly, results of the previous and present studies found that milk fat: protein could be an indicator of metritis.

Stangaferro et al. (2016a) conducted a study with rumination and activity for detecting metritis. The overall sensitivity was 59%, and specificity was 98% in their study. But in this study, the sensitivity was 74%, and specificity was 74%. In Stangaferro et al. (2016a), cows were

diagnosed with metritis was moved backward 5 d to forward 2 d range relative to the time of metritis was diagnosed. In the present study, cows that were diagnosed with metritis were analyzed the 5d moving range only about to the time of metritis to diagnosis. Further, the numbers of cows were different in this study, and cows with multiple diseases also affected the result. In this study, cows with metritis also had other metabolic diseases, which affected the change in other variables. But in Stangaferro et al. (2016a) study, cows with only metritis were considered, and 322 cows were enrolled. However, a greater sensitivity and specificity were found in this study. The different number of cows, method of analysis, and cows suffering from multiple diseases were the factors that impacted the results. Further, Titler et al. (2013) indicated that 3d before cows had been diagnosed with metritis, changes in steps, activity, lying bout, and rumination was detected. Also, in Stangaferro et al. (2016b), research showed that cows with metritis had decreased rumination. More research is needed, but rumination and activity could an indicator of metritis.

Overall performance

Technologies have been improved and perform better over time, more variables and monitoring systems in the market than there has been in the past. So, dairy producers have more choices to implement in their farming system. But few of them understand the information that technologies provide (Russell and Bewley, 2013). Dairy producers have little understanding about technologies that were available and how best to adapt their current system.
Around 25% of US farmers were aware they had not adapted technology well, but only 5% are adapting some aspect of the technology (Daberkow and McBride, 2003).

However, the best indicators were those with both high sensitivity and high specificity. Tests should rarely yield false positives (type I error; test shows positive when the animal was

actually healthy) or false negatives (type II error; test shows negative when the animal was actually sick). The best assessment measures correctly identify sick animals (i.e., high sensitivity; the ratio of true positives to the total of true positives and false negatives) and healthy ones (i.e., high specificity; the ratio of true negatives to the total of false positives and true negatives).

In this study, greater sensitivity and specificity were found within the combination of the variables. In the previous study, Stangaferro et al. (2016b), only one PDM was used, and the comparison time window of having the disease and alert occurred was different. A larger time window was used in previous studies, a narrow window of time was used to detect the change in variables in the present study. In addition, the sample size was different, the previous study had more cows than the present study, and cows with multiple disease were small number. In this study, variables changed and disease diagnosed column were move 5 d backward window, which increased the time windows for comparison. However, when more variables were used, it presented the chance to create a more accurate model. In this study, milk component was present in each different disease section of the model, which pointed to milk component as a possible indicator of diseases.

Future studies

The following are potential opportunities for improvements for future studies. Learning from experiences during the study, there are many errors. Human error, maintenance and study design are the three main areas. People training is an important part of having fully recorded data. Before using technology, people should be trained and understand who to go to and how to troubleshot the problem. People who are responsible for taking care of the technology should double-check the system every week at least to make sure is well functioning. The system should

be backed up the system every month, as this could make sure the company technicians have a resource to check the system if there is something wrong. Beside the PDM, during the fresh cow exam, training people could also affect the result. People who were trained to do fresh cow everyday need a reminder, in case of the missing data. No one is perfect, but with an effective reminder system, the chance of missing data could be reduced.

Second is maintenance the maintenance when the system was damaged by natural factors that cause system malfunction. The system was not housed inside but exposed out in the field. When the receiver was placed outside, under the severe weather, the receiver could be damaged. Natural factors include lightning, snow, and raccoons. The tag was designed to fit on the dairy cows' leg, neck or ear, but the data receiver needed to fit in with the natural environment. Thus, the location of the technology's receiver was crucial. Wild animals were the other natural factor, with the open feeding space for cows; raccoons were attracted to the feed. Thus, raccoons showed up on the farm and cheed the cable. During the study, raccoons damaged a few PDM receivers and wiring.

Next, change could be made in the study design. When intensively monitored dairy cows from 1 to 21 DIM, more samples could be taken. For blood BHBA, Ca, and NEFA, more samples could be taken. Instead of taking samples on DIM 3, 7, 14, and 21, the blood sample should be taken the intensively during first 7d, because daily fresh cow exams were already conducted, blood samples could also be taken simultaneously. Also, milk samples of BHBA and haptoglobin could be taken more often.

CONCLUSION

Early detection of transition cow diseases during the postpartum period requires a systematic and consistent monitoring program. In this study, PDM provided the possibility of

detecting disorders by monitoring physical activity, rumination and temperature. However, different method and cut-point of probability would create different levels of the performance. The greater performance was found within variables combined in the same model. In addition, with different timing comparison, the greater performances were found in 5D before cows were diagnosed with diseases and alert backward moving 5D. Overall, the greater sensitivity and specificity associated with accuracy, and the accuracy associated with how well PDM could detect diseases early. With greater accuracy, producers could apply PDM daily and save labor and time. Technology manufacturers should continue to seek ways to monitor multiple variables at once and to improve upon the variables they already monitor. The PDM used in this study have progressed from the time of this study and may be better able to predict disease than they were at this time. Overall, using PDM to predict hypocalcemia, hyperketonemia, and metritis is promising, but needs future work into evaluating the best variables and the best statistical methodology.

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entire process. Lastly, thank you to the University of Kentucky graduate students who edited and contributed to this manuscript.

Table 3.1. Introductory table outlining the tables and figures associated with disease occurrence, technology disease alert creation, and alert sensitivity, specificity, accuracy, and odds ratios by technology(s).

Technology(s)	Table(s) (page #)
Depiction of a backward moving maximum	Figure 3.1
Method of analyses 1: UNIVARIATE procedure[1]	Figure 3.2
Method of analyses 2 : GENMOD procedure[2]	Figure 3.3
All the variable that conducted in this study	Table 3.2
Overall sensitivty, specificity, and accuracy of individual technologies	
UNIVARIATE procedure	Table 3.3
AfiSystem[4]	
Alerts[5] created using UNIVARIATE procedure	Table 3.4 to 3.7
Odds ratios[6]	Table 3.15
Alerts[5] created using GENMOD procedure	Table 3.22
Track a))) Cow[7]	
Alerts[5] created using UNIVARIATE procedure	Table 3.8
Odds ratios[6]	Table 3.16
Alerts[5] created using GENMOD procedure	Table 3.23
DVM[8]	
Alerts[5] created using UNIVARIATE procedure	Table 3.9
Odds ratios[6]	Table 3.17
Alerts[5] created using GENMOD procedure	Table 3.24
IceQube[9]	
Alerts[5] created using UNIVARIATE procedure	Table 3.10
Odds ratios[6]	Table 3.18
Alerts[5] created using GENMOD procedure	Table 3.25
SCR, HR-Tag[10]	
Alerts[5] created using UNIVARIATE procedure	Table 3.11
Odds ratios[6]	Table 3.19
Alerts[5] created using GENMOD procedure	Table 3.26
Smartbow[11]	
Alerts[5] created using UNIVARIATE procedure	Table 3.12
Odds ratios[6]	Table 3.20
Alerts[5] created using GENMOD procedure	Table 3.27
CowManager[12]	
Alerts[5] created using UNIVARIATE procedure	Table 3.13
Odds ratios[6]	Table 3.21
Alerts[5] created using GENMOD procedure	Table 3.28
All the precision dairy technologies[13]	
Alerts[5] created using UNIVARIATE procedure	Table 3.14

Table 3.1. (cont.)

[1]The UNIVARIATE procedure of SAS was used to determine 10th and 90th percentiles for each variable. Either 10th or 90th percentiles were used to create a disease alert for each variable. Tables are depictions of the sensitivity, specificity, and accuracy of this disease detection method.

[2]The GENMOD procedure of SAS was used to determine probability cut-points for each variable. The probability was used to create a disease alert for each variable. Tables are depictions of the sensitivity, specificity, and accuracy of this disease detection method.

[3]Behavioral includes: lying time, lying bouts, rumination, eating time, time around the feed bunk, activity, steps, milk fat, milk protein, milk fat protein ratio, milk lactose, milk yield, milk conductivity, and body weight.

[4]AfiSystem includes: AfiAct Pedometer Plus, Afimilk, AfiLab, AfiWeigh, and all Afi technology together

[5]Alerts were categorized as true positive, true negative, false positive, or false negative. Alerts were created by predetermined thresholds for cases of hyperketonemia, hypocalcaemia, or metritis. A true positive was created when both an alert and an actual disease event occurred within the same 5d window. A true negative was created when no alert and no actual disease event occurred within the same 5d window. A false positive was created when an alert and no actual disease event occurred within the same 5d window. A false negative was created when an actual disease event and no alert occurred within the same 5d window.

[6]Each odds ratio referred to each technology mentioned directly above it. Odds ratios represented the chance of having a disease(s). If odds ratio was a positive number, the chance of having a disease increased. If odds ratio was a negative number, the chance of having a disease decreased.

[7]Track a))) cow, ENGS System Innovative Dairy Solutions, Israel.

[8]VM bolus, DVM System, LLC, Greeley, CO.

[9]IceQube, IceRobotics Ltd., Edinburgh, Scotland.

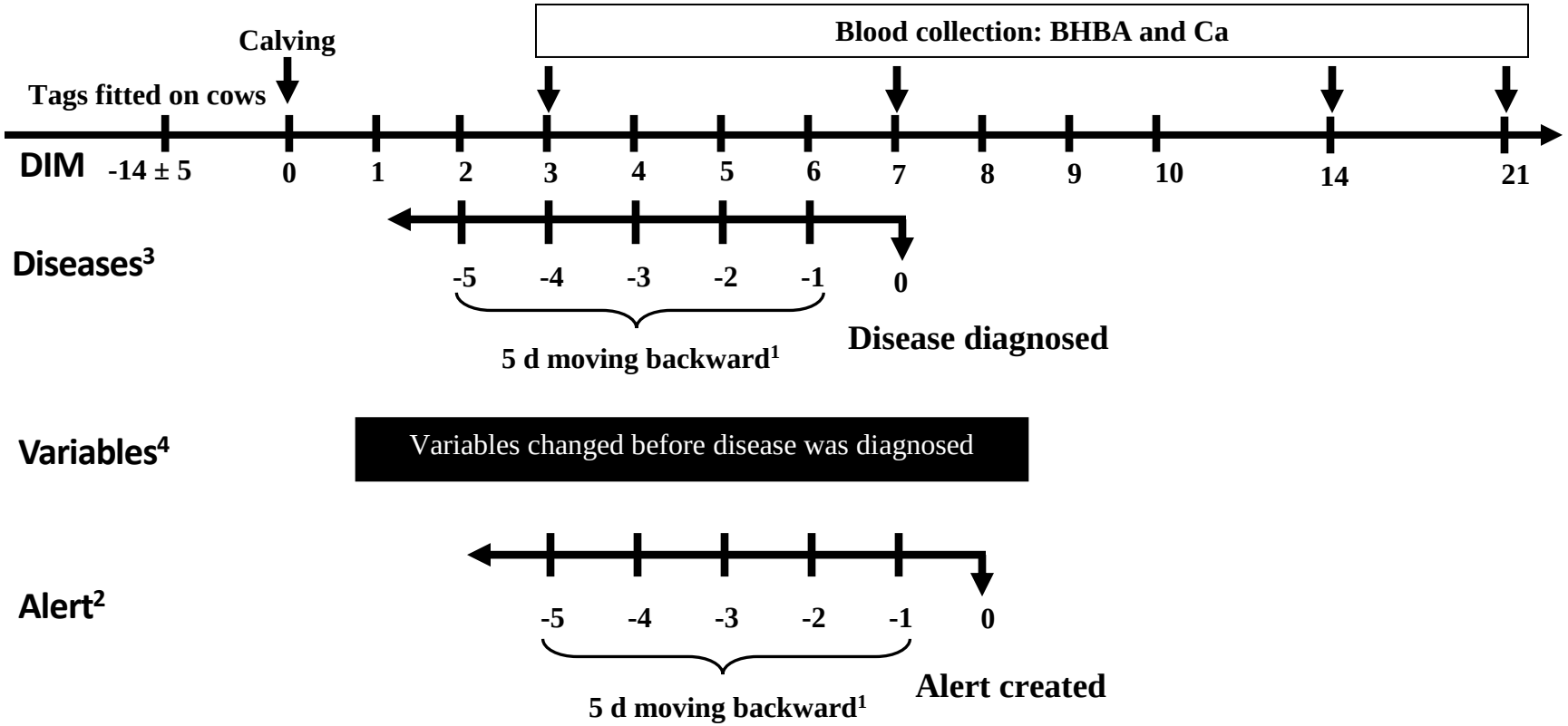
[10]HR Tag, SCR Engineers Ltd., Netanya, Israel.

[11]SmartBow, Smartbow GmbH, Jutogasse, Austria.

[12]CowManager SensoOr, Agis Automatisering, Harmelen, Netherlands.

[12]All technologies referred to all the precision dairy technologies list above combined together.

Figure 3.1 Depiction of 5d backward moving maximum[1] alert[2] and disease[3].



[1]Backward moving maximum, in order to have a wider window to compare alert and disease. In both analyses, EXPAND was used to create the wider window for calculated sensitivity, specificity and accuracy.

[2]Alert was created by UNIVARIATE and GENMOD procedure of SAS. Alerts were categorized as true positive, true negative, false positive, or false negative. Alerts were created by predetermined thresholds for cases of hyperketonemia, hypocalcaemia, or metritis. A true positive was created when both an alert and an actual disease event occurred within the same 5d window. A true negative was created when no alert and no actual disease event occurred within the same 5d window. A false positive was created when an alert and no actual disease event occurred within the same 5d window. A false negative was created when an actual disease event and no alert occurred within the same 5d window.

[3]Disease was diagnosed from daily fresh cow, and 5d backward moving maximum was applied. Before disease was diagnosed, behavior changed, so 5d backward moving would increase the detection of metabolic disease.

[4]Variables changed before disease was diagnosed, and technologies sensed the increase or decrease of the variables during this time.

Figure 3.2. Analysis 1, Flowchart of how alerts were created using precision dairy monitoring technologies to detect fresh cow disease in dairy cows within UNIVARATE procedure of SAS.

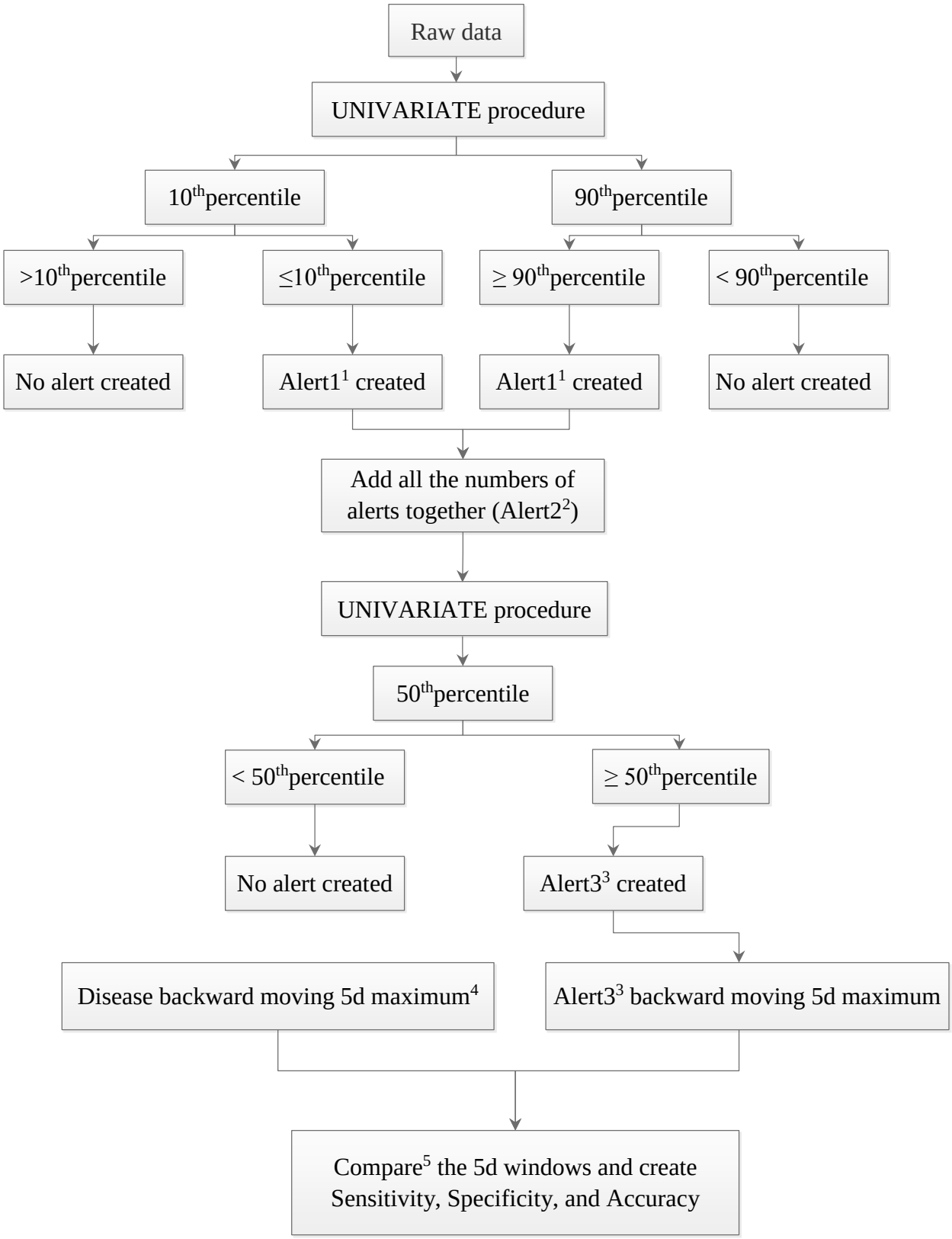


Figure 3.2. (cont.)

[1]Alert1 was created by each variable from individual technology. For example, AfiAct Pedometer Plus has activity, lying time, and lying bouts; so three of the variable would be consider to be three alert1s.

[2]Alert2 was created by all the variables from individual technology. For example, add all the AfiAct Pedometer Plus variables together to generate one number, alert2.

[3]Alert3 was after running UNIVERIATE procedure of SAS on alert2. If alert2 was greater than 50^{th} percentile, Alert3 was generated.

[4]Disease was defined when blood Ca levels $\leq$ 8.6 mg/dL were considered as hypocalcaemia (Chapinal et al., 2011). Blood ketone levels $\geq$ 1.2 mmol/l were considered as hyperketonemia (McArt et al., 2012b). MetriCheck scores $\geq$ 2 was considered as metritis (Sterrett et al., 2014).

[5]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Figure 3.3. Analysis 2, Flowchart of how alerts were created using precision dairy monitoring technologies to detect fresh cow disease in dairy cows within GENMOD procedure of SAS.

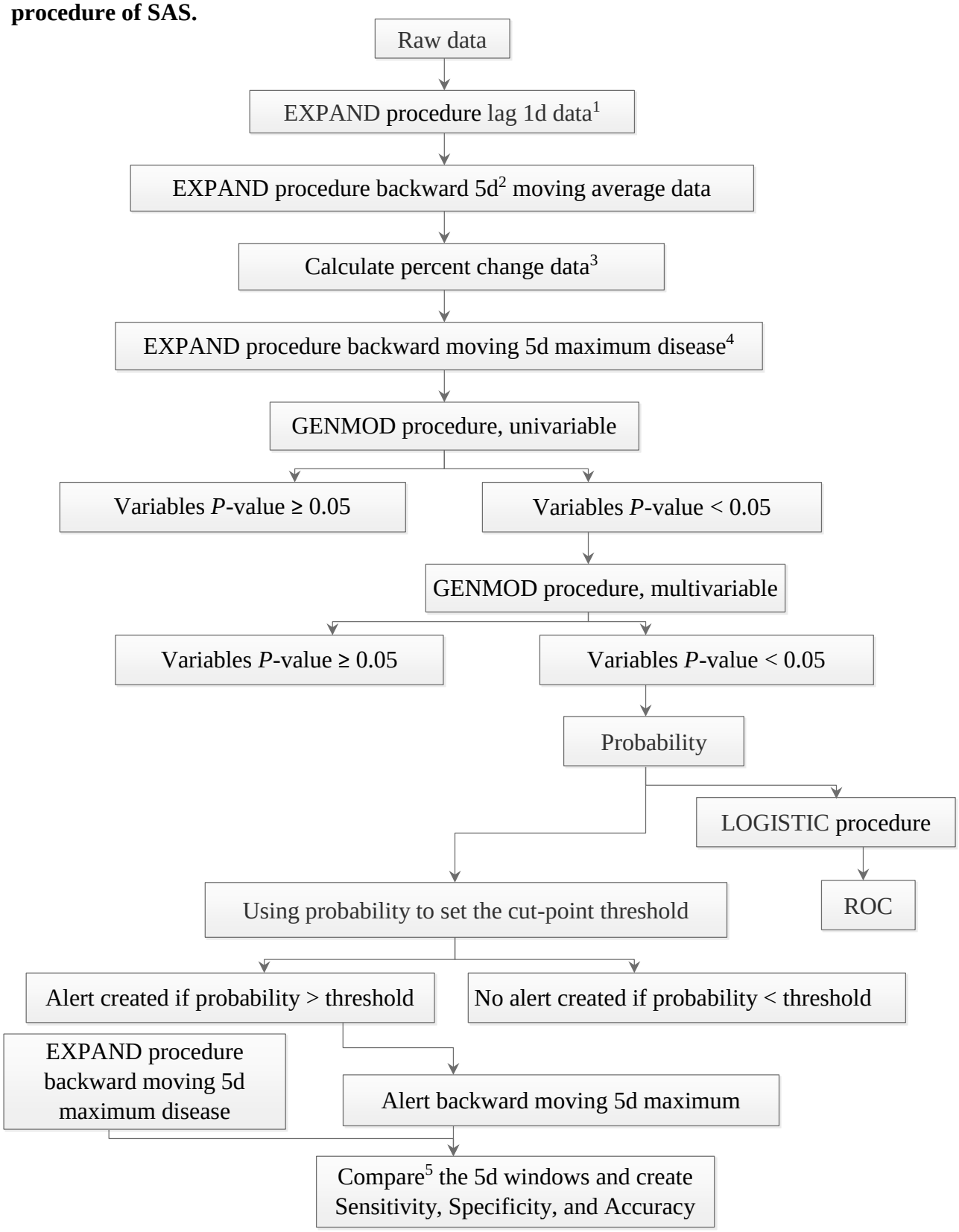


Figure 3.3. (cont.)

[1]Lag 1d data was generated by EXPAND procedure of SAS. If cows were found to be sick, their variables would change before the day diagnosed. Thus, using the day before the cow was recognized as sick was used.

[2]Backward moving 5d was generated for each cow, in order to calculate the average for every 5d.

[3]Percent change data was generated by the backward moving 5d data. By dividing the average and lag 1d data to create the percent change data.

[4]Disease was defined: when blood Ca levels ≤ 8.6 mg/dL were considered as hypocalcaemia (Chapinal et al., 2011). Blood ketone levels ≥ 1.2 mmol/l were considered as hyperketonemia (McArt et al., 2012b). MetriCheck scores ≥ 2 was considered as metritis (Sterrett et al., 2014).

[5]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.2. Precision dairy technologies used in evaluation of transition cow diseases including: hyperketonemia, hypocalcaemia, and metritis.

	Variables measured	Frequency of measurements/ reporting data
AfiAct Pedometer Plus, Afimilk, Kibbutz Afikim, Israel	Activity (steps/d) Lying time (min/d) Lying bouts (bouts/d)	Continuously/ per hour
AfiLab Milk Analyzer, Afimilk, Kibbutz Afikim, Israel	Protein (%) Fat (%) Lactose (%)	Each milking/ End of milking
AfiMilk MPC Milk Meter Afimilk, Kibbutz Afikim, Israel	Milk yield (kg/d) Fat protein ratio Milk conductivity (%)	Each milking/ End of milking
AfiWeigh, Afimilk, Kibbutz Afikim, Israel	Body weight (kg/d)	Each milking/ End of milking
CowManager SensoOr, Agis Automatisering, Harmelen, Netherlands	Rumination time (min/d) Eating time (min/d) Time not active (min/d) Time active (min/d) Time high active (min/d)	Every minute/ Every hour
DVM bolus, DVM System, LLC, Greeley, CO	Reticulorumen temperature (ºC)	Every 5 minutes/ Hourly
HR Tag, SCR Engineers Ltd., Netanya, Israel	Neck activity (units/d) Rumination time (min/d)	Continuously / Every 2 hours
IceQube, IceRobotics Ltd., Edinburgh, Scotland	Lying time (min) Steps (number/d) Motion index Lying bouts (bouts/d) Bout duration (unit/d)	Continuously/ 15 minute intervals
Track a))) Cow, ENGS System Innovative Dairy Solutions, Israel	Steps (number/d) Lying time (min) Lying bouts (bouts/d) Time spent at feed bunk (min/d) Feed bunk visit time (number/d)	Continuously/ Every 5 minutes
SmartBow, Smartbow GmbH, Jutogasse, Austria	Rumination time (min/d) Lying time (min/d) Time not active (min/d) Time active (min/d) Time high active (min/d)	Continuously/15 minute intervals

Table 3.3. Sensitivity[1], specificity[2], and accuracy[3] of precision dairy monitoring technology's[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined by the UNIVARIATE procedure in SAS[9,10,11].

Technology	Disease[5]			Hyperketonemia[6]			Hypocalcaemia[7]			Metritis[8]		
	Se[1] (%)	Sp[2] (%)	Acc[3] (%)	Se[1] (%)	Sp[2] (%)	Acc[3] (%)	Se[1] (%)	Sp[2] (%)	Acc[3] (%)	Se[1] (%)	Sp[2] (%)	Acc[3] (%)
AfiAct Pedometer Plus	71	82	78	78	68	67	77	71	72	72	77	76
AfiLab Milk Analyzer	75	86	82	78	84	84	79	82	81	76	79	78
AfiWeigh	33	80	94	61	90	90	49	92	88	28	91	81
All Afi system	78	81	80	74	90	89	71	86	88	70	82	79
Track a))) cow	79	79	79	79	74	74	74	78	78	75	78	78
DVM	35	92	79	32	94	92	31	95	90	41	93	85
IceQube	71	84	80	70	78	77	70	82	80	72	80	78
SCR, HR-Tag	42	96	82	70	83	82	68	87	84	54	88	81
Smartbow	53	90	79	70	81	81	64	74	73	61	78	74
CowManager	56	91	81	71	81	81	62	83	81	57	87	80

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.

[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.

[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).

[4]AfiAct Pedometer Plus, AfiLab Milk Analyzer, AfiMilk MPC Milk Meter, AfiWeigh, Afimilk, Kibbutz Afikim, Israel. Track a))) Cow, ENGS System Innovative Dairy Solutions, Israel. DVM bolus, DVM System, LLC, Greeley, CO. IceQube, IceRobotics Ltd., Edinburgh, Scotland. HR Tag, SCR Engineers Ltd., Netanya, Israel. SmartBow, Smartbow GmbH, Jutogasse, Austria. CowManager SensoOr, Agis Automatisering, Harmelen, Netherlands

[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.

[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.

[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.

[9]AfiAct rest bouts, AfiAct rest, and AfiAct steps 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.

[10]Alerts were created for any instances of AfiAct steps, AfiAct rest bout, and AfiAct rest that fell below the 10th percentile (AfiAct steps 2400) or above the 90th percentile (AfiAct rest bout 17, and AfiAct rest 711 min) for disease, hyperketonemia, hypocalcaemia, and metritis respectively

[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when AfiAct steps fell below 2400, AfiAct rest bout rose above 17, and AfiAct rest time rose above 711 min. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.4 Sensitivity[1], specificity[2], and accuracy[3] of AfiAct Pedometer Plus, (Afimilk, Kibbutz Afikim, Israel)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease	1	71	82	78
	2	52	91	80
Hyperketonemia	1	78	68	67
	2	63	82	81
Hypocalcaemia	1	77	71	72
	2	59	85	81
Metritis	1	72	77	76
	2	55	89	81

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.

[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.

[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).

[4]AfiAct Pedometer Plus measured activity, lying time and lying bouts.

[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.

[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.

[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.

[9]AfiAct rest bouts, AfiAct rest, and AfiAct steps 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.

[10]Alerts3 were created for any instances of AfiAct steps, AfiAct rest bout, and AfiAct rest that fell below the 10th percentile (AfiAct steps 2400) or above the 90th percentile (AfiAct rest bout 17, and AfiAct rest 711 min) for disease, hyperketonemia, hypocalcaemia, and metritis respectively

[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when AfiAct steps fell below 2400, AfiAct rest bout rose above 17, and AfiAct rest time rose above 711 min. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.5. Sensitivity[1], specificity[2], and accuracy[3] of AfiLab Milk Analyzer (Afimilk, Kibbutz Afikim, Israel) [4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease	1	82	78	80
	2	75	86	82
Hyperketonemia	1	89	60	62
	2	87	70	71
	3	84	76	78
	4	78	84	84
Hypocalcaemia	1	87	65	69
	2	84	75	77
	3	79	82	81
Metritis	1	82	70	74
	2	76	79	78

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]AfiLab MPC milk meter, measured milk fat, milk protein, and milk lactose.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
9AfiLab milk protein, AfiLab milk fat, AfiLab milk lactose, AfiLab milk fat protein ratio, AfiLab milk conductivity AfiLab milk yield, and AfiLab milking time 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.
[10]Alerts3 were created for any instances of AfiLab milk protein, AfiLab milk lactose, AfiLab milk yield, AfiLab conductivity, AfiLab milk fat, and AfiLab fat protein ratio that fell below the 10th percentile (AfiLab milk protein 2.7 %, AfiLab milk lactose 4.4 %, and AfiLab milk yield 18 kg) or above the 90th percentile (AfiLab milk conductivity 9.1 %, AfiLab milk fat 4.9 %, and AfiLab milk fat protein ratio 1.63) for disease, hyperketonemia, hypocalcaemia, and metritis respectively. If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.
[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when AfiLab milk protein fell below 2.7 %, AfiLab milk lactose fell below 4.4 %, AfiLab milk yield fell below 18 kg, AfiLab milk conductivity rose above 9.1 %, AfiLab milk fat rose above 4.9 %, and AfiLab milk fat protein ratio rose above 1.63. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.6. Sensitivity[1], specificity[2], and accuracy[3] of AfiWeigh (Afimilk, Kibbutz Afikim, Israel) [4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease	1	33	80	94
	2	26	96	80
Hyperketonemia	1	61	90	90
	2	51	94	92
Hypocalcaemia	1	49	92	88
	2	41	95	90
Metritis	1	28	91	81
	2	21	94	82

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]AfiWeigh measure body weight.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[9]AfiWeigh body weight 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.
[10]Alerts3 were created for any instances of AfiWeigh body weight above the 90th percentile (817.4 kg) for disease, hyperketonemia, hypocalcaemia, and metritis respectively. If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.
[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when AfiWeigh body weight rose above 817.4 kg. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.7. Sensitivity[1], specificity[2], and accuracy[3] of AfiMilk, AfiLab, and AfiWeigh (Afimilk, Kibbutz Afikim, Israel)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease	2	84	74	78
	3	78	81	80
	4	71	88	82
Hyperketonemia	4	87	74	75
	5	82	80	80
	6	77	85	84
	7	75	88	87
	8	74	90	89
Hypocalcaemia	4	81	79	79
	5	75	84	83
	6	71	86	88
Metritis	4	70	82	79
	5	64	86	81

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.

[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.

[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).

[4]AfiMilk, AfiLab, and AfiWeigh were combined together.

[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.

[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.

[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.

[9]Afimilk rest bouts, Afimilk rest, AfiMilk steps, AfiMilk milk protein, AfiMilk milk fat, AfiMilk milk lactose, AfiMilk milk fat protein ratio, AfiMilk milk conductivity AfiMilk milk yield, AfiMilk milking time, and AfiWeigh body weight 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.

[10]Alerts3 were created for any instances of AfiMilk milk protein, AfiMilk milk lactose, AfiMilk steps, AfiMilk milk yield, AfiMilk rest bout, AfiMilk conductivity, AfiMilk rest, AfiWeigh body weight, AfiMilk milk fat, and AfiMilk fat protein ratio that fell below the 10th percentile (AfiMilk milk protein 2.7 %, AfiMilk milk lactose 4.4 %, AfiMilk steps 2400, AfiMilk milk yield 18 kg) or above the 90th percentile (AfiMilk rest bout 17, AfiMilk milk conductivity 9.1 %, AfiMilk rest 711 min, AfiWeigh body weight 817.4 kg, AfiMilk milk fat 4.9 %, and AfiMilk milk fat protein ratio 1.63) for disease, hyperketonemia, Hypocalcaemia , and metritis respectively. If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.

[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when AfiMilk milk protein fell below 2.7 %, AfiMilk milk lactose fell below 4.4 %, AfiMilk steps fell below 2400, AfiMilk milk yield fell below 18 kg, AfiMilk rest bout rose above 17, AfiMilk milk conductivity rose above 9.1 %, AfiMilk rest rose above 711 min, AfiWeigh body weight rose

above 817.4 kg, AfiMilk milk fat rose above 4.9 %, and AfiMilk milk fat protein ratio rose above 1.63. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.8. Sensitivity[1], specificity[2], and accuracy[3] of Track a))) cow (ENGS System Innovative Dairy Solutions, Israel)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease	1	79	79	79
	2	68	87	81
Hyperketonemia	2	79	74	74
	3	69	82	81
Hypocalcaemia	1	74	78	78
	2	67	85	83
Metritis	2	75	78	78
	3	61	89	82

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]Track a))) cow measured, steps, lying time, lying bouts, time around the feed bunk, and time visit feed bunk.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[9]Track a))) cow lying time, Track a))) cow lying bouts, Track a))) cow steps, Track a))) cow time around feed bunk, and Track a))) cow feed bunk visit 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.
[10]Alert3 were created for any instances of Track a))) cow steps, Track a))) cow lying bouts, Track a))) cow time around the feed bunk, and Track a))) cow feed bunk visit that fell below the 10th percentile (Track a))) cow steps 1228, Track a))) cow lying bouts 7, Track a))) cow time around the feed bunk 66 min, and Track a))) cow feed bunk visit 5,), and Track a))) cow lying above the 90th percentile (741.5 min) for disease, Hyperketonemia, and Hypocalcaemia, respectively. For metritis, Track a))) cow steps fell below 10th percentile (Track a))) cow steps 1228) and Track a))) cow lying, Track a))) cow lying bout, Track a))) cow time around feed bunk, and Track a))) cow feed bunk visit rose above 90th percentile (Track a))) cow lying 741.5, Track a))) cow lying bouts 23, Track a))) cow time around feed bunk 261 min, and Track a))) cow feed bunk visit 12). If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.
[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when Track a))) cow steps fell below 1228, Track a))) cow lying bouts fell below 7, Track a))) cow time around the feed bunk fell below 66 min, and Track a))) cow feed bunk visit fell below 5. A 5-day window was created from each initial alert when Track a))) cow lying rose above 741.5 min for disease, hyperketonemia, and hypocalcaemia. A5-day window was created from each initial alert when Track a))) cow steps fell below 1228, Track a))) cow lying rose above 741.5 min, Track a cow lying bouts rose above 23, Track a))) cow time around feed bunk rose above 261 min, and Track a))) cow feed bunk visit rose above 12 for metritis. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An

event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.9. Sensitivity[1], specificity[2], and accuracy[3] of DVM (DVM System, LLC, Greeley, CO) [4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease	1	35	92	79
	2	21	97	80
Hyperketonemia	1	45	89	87
	2	32	94	92
Hypocalcaemia	1	49	90	87
	2	31	95	90
Metritis	1	41	93	85
	2	17	97	85

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]DVM bolus measured reticulorumen temperature.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[9]Reticulorumen temperature 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th percentile as more promising for disease, hyperketonemia, and hypocalcaemia alert creation. Graphical examination identified the 90th percentile as more promising for metritis alert creation.
[10]Alert3 were created for any instances of reticulorumen temperature that fell below the 10th percentile (39.1ºC for disease, hyperketonemia, and hypocalcaemia, respectively) or above the 90th percentile (40.3ºC) for metritis. If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.
[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when reticulorumen temperature fell below 39.1ºC for disease, Hyperketonemia, and hypocalcaemia. A 5-day window was created from each initial alert when reticulorumen temperature rose above 40.3 ºC for metritis. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.10. Sensitivity[1], specificity[2], and accuracy[3] of IceQube (IceRobotics Ltd., Edinburgh, Scotland)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[6]	2	76	80	78
	3	71	84	80
Hyperketonemia	3	79	69	70
	4	70	78	77
Hypocalcaemia	3	78	74	75
	4	70	82	80
Metritis	3	72	80	78
	4	67	85	80

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/(true positive + false positive + true negative + false negative).
[4]IceQube measured lying time, lying bout, steps, motion, and lying duration.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[9]IceQube lying time, IceQube lying bouts, IceQube steps, IceQube standing time, IceQube motion index, and IceQube lying bouts duration 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.
[10]Alert3 were created for any instances of IceQube steps, IceQube standing time, and IceQube motion index that fell below the 10th percentile (IceQube steps 581.5, IceQube standing time 705.3 min, and IceQube motion index 2028), and IceQube lying time, IceQube lying bouts, and IceQube lying bouts duration above the 90th percentile (IceQube lying time 734.7 min, IceQube lying bouts 30, and IceQube lying bouts duration 734.90 min) for disease, hyperketonemia, and hypocalcaemia, respectively. For metritis, IceQube lying time, IceQube lying bouts, IceQube steps, IceQube standing time, IceQube motion index, and IceQube lying bouts duration fell below 10th percentile (IceQube lying time 360.3 min, IceQube lying bouts 11, IceQube steps 581.5, IceQube standing time705.3, IceQube motion index 2028) and IceQube lying bouts duration rose above 90th percentile(734.9 min). If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.
[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert IceQube steps fell below 581.5, IceQube standing time fell below 705.3 min, and IceQube motion index fell below 2028, IceQube lying time rose above 734.7 min, IceQube lying bouts rose above 30, and IceQube lying bouts duration rose above 734.90 min for disease, Hyperketonemia, and Hypocalcaemia . A5-day window was created from each initial alert when IceQube lying time fell below 360.3 min, IceQube lying bouts fell below 11, IceQube steps fell below 581.5, IceQube standing time fell below 705.3, IceQube motion index fell below 2028, and IceQube lying bouts duration rose above 360.3 min for metritis. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.11. Sensitivity[1], specificity[2], and accuracy[3] of SCR, HR-Tag (Engineers Ltd., Netanya, Israel)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[6]	1	54	92	81
	2	42	96	82
Hyperketonemia	1	70	83	82
	2	57	89	88
Hypocalcaemia	1	68	87	84
	2	55	91	88
Metritis	1	54	88	81
	2	44	93	84

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.

[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.

[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).

[4]SCR HR tag measured neck activity and rumination time.

[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.

[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.

[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.

[9]HR-tag neck activity and HR-tag rumination 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.

[10]Alerts3 were created for any instances of HR-tag neck activity and HR-tag rumination that fell below the 10th percentile (HR-tag neck activity 257 and HR-tag rumination 345) for disease, hyperketonemia, hypocalcaemia, and metritis respectively. If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.

[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert HR-tag neck activity fell below 257 and HR-tag rumination fell below 345 for disease, Hyperketonemia, hypocalcaemia, and metritis. Any alert window that overlapped with an event (disease, Hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.12. Sensitivity[1], specificity[2], and accuracy[3] of Smartbow (Smartbow GmbH, Jutogasse, Austria)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[6]	1	61	82	75
	2	53	90	79
Hyperketonemia	1	75	72	72
	2	70	81	81
Hypocalcaemia	1	64	74	73
	2	57	82	80
Metritis	1	54	88	81
	2	61	78	74

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]Smartbow measured rumination time, lying time, time not active, time active, and time high active.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[9]Smartbow lying time, Smartbow rumination, Smartbow standing time, Smartbow time not active, Smartbow active, and SmartBow high active 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.
[10]Alerts3 were created for any instances of Smartbow rumination, Smartbow standing time, SmartBow high active, and Smartbow active that fell below the 10th percentile (Smartbow rumination 411, Smartbow standing time 537 min, SmartBow high active 41, and Smartbow active 790 min), Smartbow lying time and Smartbow time not active above the 90th percentile (Smartbow lying time 903 min and Smartbow time not active 498 min) for disease, hyperketonemia, hypocalcaemia, and metritis respectively. If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.
[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when Smartbow rumination fell below 411, Smartbow standing time fell below 537 min, SmartBow high active fell below 41, and Smartbow active fell below 790 min. A 5-day window was created from each initial alert when Smartbow lying time rose above 903 min and Smartbow time not active rose above 498 min for disease, hyperketonemia, hypocalcaemia, and metritis. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.13. Sensitivity[1], specificity[2], and accuracy[3] of CowManager, SensoOr (Agis Automatisering, Harmelen, Netherlands)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[6]	1	56	91	81
	2	45	94	81
Hyperketonemia	1	71	81	81
	2	65	87	86
Hypocalcaemia	1	62	83	81
	2	54	89	86
Metritis	1	57	87	80
	2	44	91	82

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]CoManager SensoOr measured rumination time, lying time, time not active, time active, and time high active.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[9]Sensoor rumination, SensoOr time not active, SensoOr active, SensoOr eating time and SensoOr high active 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation.
[10]Alert3 were created for any instances of SensoOr rumination, SensoOr high active, SensoOr eating time, and SensoOr active that fell below the 10th percentile (SensoOr rumination 400 min, SensoOr high active 34.4, SensoOr eating time 101 min, and SensoOr active 47), SensoOr time not active above the 90th percentile (724 min) for disease, Hyperketonemia, Hypocalcaemia , and metritis respectively. If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.
[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when SensoOr rumination fell below 400 min, SensoOr high active fell below 34.4, SensoOr eating time fell below 101 min, and SensoOr active fell below 47. A 5-day window was created from each initial alert when SensoOr time not active rose above 724 min for disease, hyperketonemia, hypocalcaemia, and metritis. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.14. Sensitivity[1], specificity[2], and accuracy[3] of All the precision dairy technology's[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection defined from the UNIVARIATE procedure in SAS[9,10,11].

Diseases[5]	Alert3[10]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease	9	81	83	82
	10	78	87	83
	11	76	89	84
	12	71	91	85
Hyperketonemia	13	85	79	80
	14	83	81	82
	15	80	83	83
	16	77	85	85
Hypocalcaemia	12	81	81	81
	13	78	84	83
	14	76	86	84
	15	73	87	85
Metritis	17	84	70	75
	18	82	74	76
	19	79	77	78

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.

[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.

[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).

[4]All the Precision dairy technologies that were used in this study, including Afi (Afimilk, Kibbutz Afikim, Israel), Track a))) cow (ENGS System Innovative Dairy Solutions, Israel), DVM bolus, DVM System, LLC, Greeley, CO, IceQube (IceRobotics Ltd., Edinburgh, Scotland), HR Tag, SCR Engineers Ltd., Netanya, Israel, SmartBow (Smartbow GmbH, Jutogasse, Austria), CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands)

[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations.

[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.

[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.

[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.

[9]AfiMilk milk protein, AfiMilk milk lactose, AfiMilk steps, AfiMilk milk yield, AfiMilk rest bout, AfiMilk conductivity, AfiMilk rest, AfiWeigh body weight, AfiMilk milk fat, AfiMilk fat protein ratio, Reticulorumen temperature, Track a))) cow lying time, Track a))) cow lying bouts, Track a))) cow steps, Track a))) cow time around feed bunk, Track a))) cow feed bunk visit, IceQube lying time, IceQube lying bouts, IceQube steps, IceQube standing time, IceQube motion index, IceQube lying bouts duration, HR-tag neck activity, HR-tag rumination, Smartbow lying time, Smartbow rumination, Smartbow standing time, Smartbow time not active, Smartbow active, SmartBow high active, SensoOr rumination, SensoOr time not active, SensoOr active, SensoOr eating time, SensoOr high active 90th and 10th percentiles were identified using the UNIVARIATE procedure in SAS 9.3 (SAS Inc, Raleigh, NC). Graphical examination identified the 10th and 90th percentile as more promising for disease, hyperketonemia, hypocalcaemia, and metritis alert creation. If an alert occurred for either the 10th or 90th percentile, the number of alerts was equal to 1. If an alert occurred at both the 10th and 90th percentiles, the number of alerts was equal to 2.

[10]Alert3 were created for any instances of AfiMilk milk protein, AfiMilk milk lactose, AfiMilk steps , AfiMilk milk yield, Track a))) cow steps, Track a))) cow lying bouts, Track a))) cow time around the feed bunk, Track a))) cow

feed bunk visit, IceQube steps, IceQube standing time, IceQube motion index, HR-tag neck activity, HR-tag rumination, Smartbow rumination, Smartbow standing time, SmartBow high active, Smartbow active, SensoOr rumination, SensoOr high active, SensoOr eating time, and SensoOr active that fell below the 10^{th} , and AfiMilk rest bout, AfiMilk milk conductivity, AfiMilk rest, AfiWeigh body weight, AfiMilk milk fat, AfiMilk milk fat protein ratio, Track a))) cow lying, IceQube lying time, IceQube lying bouts, and IceQube lying bouts duration, Smartbow lying time, Smartbow time not active, and SensoOr time not active above the 90^{th} percentile for disease, Hyperketonemia, and Hypocalcaemia , respectively.

[11]Alert windows were created with the backward moving maximum feature of the EXPAND procedure in SAS. A 5-day window was created from each initial alert when Track a))) cow steps fell below 1228, Track a))) cow lying bouts fell below 7, Track a))) cow time around the feed bunk fell below 66 min, and Track a))) cow feed bunk visit fell below 5. A 5-day window was created from each initial alert when Track a))) cow lying rose above 741.5 min for disease, hyperketonemia, and hypocalcaemia. A5-day window was created from each initial alert when Track a))) cow steps fell below 1228, Track a))) cow lying rose above 741.5 min, track a cow lying bouts rose above 23, Track a))) cow time around feed bunk rose above 261 min, and Track a))) cow feed bunk visit rose above 12 for metritis. Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.15. Odds ratios[1] of cows having any disease[2], hyperketonemia[3], hypocalcaemia[4], or metritis[5] based on variables measured by AfiMilk, AfiLab, and AfiWeigh (Afimilk, Kibbutz Afikim, Israel) for fresh cows from 1 to 21 DIM (GENMOD procedure of SAS[6]).

Disease / Variable	SD[7]	Odds ratios	95% Confidence interval		*P*-value
Disease					
Milk fat (%)	0.7	1.33	1.12	1.57	<0.01
Milk protein (%)	-0.3	1.20	1.06	1.36	<0.01
Milk fat protein ratio	0.2	1.61	1.35	1.93	<0.01
Milk lactose	0.3	1.22	1.08	1.39	<0.01
Milking time (min)	-1.9	1.25	1.06	1.47	<0.01
Milk yield (kg/d)	-10	1.25	1.01	1.55	0.03
Hyperketonemia					
Milk fat (%)	0.7	1.76	1.37	2.27	<0.01
Fat protein ratio	0.2	1.75	1.32	2.32	<0.01
Milk conductivity (%)	0.9	1.21	1.02	1.44	0.02
Body weight (kg)	87	1.89	1.35	2.63	<0.01
Hypocalcaemia					
Milk fat (%)	0.7	1.87	1.62	2.39	<0.01
Milk protein (%)	0.3	1.40	1.15	1.70	<0.01
Milk lactose (%)	-0.3	1.28	1.14	1.45	<0.01
Milk fat protein ratio	0.2	1.48	1.22	1.81	<0.01
Milk yield (kg)	-10	2.21	1.57	3.10	<0.01
Milk conductivity (%)	0.9	1.43	1.06	1.93	0.02
Milking time (min)	-1.9	1.46	1.00	2.13	0.04
Body weight (kg)	-87	2.00	1.45	2.74	<0.01
Rest time (min)	153	1.15	1.00	1.33	0.04
Metritis					
Milk protein (%)	-0.3	1.62	1.38	1.91	<0.01
Milk lactose (%)	0.3	1.48	1.25	1.75	<0.01
Fat protein ratio	0.2	1.48	1.23	1.77	<0.01
Milk conductivity (%)	0.9	1.31	1.12	1.52	<0.01

[1]Odd ratio represents the relative odds of having disease. If odd ratio is >1, the odds of having disease increased. If odd ratio is <1, the odds of having disease decreased. Odd ratio was affected by the number of unit.
[2]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, and any of their combinations.
[3]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[4] Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[5]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[6]Univerable model in the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC) was used, but only variables that is significant from univariable would be calculated for odd ratio.
[7]SD = one standard deviation different from the herd average and the change observe a corresponding of odds ratio. For example, if milk fat percentage increased by .2%, then that animal had a 1.33 greater chance of experiencing any disease (hyperketonemia, hypocalcaemia, metritis, or any combination).

Table 3.16. Odds ratios[1] of cows having any disease[2], hyperketonemia[3], hypocalcaemia[4], or metritis[5] based on variables measured by Track a))) cow (ENGS System Innovative Dairy Solutions, Israel) for fresh cows from 1 to 21 DIM (GENMOD procedure of SAS[6]).

Disease / Variable	SD[7]	Odd ratio	95% Confidence interval		*P*-value
Disease					
Time at the feed bunk (min)	-76	1.19	1.03	1.37	0.02
Step	-679	1.23	1.05	1.43	<0.01
Lying time (min)	164	1.16	1.00	1.34	0.04
Hyperketonemia	N/A				
Hypocalcaemia					
Time at the feed bunk (min)	-76	1.65	1.35	2.03	<0.01
Metritis					
Step	-679	1.24	1.06	1.45	<0.01

[1]Odd ratio represents the relative odds of having disease. If odd ratio is >1, the odds of having disease increased. If odd ratio is <1, the odds of having disease decreased. Odd ratio was affected by the number of unit.
[2]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, and any of their combinations.
[3]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[4] Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[5]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[6]Univerable model in the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC) was used, but only variables that is significant from univariable would be calculated for odd ratio.
[7]SD = one standard deviation different from the herd average and the change observe a corresponding of odds ratio. For example, if time at the feed bunk decreased by 76 min, then that animal had a 1.19 greater chance of experiencing any disease (hyperketonemia, hypocalcaemia, metritis, or any combination).

Table 3.17. Odds ratios[1] of cows having any disease[2], hyperketonemia[3], hypocalcaemia[4], or metritis[5] based on variables measured by DVM bolus (DVM System, LLC, Greeley, CO) for fresh cows from 1 to 21 DIM (GENMOD procedure of SAS[6]).

Disease / Variable	SD[7]	Odd ratio	95% Confidence interval		*P*-value
Disease					
Reticulorumen temperature (ºC)	0.8	1.18	1.01	1.38	0.04
Hyperketonemia	N/A				
Hypocalcaemia	N/A				
Metritis	N/A				

[1]Odd ratio represents the relative odds of having disease. If odd ratio is >1, the odds of having disease increased. If odd ratio is <1, the odds of having disease decreased. Odd ratio was affected by the number of unit.
[2]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, and any of their combinations.
[3]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[4] Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[5]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[6]Univerable model in the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC) was used, but only variables that is significant from univariable would be calculated for odd ratio.
[7]SD = one standard deviation different from the herd average and the change observe a corresponding of odds ratio. For example, if reticulorumen temperature increased by 0.8ºC, then that animal had a 1.18 greater chance of experiencing any disease (hyperketonemia, hypocalcaemia, metritis, or any combination).

Table 3.18. Odds ratios[1] of cows having any disease[2], hyperketonemia[3], hypocalcaemia[4], or metritis[5] based on variables measured by IceQube (IceRobotics Ltd., Edinburgh, Scotland) for fresh cows from 1 to 21 DIM (GENMOD procedure of SAS[6]).

Disease / Variable	SD[7]	Odd ratio	95% Confidence interval		*P*-value
Disease					
Lying time (min)	142	1.18	1.05	1.33	<0.01
Bout duration (min)	142	1.18	1.04	1.33	<0.01
Hyperketonemia					
Lying time (min)	142	1.27	1.03	1.56	0.02
Bout duration (min)	142	1.27	1.03	1.56	0.02
Hypocalcaemia					
Lying time (min)	142	1.26	1.08	1.47	<0.01
Bout duration (min)	142	1.26	1.08	1.47	<0.01
Step	474	1.17	1.00	1.36	0.04
Metritis					
Step	-474	1.29	1.14	1.46	<0.01
Motion index	-1667	1.32	1.02	1.07	<0.01

[1]Odd ratio represents the relative odds of having disease. If odd ratio is >1, the odds of having disease increased. If odd ratio is <1, the odds of having disease decreased. Odd ratio was affected by the number of unit.
[2]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, and any of their combinations.
[3]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[4] Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[5]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[6]Univerable model in the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC) was used, but only variables that is significant from univariable would be calculated for odd ratio.
[7]SD = one standard deviation different from the herd average and the change observe a corresponding of odds ratio. For example, if lying time increased by 142 min, then that animal had a 1.18 greater chance of experiencing any disease (hyperketonemia, hypocalcaemia, metritis, or any combination).

Table 3.19. Odds ratios[1] of cows having any disease[2], hyperketonemia[3], hypocalcaemia[4], or metritis[5] based on variables measured by HR Tag (SCR Engineers Ltd., Netanya, Israel) for fresh cows from 1 to 21 DIM (GENMOD procedure of SAS[6]).

Disease / Variable	SD[7]	Odd ratio	95% Confidence interval		*P*-value
Disease					
Neck activity	-119	1.39	1.12	1.71	<0.01
Hyperketonemia					
Neck activity	-119	2.72	1.64	4.53	<0.01
Hypocalcaemia					
Neck activity	-119	1.96	1.41	2.73	<0.01
Rumination	-110	1.54	1.26	1.89	<0.01
Metritis					
Rumination	110	1.31	1.09	1.58	<0.01

[1]Odd ratio represents the relative odds of having disease. If odd ratio is >1, the odds of having disease increased. If odd ratio is <1, the odds of having disease decreased. Odd ratio was affected by the number of unit.
[2]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, and any of their combinations.
[3]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[4] Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[5]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[6]Univerable model in the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC) was used, but only variables that is significant from univariable would be calculated for odd ratio.
[7]SD = one standard deviation different from the herd average and the change observe a corresponding of odds ratio. For example, if neck activity decreased by 119 unit, then that animal had a 1.39 greater chance of experiencing any disease (hyperketonemia, hypocalcaemia, metritis, or any combination).

Table 3.20. Odds ratios[1] of cows having any disease[2], hyperketonemia[3], hypocalcaemia[4], or metritis[5] based on variables measured by SmartBow (Smartbow GmbH, Jutogasse, Austria) for fresh cows from 1 to 21 DIM (GENMOD procedure of SAS[6]).

Disease / Variable	SD[7]	Odd ratio	95% Confidence interval		*P*-value
Disease					
Not active (min)	107	1.20	1.01	1.43	0.03
Lying time (min)	137	1.32	1.12	1.54	<0.01
Hyperketonemia					
Not active (min)	107	1.64	1.25	2.14	<0.01
Lying time (min)	137	1.51	1.09	2.08	0.02
Rumination (min)	-96	1.62	1.20	2.19	<0.01
Hypocalcaemia					
Not active (min)	107	1.42	1.17	1.72	<0.01
Rumination (min)	-96	1.38	1.11	1.72	<0.01
Metritis	N/A				

[1]Odd ratio represent the relative odds of having disease. If odd ratio is >1, the odds of having disease increased. If odd ratio is <1, the odds of having disease decreased. Odd ratio was affected by the number of unit.
[2]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, and any of their combinations.
[3]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[4] Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[5]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[6]Univerable model in the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC) was used, but only variables that is significant from univariable would be calculated for odd ratio.
[7]SD = one standard deviation different from the herd average and the change observe a corresponding of odds ratio. For example, if lying time increased by 137 min, then that animal had a 1.32 greater chance of experiencing any disease (hyperketonemia, hypocalcaemia, metritis, or any combination).

Table 3.21. Odds ratios[1] of cows having any disease[2], hyperketonemia[3], hypocalcaemia[4], or metritis[5] based on variables measured by CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands) for fresh cows from 1 to 21 DIM (GENMOD procedure of SAS[6]).

Disease / Variable	SD[7]	Odd ratio	95% Confidence interval		*P*-value
Disease					
Eating (min)	-113	1.33	1.03	1.72	0.02
Hyperketonemia					
Not active (min)	172	1.58	1.19	2.11	<0.01
Hypocalcaemia					
Not active (min)	172	1.47	1.14	1.88	<0.01
Rumination (min)	-120	1.30	0.99	1.70	0.05
Eating (min)	-113	1.43	1.09	1.88	<0.01
Metritis					
Active (min)	-23	1.21	1.02	1.42	0.02
Rumination (min)	120	1.33	1.08	1.65	<0.01

[1]Odd ratio represents the relative odds of having disease. If odd ratio is >1, the odds of having disease increased. If odd ratio is <1, the odds of having disease decreased. Odd ratio was affected by the number of unit.
[2]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, and any of their combinations.
[3]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM.
[4] Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[5]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM.
[6]Univerable model in the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC) was used, but only variables that is significant from univariable would be calculated for odd ratio.
[7]SD = one standard deviation different from the herd average and the change observe a corresponding of odds ratio. For example, if eating time decreased by 113 min, then that animal had a 1.33 greater chance of experiencing any disease (hyperketonemia, hypocalcaemia, metritis, or any combination).

Table 3.22. Sensitivity[1], specificity[2], and accuracy[3] of AfiMilk, AfiLab, and AfiWeigh (Afimilk, Kibbutz Afikim, Israel)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection created from the GENMOD procedure in SAS[9].

Diseases	AUC[10]	Disease probability threshold[11,12,13]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[5]	0.75	0.01	84	70	76
		0.50	80	85	83
		0.60	75	90	85
Hyperketonemia[6]	0.81	0.01	80	68	68
		0.05	80	79	79
		0.10	74	90	89
Hypocalcaemia[7]	0.83	0.01	86	50	55
		0.16	82	80	80
		0.27	76	90	89
Metritis[8]	0.67	0.30	90	61	71
		0.45	83	80	81
		0.55	70	90	86

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/(true positive + false positive + true negative + false negative).
[4]AfiMilk, AfiLab, and AfiWeigh were combined together.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations. Disease multivariable included milk fat protein ratio, milk yield, milking time, milk lactose, milk protein, milk fat, percent change of milk fat protein ratio, percent change of milk yield, percent change of milk conductivity, percent change of milk lactose, percent change of milk protein, and any of the interaction.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included pervious lactation 305 days' actual milk, milk fat protein ratio, milk conductivity, body weight, milk fat, percent change of milk fat protein ratio, percent change of milk conductivity, percent change of milk lactose, percent change of milk protein, and any of the interaction.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM. Hypocalcaemia multivariable included milk fat protein ratio, milk yield, milk conductivity, milking time, body weight, milk lactose, milk protein, milk fat, resting time, percent change of milk fat protein ratio, percent change of milk yield, percent change of milking time, percent change of milk lactose, percent change of milk protein, and any of the interaction.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM. Metritis multivariable included milk fat protein ratio, milk conductivity, milk lactose, milk protein, percent change of milk conductivity, percent change of milk time, and any of the interaction.
[9]The previous day's data and percent change data were included in multivariable model using the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC).
[10]AUC, signifies the magnitude of the quantity that is obtained by the product of the quantities signified by the 1-specificity and the sensitivity axes. If AUC was > 0.7, the accurate performance would found (Swets, 1988).
[11]Probability was created from GENMOD, predicted probability that the response variable is less than or equal to the value.
[12]Alert was created when probability is greater than the threshold, and backward moving maximum feature of the EXPAND procedure in SAS.
[13]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An

event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.23. Sensitivity[1], specificity[2], and accuracy[3] of Track a))) cow (ENGS System Innovative Dairy Solutions, Israel)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection created from the GENMOD procedure in SAS[9].

Diseases	AUC[10]	Disease probability threshold[11,12,13]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[5]	0.63	0.01	84	66	74
		0.59	80	81	81
		0.66	69	90	83
Hyperketonemia[6]	0.64	0.01	83	63	65
		0.81	77	70	71
		0.91	21	90	88
Hypocalcaemia[7]	0.64	0.01	86	43	51
		0.75	62	66	65
		0.85	23	90	86
Metritis[8]	0.58	0.35	90	54	67
		0.48	73	76	75
		0.53	41	90	82

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/(true positive + false positive + true negative + false negative).
[4]Track a))) cow measured, steps, lying time, lying bouts, time around the feed bunk, and time visit feed bunk.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations. Disease multivariable included time around the feed bunk, steps, lying time, and any of the interaction.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included pervious lactation 305 days' actual milk, time around the feed bunk, and any of the interaction.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM. Hypocalcaemia multivariable included, time around the feed bunk
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM. Metritis multivariable included steps.
[9]The previous day's data and percent change data were included in multivariable model using the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC).
[10]AUC, signifies the magnitude of the quantity that is obtained by the product of the quantities signified by the 1-specificity and the sensitivity axes. If AUC was > 0.7, the accurate performance would found (Swets, 1988).
[11]Probability was created from GENMOD, predicted probability that the response variable is less than or equal to the value.
[12]Alert was created when probability is greater than the threshold, and backward moving maximum feature of the EXPAND procedure in SAS.
[13]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.24. Sensitivity[1], specificity[2], and accuracy[3] of DVM bolus (DVM System, LLC, Greeley, CO)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection created from the GENMOD procedure in SAS[9].

Diseases	AUC[10]	Disease probability threshold[11,12,13]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[5]	0.56	0.01	70	76	74
		0.50	70	77	75
		0.62	50	92	81
Hyperketonemia[6]	0.77	0.01	69	76	76
		0.02	69	78	77
		0.09	57	92	90
Hypocalcaemia[7]	0.54	0.01	77	59	61
		0.21	70	75	74
		0.24	43	93	88
Metritis[8]	N/A	N/A	N/A	N/A	N/A

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]DVM bolus measured reticulorumen temperature.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations. Disease multivariable included DHI protein record, reticulum temperature, percent change of reticulum temperature, and any of the interaction.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included pervious lactation 305 days' actual milk, time around the feed bunk, and any of the interaction.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included pervious lactation 305 days' actual milk, temperature, percent change of reticulum temperature, and any of the interaction.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM. Metritis multivariable included percent change of reticulum temperature.
[9]The previous day's data and percent change data were included in multivariable model using the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC).
[10]AUC, signifies the magnitude of the quantity that is obtained by the product of the quantities signified by the 1-specificity and the sensitivity axes. If AUC was > 0.7, the accurate performance would found (Swets, 1988).
[11]Probability was created from GENMOD, predicted probability that the response variable is less than or equal to the value.
[12]Alert was created when probability is greater than the threshold, and backward moving maximum feature of the EXPAND procedure in SAS.
[13]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.25. Sensitivity[1], specificity[2], and accuracy[3] of IceQube (IceRobotics Ltd., Edinburgh, Scotland) [4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection created from the GENMOD procedure in SAS[9].

Diseases	AUC[10]	Disease probability threshold[11,12,13]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[5]	0.60	0.40	92	50	70
		0.64	78	82	80
		0.68	65	90	81
Hyperketonemia[6]	0.64	0.10	90	67	69
		0.13	83	79	80
		0.18	55	90	88
Hypocalcaemia[7]	0.61	0.20	90	52	59
		0.29	77	81	80
		0.35	65	90	88
Metritis[8]	0.59	0.46	92	57	70
		0.50	81	75	77
		0.55	52	92	84

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]IceQube measured lying time, lying bout, steps, motion, and lying duration.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations. Disease multivariable included DHI protein record, lying time, bout duration time, and any of the interaction.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included pervious lactation 305 days' actual milk, lying time, bout duration time, and any of the interaction.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM. Hypocalcaemia multivariable included lying time, step, bout duration time, percent change of bout duration, percent change of steps, percent change of motion, percent change of lying time, and any of the interaction.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM. Metritis multivariable included motion, steps, and any of the interaction.
[9]The previous day's data and percent change data were included in multivariable model using the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC).
[10]AUC, signifies the magnitude of the quantity that is obtained by the product of the quantities signified by the 1-specificity and the sensitivity axes. If AUC was > 0.7, the accurate performance would found (Swets, 1988).
[11]Probability was created from GENMOD, predicted probability that the response variable is less than or equal to the value.
[12]Alert was created when probability is greater than the threshold, and backward moving maximum feature of the EXPAND procedure in SAS.
[13]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.26. Sensitivity[1], specificity[2], and accuracy[3] HR Tag (SCR Engineers Ltd., Netanya, Israel)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection created from the GENMOD procedure in SAS[9].

Diseases	AUC[10]	Disease probability threshold[11,12,13]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[5]	0.61	0.01	80	70	73
		0.57	76	80	78
		0.67	62	90	82
Hyperketonemia[6]	0.69	0.01	79	54	55
		0.10	71	78	78
		0.17	75	74	75
Hypocalcaemia[7]	0.66	0.01	84	52	57
		0.18	69	85	83
		0.30	65	90	87
Metritis[8]	0.52	0.01	84	60	69
		0.48	74	74	74
		0.55	53	90	82

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]SCR HR tag measured neck activity and rumination time.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations. Disease multivariable included DHI protein record, neck activity, and any of the interaction.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included DHI protein record, neck activity, and any of the interaction.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM. Hypocalcaemia multivariable included rumination, neck activity, percent change of rumination, percent change of neck activity, and any of the interaction.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM. Metritis multivariable included rumination.
[9]The previous day's data and percent change data were included in multivariable model using the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC).
[10]AUC, signifies the magnitude of the quantity that is obtained by the product of the quantities signified by the 1-specificity and the sensitivity axes. If AUC was > 0.7, the accurate performance would found (Swets, 1988).
[11]Probability was created from GENMOD, predicted probability that the response variable is less than or equal to the value.
[12]Alert was created when probability is greater than the threshold, and backward moving maximum feature of the EXPAND procedure in SAS.
[13]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.27. Sensitivity[1], specificity[2], and accuracy[3] SmartBow (Smartbow GmbH, Jutogasse, Austria) [4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection created from the GENMOD procedure in SAS[9].

Diseases	AUC[10]	Disease probability threshold[11,12,13]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[5]	0.71	0.01	46	87	76
		0.20	46	88	77
		0.30	45	90	78
Hyperketonemia[6]	0.91	0.01	47	93	91
		0.02	45	94	93
		0.03	45	96	94
Hypocalcaemia[7]	0.70	0.01	58	72	70
		0.15	54	82	80
		0.20	47	90	86
Metritis[8]	0.51	0.01	75	68	70
		0.45	70	77	75
		0.47	47	92	84

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]Smartbow measured rumination time, lying time, time not active, time active, and time high active.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations. Disease multivariable included DHI protein record, percent of the day at water, not active, lying time, percent change of active, percent change of rumination, and any of the interaction.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included pervious lactation 305 days' actual milk, percent of the day at water, not active, lying time, rumination, percent change of rumination, and any of the interaction.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM. Hypocalcaemia multivariable included not active, rumination, percent of the day at water, percent of the day at freestall and any of the interaction.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM. Metritis multivariable included percent of the day at freestall.
[9]The previous day's data and percent change data were included in multivariable model using the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC).
[10]AUC, signifies the magnitude of the quantity that is obtained by the product of the quantities signified by the 1-specificity and the sensitivity axes. If AUC was > 0.7, the accurate performance would found (Swets, 1988).
[11]Probability was created from GENMOD, predicted probability that the response variable is less than or equal to the value.
[12]Alert was created when probability is greater than the threshold, and backward moving maximum feature of the EXPAND procedure in SAS.
[13]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

Table 3.28. Sensitivity[1], specificity[2], and accuracy[3] CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands)[4] transition cow disease[5], hyperketonemia[6], hypocalcaemia[7], or metritis[8] detection created from the GENMOD procedure in SAS[9].

Diseases	AUC[10]	Disease probability threshold[11,12,13]	[1]Se (%)	[2]Sp (%)	[3]Acc (%)
Disease[5]	0.69	0.01	61	83	77
		0.40	60	85	78
		0.57	55	90	80
Hyperketonemia[6]	0.71	0.01	59	83	82
		0.08	59	86	85
		0.10	56	90	88
Hypocalcaemia[7]	0.67	0.01	71	74	73
		0.10	71	76	75
		0.27	57	90	86
Metritis[8]	0.52	0.01	63	76	73
		0.20	62	77	73
		0.49	43	90	84

[1]Sensitivty (Se) = (true positive rate + false negative rate)/true positive rate.
[2]Specificity (Sp) = (true negative rate + false positive rate)/true negative rate.
[3]Accuracy (Acc) = (true positive rate + true negative rate)/ (true positive + false positive + true negative + false negative).
[4]CoManager SensoOr measured rumination time, lying time, time not active, time active, and time high active.
[5]Disease referred to any occurrence of hyperketonemia, hypocalcaemia, metritis, or any of their combinations. Disease multivariable included DHI protein record, eating time, percent change of rumination, percent change of no active, and any of the interaction.
[6]Hyperketonemia was defined as any blood BHBA concentration ≥1.2 mmol/L identified by Precision Xtra™ at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included pervious lactation 305 days' actual milk, percent of the day at water, not active, lying time, rumination, percent change of rumination, and any of the interaction.
[7]Hypocalcaemia was defined as any blood serum Ca concentrations ≤8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM. Hyperketonemia multivariable included pervious lactation 305 days' actual milk, no active, and any of the interaction.
[8]Metritis was defined as any abnormal vaginal discharge according to Sterrett et al. (2014) with anything scored ≥ 2 considered abnormal at 3, 5, 7, 11, 14, 16, 17, 19, or 21 DIM. Metritis multivariable included rumination, active, percent change of eating, and any of the interaction.
[9]The previous day's data and percent change data were included in multivariable model using the GENMOD procedure in SAS 9.3 (SAS Inc, Raleigh, NC).
[10]AUC, signifies the magnitude of the quantity that is obtained by the product of the quantities signified by the 1-specificity and the sensitivity axes. If AUC was > 0.7, the accurate performance would found (Swets, 1988).
[11]Probability was created from GENMOD, predicted probability that the response variable is less than or equal to the value.
[12]Alert was created when probability is greater than the threshold, and backward moving maximum feature of the EXPAND procedure in SAS.
[13]Any alert window that overlapped with an event (disease, hyperketonemia, hypocalcaemia, or metritis) was considered a true positive. Any alert window that did not overlap with an event was considered a false positive. An event that occurred without a corresponding alert window was considered a false negative. Lack of an alert window and a disease at the same time point was considered a true negative.

APPENDIX

Table 2.1. Means of variables[1] measured by precision dairy monitoring technologies[2] for dairy cows from 1 to 21 DIM for all healthy[3] cows, cows with hypocalcaemia, and cows with metritis[5]

Variables[1]	Technology[2]	Mean ± SD					
		Healthy[3]	N[6]	Hypocalcaemia[4]	N[6]	Metritis[5]	N[6]
Activity (steps/d)	AfiAct pedometer Plus	3699 ± 761	10	4137 ± 845	5	3814 ± 1017	23
Activity (steps/d)	Track a)) Cow	2006 ± 434	6	2156 ± 10	4	2191 ± 603	21
Activity (steps/d)	IceQube	1339 ± 382	10	1198 ± 468	5	1143 ± 324	26
Motion index	IceQube	4646 ± 1392	10	4169 ± 1551	5	3962 ± 1122	26
Active time (min/d)	SensoOr	80 ± 18	7	83 ± 57	4	70 ± 21	16
High activity	SensoOr	88 ± 53	7	122 ± 57	4	77 ± 38	16
Neck activity	HR Tag	375 ± 82	7	454 ± 154	2	485 ± 113	19
Active time (min/d)	Smartbow	934 ± 58	8	1025 ± 7606	5	964 ± 69	19
High activity	Smartbow	154 ± 79	8	122 ± 67	5	143 ± 89	19
Lying time (min /d)	AfiAct pedometer Plus	533 ± 128	10	491 ± 35	5	469 ± 112	23
Lying bouts	AfiAct pedometer Plus	10 ± 3	10	14 ± 2	5	10 ± 3	23
Lying time (min /d)	IceQube	553 ± 112	10	536 ± 58	5	484 ± 100	26
Lying bouts	IceQube	15 ± 5	10	28 ± 7	5	19 ± 6	26
Bout duration (min/bout)	IceQube	553 ± 112	10	536 ± 58	5	484 ± 100	26
Time not active (min /d)	SensoOr	482 ± 100	7	434 ± 162	4	442 ± 130	16
Lying time (min/d)	Track a)) Cow	617 ± 125	6	535 ± 43	4	482 ± 117	21
Lying bouts	Track a)) Cow	11 ± 2	6	17 ± 7	4	16 ± 5	21
Time not active (min/d)	Smartbow	352 ± 64	8	293 ± 68	5	332 ± 83	19
Lying time (min/d)	Smartbow	736 ± 115	8	655 ± 203	5	683 ± 112	19
Rumination time (min/d)	SensoOr	580 ± 69	7	534 ± 56	4	607 ± 73	16
Rumination time (min/d)	HR Tag	543 ± 78	7	517 ± 108	2	502 ± 92	19
Rumination time (min/d)	Smartbow	557 ± 53	8	578 ± 87	5	552 ± 64	19
Eating time (min/d)	SensoOr	220 ± 101	7	280 ± 140	4	251 ± 109	16
Intake visits (d)	Track a)) Cow	6 ± 2	6	7 ± 2	4	9 ± 1	21
Time at feedbunk (min/d)	Track a)) Cow	128 ± 74	6	120 ± 31	4	182 ± 49	21
Mean rectal temperature (ºC)	GLA	38.5 ± 0.1	10	38.6 ± 0.2	5	38.6 ± 0.1	26
Reticulorumen temperature (ºC)	DVM bolus	39.6 ± 0.4	9	39.6 ± 0.2	5	39.8 ± 0.5	20
Milk yield (kg/d)	Afimilk MPC Milk Meter	37.8 ± 9.4	10	27.3 ± 6.3	5	32.9 ± 9.6	23
Milk fat (%)	AfiLab Milk Analyzer	3.9 ± 0.4	10	3.8 ± 0.6	5	4.1 ± 0.5	23

Milk protein (%)	AfiLab Milk Analyzer	3.2 ± 0.2	10	3.3 ± 0.4	5	3.1 ± 0.2	23
Milk fat protein ratio	AfiLab Milk Analyzer	1.2 ± 0.2	10	1.2 ± 0.2	5	1.3 ± 0.1	23
Milk lactose (%)	AfiLab Milk Analyzer	4.7 ± 0.2	10	4.6 ± 0.4	5	4.8 ± 0.1	23
Milk conductivity (%)	Afimilk MPC Milk Meter	7.9 ± 0.7	10	8.8 ± 2.1	5	7.7 ± 0.6	23
Body weight (kg)	AfiWeigh	746 ± 110	10	664 ± 86	5	667 ± 67	23

Table 2.1. (cont.)

[1]Variables were parameters measured from the corresponding precision dairy monitoring technology. For example, AfiAct Pedometer Plus recorded activity (steps/d), lying time (min/d), and lying bouts (#/d).
[2]Precision dairy monitoring technologies included: AfiAct Pedometer Plus, Afimilk, AfiLab, AfiWeigh (Kibbutz Afikim, Israel); Track a))) cow (ENGS System Innovative Dairy Solutions, Israel); DVM bolus (DVM System, LLC, Greeley, CO); IceQube **(**IceRobotics Ltd., Edinburgh, Scotland); HR Tag, SCR (Engineers Ltd., Netanya, Israel); SmartBow (Smartbow GmbH, Jutogasse, Austria); and CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands).
[3]Healthy included any animals without hyperketonemia, hypocalcaemia, metritis, or any combination of diseases.
[4]Hypocalcaemia was identified on 3, 7, 14, or 21 DIM by University of Kentucky Veterinary Diagnostic Laboratory using coccygeal vein blood serum.
[5]Metricheck device was used to score vaginal discharge on a scale of 1 to 3 with 1 being no metritis and >1 being metritis (Sterrett et al., 2014).
[6]N referred to the total number of cows in each row and column.

Table 2.2. Means of variables[1] measured by precision dairy monitoring technologies[2] for dairy cows from 1 to 21 DIM for all cows with hyperketonemia and hypocalcaemia [3], cows with hyperketonemia and metritis[4], and cows with hypocalcaemia and metritis[5]

Variables[1]	Technology[2]	Mean ± SD					
		Hyper + Hypo[3]	N[6]	Hyper + Metr[4]	N[6]	Hypo + Metr[5]	N[6]
Activity (steps/d)	AfiAct pedometer Plus	3896 ± 857	4	3147 ± 857	8	3632 ± 836	47
Activity (steps/d)	Track a)) Cow	2386 ± 825	3	1791 ± 499	9	1909 ± 540	42
Activity (steps/d)	IceQube	1472 ± 203	4	1065 ± 318	9	1095 ± 359	47
Motion index	IceQube	5508 ± 590	4	3637 ± 1045	9	3732 ± 1212	47
Active time (min/d)	SensoOr	57 ± 16	2	62 ± 19	7	69 ± 18	31
High activity	SensoOr	49 ± 33	2	57 ± 33	7	66 ± 38	31
Neck activity	HR Tag	389 ± 125	3	394 ± 157	6	393 ± 102	41
Active time (min/d)	Smartbow	903 ± 101	3	947 ± 67	6	910 ± 82	27
High activity	Smartbow	162 ± 70	3	112 ± 75	6	154 ± 891	27
Lying time (min /d)	AfiAct pedometer Plus	500 ± 164	4	444 ± 130	8	505 ± 111	47
Lying bouts	AfiAct pedometer Plus	9 ± 3	4	10 ± 6	8	10 ± 3	47
Lying time (min /d)	IceQube	533 ± 119	4	479 ± 102	9	545.5 ± 95.1	47
Lying bouts	IceQube	17 ± 3	4	17 ± 10	9	18 ± 5	47
Bout duration (min/bout)	IceQube	533 ± 119	4	479 ± 102	9	545 ± 95	47
Time not active (min /d)	SensoOr	461 ± 158	2	519 ± 103	7	506 ± 159	31
Lying time (min/d)	Track a)) Cow	470 ± 105	3	475 ± 139	9	530 ± 132	42
Lying bouts	Track a)) Cow	11 ± 7	3	12 ± 7	9	12 ± 5	42
Time not active (min/d)	Smartbow	374 ± 70	3	381 ± 52	6	376 ± 84	27
Lying time (min/d)	Smartbow	685 ± 150	3	809 ± 113	6	718 ± 135	27
Rumination time (min/d)	SensoOr	617 ± 120	2	622 ± 120	7	601 ± 115	31
Rumination time (min/d)	HR Tag	426 ± 44	3	482 ± 105	6	484 ± 81	41
Rumination time (min/d)	Smartbow	489 ± 68	3	599 ± 61	6	536 ± 77	27
Eating time (min/d)	SensoOr	262 ± 50	2	173 ± 100	7	204 ± 104	31
Intake visits (d)	Track a)) Cow	7 ± 2	3	9 ± 1	9	8 ± 2	42
Time at feedbunk (min/d)	Track a)) Cow	153 ± 73	3	148 ± 44	9	164 ± 60	42
Mean rectal temperature (ºC)	GLA	38.6 ± 0.1	4	38.6 ± 0.3	9	38.6 ± 0.2	48
Reticulorumen temperature (ºC)	DVM bolus	39.4 ± 0.0	1	39.6 ± 0.5	8	39.6 ± 0.3	34
Milk yield (kg/d)	Afimilk MPC Milk Meter	38.6 ± 12.1	4	32.6 ± 9.1	8	32.6 ± 9.1	47
Milk fat (%)	AfiLab Milk Analyzer	4.1 ± 0.8	4	4.0 ± 0.3	8	4.1 ± 0.5	47
Milk protein (%)	AfiLab Milk Analyzer	2.9 ± 0.2	4	3.1 ± 0.1	8	3.1 ± 0.2	47
Milk fat protein ratio	AfiLab Milk Analyzer	1.4 ± 0.3	4	1.3 ± 0.1	8	1.3 ± 0.2	47
Milk lactose (%)	AfiLab Milk Analyzer	4.6 ± 0.2	4	4.7 ± 0.2	8	4.8 ± 0.1	47

Milk conductivity (%)	Afimilk MPC Milk Meter	7.9 ± 0.7	4	7.9 ± 0.9	8	7.7 ± 0.6	47
Body weight (kg)	AfiWeigh	801 ± 81	4	688 ± 55	8	667 ± 67	47

Table 2.2. (cont.)

[1]Variables were parameters measured from the corresponding precision dairy monitoring technology. For example, AfiAct Pedometer Plus recorded activity (steps/d), lying time (min/d), and lying bouts (#/d).
[2]Precision dairy monitoring technologies included: AfiAct Pedometer Plus, Afimilk, AfiLab, AfiWeigh (Kibbutz Afikim, Israel); Track a))) cow (ENGS System Innovative Dairy Solutions, Israel); DVM bolus (DVM System, LLC, Greeley, CO); IceQube (IceRobotics Ltd., Edinburgh, Scotland); HR Tag, SCR (Engineers Ltd., Netanya, Israel); SmartBow (Smartbow GmbH, Jutogasse, Austria); and CowManager SensoOr (Agis Automatisering, Harmelen, Netherlands).
[3]Hyperketonemia and hypocalcaemia referred to the cows with hypocalcaemia and hypocalcaemia.
[4]Hyperketonemia and metritis referred to the cows with hypocalcaemia and metritis.
[5] Hypocalcaemia and metritis referred to the cows with hypocalcaemia and metritis.
[6]N referred to the total number of cows in each row and column.

Table 2.3. Hyperketonemia[1] and hypocalcaemia[2] disease occurrence on 3, 7, 14, or 21 DIM (n = 138 cows) from January 2013 to October 2015.

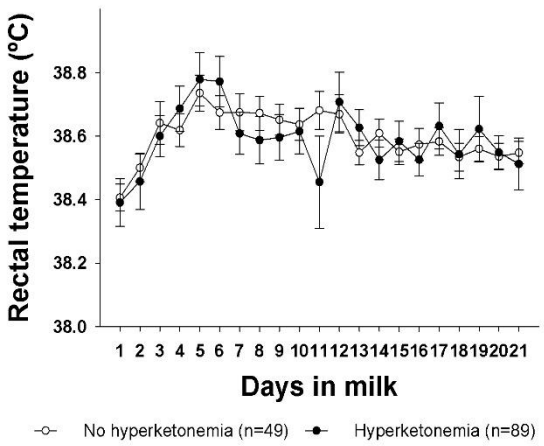
		Days in milk			
Disease		**3**	**7**	**14**	**21**
Hyperketonemia[1]	N	117 (85%)	111 (80%)	125 (90%)	123 (89%)
	Y	21 (15%)	27 (20%)	13 (10%)	15 (11%)
Total		138	138	138	138
Hypocalcaemia [2]	N	64 (46%)	100 (72%)	116 (84 %)	109 (79%)
	Y	74 (54%)	38 (28%)	22 (16%)	29 (21%)
Total		138	138	138	138

[1]Hyperketonemia was identified on 3, 7, 14, or 21 DIM by using Precision Xtra (Abbott Laboratories, Chicago, IL, USA) with coccygeal vein blood. N referred to cows without subclinical or clinical hyperketonemia at each DIM. Y referred to cows with subclinical or clinical hyperketonemia at each DIM.

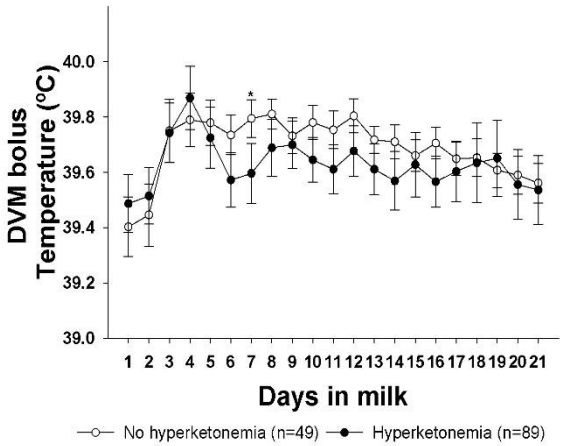
[2]Hypocalcaemia was identified on 3, 7, 14, or 21 DIM by University of Kentucky Veterinary Diagnostic Laboratory using coccygeal vein blood serum. N referred to cows without subclinical or clinical hypocalcaemia at each DIM. Y referred to cows with subclinical or clinical hypocalcaemia at each DIM.

Figure 2.1. Compare reticulorumen temperature and rectal temperature changed by average all the cows from DIM 1 to DIM 21 with and without hyperketonemia[1] by in MIXED procedure of SAS 9.3.

a)



b)



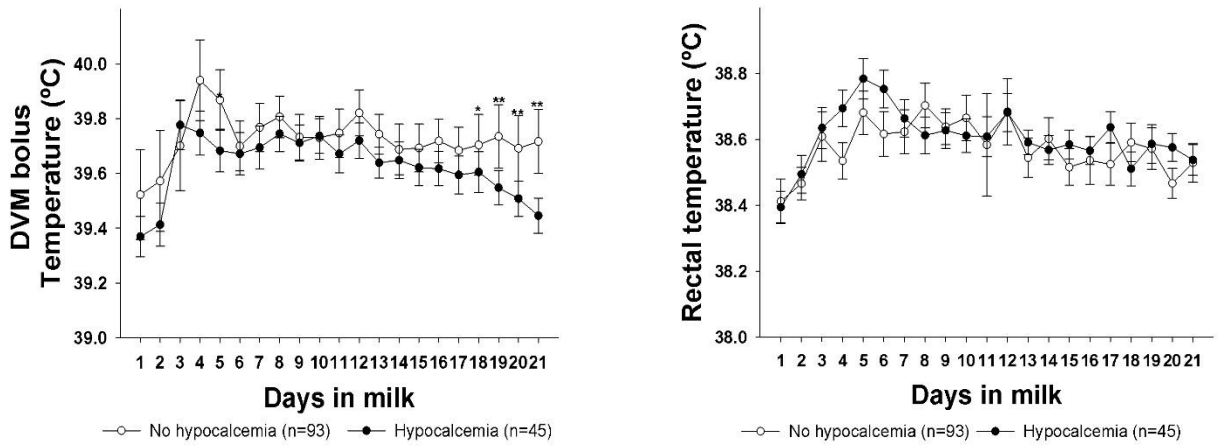
[1]Hyperketonemia was detected by Precision Xtra (Abbott Laboratories, Chicago, IL, USA) BHBA, when blood BHBA was ≥ 1.2 mmol/L at 3, 7, 14, or 21 DIM.

[2]a) DVM bolus (DVM System, LLC, Greeley, CO).

[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.2. Compare reticulorumen temperature and rectal temperature changed by average all the cows from DIM 1 to DIM 21 with and without hypocalcemia[1] by in MIXED procedure of SAS 9.3.

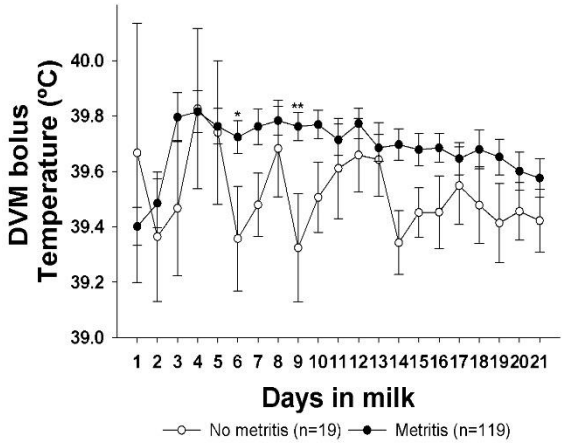
a) b)



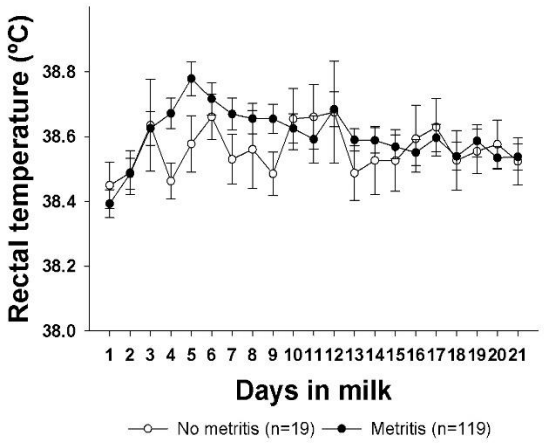
[1]Hypocalcemia was defined as any blood serum concentrations ≤ 8.6 mg/dL by the University of Kentucky Veterinary Diagnostic Laboratory at 3, 7, 14, or 21 DIM.
[2]a) DVM bolus (DVM System, LLC, Greeley, CO).
[3] † $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Figure 2.3. Compare reticulorumen temperature and rectal temperature changed by average all the cows from DIM 1 to DIM 21 with and without metritis[1] by in MIXED procedure of SAS 9.3.

a)



b)



[1]Metritis was diagnosed by vaginal discharge evaluation with the MetriCheck device (Simcro Tech Ltd, Hamilton, New Zealand). A uterine discharge scoring system (Sterrett et al., 2014) was used, based on discharge visual appearance. Score 1: thick, viscous discharge, clear, opaque or red to brown in color, no odor or mild, non-offensive odor; score 2: white or yellow pus, moderate to thick discharge, mild odor; score 3: pink, red, dark red, or black watery discharge, detectable offensive odor, possibly intolerable. Cows with at least one uterine discharge score ≥ 2 were classified as clinical metritis cases.

[2]a) DVM bolus (DVM System, LLC, Greeley, CO)

[3]† $P < 0.1$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 3.1. Mean ± SD percent change in behavioral, physiological, and production indicators monitored using precision dairy monitoring technologies the day disease develop evaluation compared to a backward moving 5-d baseline for each cow.[1,2,3]

Automated health detection device parameters	Technology	Mean ± S.D.	N (cows)
Activity (steps/d)	AfiAct pedometer Plus	-0.74 ± 3.49	131
Activity (steps/d)	Track a)) Cow	-0.59 ± 4.45	114
Activity (steps/d)	IceQube	-3.11 ± 4.35	135
Motion index	IceQube	-3.19 ± 4.21	135
Active time (min/d)	SensoOr	-2.10 ± 4.29	90
High activity (min/d)	SensoOr	-2.19 ± 5.44	90
Neck activity (units/d)	HR Tag	0.43 ± 2.62	106
Active time (min/d)	Smartbow	-0.06 ± 2.13	90
High activity (min/d)	Smartbow	4.26 ± 8.95	90
Lying time (min/d)	AfiAct pedometer Plus	0.27 ± 3.72	131
Lying bouts (bouts/d)	AfiAct pedometer Plus	-0.13 ± 5.33	131
Lying time (min /d)	IceQube	0.45 ± 3.31	135
Lying bouts (bouts/d)	IceQube	-0.58 ± 4.14	135
Bout duration (min/bout)	IceQube	0.45 ± 3.32	135
Time not active (min /d)	SensoOr	-1.12 ± 3.09	90
Lying time (min/d)	Track a)) Cow	1.09 ± 4.42	114
Lying bouts (bouts/d)	Track a)) Cow	-0.10 ± 4.98	114
Time not active (min/d)	Smartbow	-0.78 ± 4.48	90
Lying time (min/d)	Smartbow	0.18 ± 2.57	90
Rumination time (min/d)	SensoOr	1.33 ± 2.55	90
Rumination time (min/d)	HR Tag	1.71 ± 3.29	106
Rumination time (min/d)	Smartbow	1.10 ± 2.84	90
Eating time (min/d)	SensoOr	0.32 ± 3.95	90
Intake visits (d)	Track a)) Cow	1.38 ± 6.85	114
Time at feedbunk (min/d)	Track a)) Cow	5.81 ± 7.24	114
Mean rectal temperature (ºC)	GLA	0.02 ± 0.10	138
Reticulorumen temperature (ºC)	DVM bolus	0.02 ± 0.23	97
Milk yield (kg/d)	AfiMilk MPC Milk Meter	3.43 ± 5.22	131
Milk fat (%)	AfiLab Milk Analyzer	-1.42 ± 1.54	131
Milk protein (%)	AfiLab Milk Analyzer	-1.11 ± 1.33	131
Milk fat protein ratio	AfiLab Milk Analyzer	-0.29 ± 2.02	131
Milk lactose (%)	AfiLab Milk Analyzer	0.67 ± 1.20	131
Milk conductivity (%)	AfiMilk MPC Milk Meter	-0.30 ± 0.86	131
Body weight (kg)	AfiWeigh	-0.47 ± 0.54	131

[1]Average of the baseline was created from EXPAND procedure of SAS, 5d backward moving average was calculating for each cows to create each cows baseline of behavioral such as, lying, steps, rumination, and milk composition.

[2] EXPAND procedure of SAS was used to have pervious day data as an indicator.

[3]Lag 1d and 5d backward moving average were used to calculate percent change of each cows.

Table 3.2. Variables conducted in UNIVARIATE[1] procedure in SAS with 90th and 10th to create alert[2].

Precision dairy monitoring technology	Variables measured	90%	10%
AfiAct Pedometer Plus, Afimilk, Kibbutz Afikim, Israel	Activity (steps/d)	5107	2400
	Lying time (min/d)	711	315
	Lying bouts (bouts/d)	17	6
AfiLab Milk Analyzer, Afimilk, Kibbutz Afikim, Israel	Protein (%)	3.45	2.77
	Fat (%)	4.93	3.28
	Lactose (%)	4.98	4.42
	Fat protein ratio	1.63	1.05
AfiMilk MPC Milk Meter Afimilk, Kibbutz Afikim, Israel	Milk yield (kg/d)	45.9	18
	Milk conductivity (%)	9.10	6.95
	Milking time (min/d)	8.35	3.85
AfiWeigh, Afimilk, Kibbutz Afikim, Israel	Body weight (kg/d)	817.4	577.3
CowManager SensoOr, Agis Automatisering, Harmelen, Netherlands	Rumination time (min/d)	704	400
	Eating time (min/d)	399	101
	Time not active (min/d)	724	293
	Time active (min/d)	106	47
	Time high active (min/d)	161	34.4
DVM bolus, DVM System, LLC, Greeley, CO	Reticulorumen temperature (ºC)	40.27	39.05
HR Tag, SCR Engineers Ltd., Netanya, Israel	Neck activity (units/d)	570	257
	Rumination time (min/d)	625	345
IceQube, IceRobotics Ltd., Edinburgh, Scotland	Lying time (min)	734.7	360.3
	Steps (number/d)	1775	581.5
	Motion index	6137	2028
	Lying bouts (bouts/d)	30	11
	Bout duration (unit/d)	734.9	358.1
Track a))) Cow, ENGS System Innovative Dairy Solutions, Israel	Steps (number/d)	2829	1228
	Lying time (min)	741.5	330.5
	Lying bouts (bouts/d)	23	7
	Time spent at feed bunk (min/d)	261	66
	Feed bunk visit time (number/d)	12	5
SmartBow, Smartbow GmbH, Jutogasse, Austria	Rumination time (min/d)	667	411
	Lying time (min/d)	903	532
	Time not active (min/d)	498	230
	Time active (min/d)	1069	790
	Time high active (min/d)	278	41

Table 3.2. (cont.)

[1]The UNIVARIATE procedure of SAS was used to determine 10^{th} and 90^{th} percentiles for each variable. Either 10^{th} or 90^{th} percentiles were used to create a disease alert for each variable. Tables are depictions of the sensitivity, specificity, and accuracy of this disease detection method.

[2]Alert were created for any instances of variables that fell below the 10^{th} percentile or above the 90^{th} percentile for disease, hyperketonemia, hypocalcaemia, and metritis respective

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VITA

I Ching, Tsai was born in Kaohsiung, Taiwan. She graduated from St. Dominic high school in 2006. In 2011, she obtained a Bachelor of Science degree from Tunghai University in Animal Science. I Ching participated in several research projects, assisting graduate students and professors from 2010 to 2011. I Ching began studying for her Master's of Science degree under Dr. Jeffrey Bewley in August of 2013. Her research focused on using the precision dairy technology of detection transition cow diseases. I Ching presented her research findings at the 2014 and 2015 Joint Annual ADSA Meetings. I Ching acted as a teaching assistant in the Introduction to Animal Science course in 2013.