THE ASSOCIATION BETWEEN FEEDING BEHAVIORS MEASURED BY AUTOMATED MILK FEEDERS AND HEALTH IN PREWEANED HOLSTEIN CALVES FED A HIGH ALLOWANCE OF MILK REPLACER

By

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To my family, my God, and the noble creatures I love and care for…
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Feeding behaviors measured by automated milk feeders have been compared in sick and healthy preweaned dairy calves to assess the potential of using feeder behavior data to aid in the detection of disease. The effects of individual diseases on feeding behaviors measured by automated milk feeders is not well understood. The objective of this study was to investigate the effects of diarrhea and respiratory disease on the feeding behaviors of preweaned dairy heifers fed a high milk allowance by automated milk feeders. Data on calves born from May 1, 2016 to December 31, 2016 were collected from a commercial dairy farm in north Florida. PROC MIXED of SAS 9.4 was used to analyze the effects of diarrhea and respiratory disease on daily intake of milk replacer, average daily drinking speed, and number of rewarded visits to the feeder per day. On the day of diagnosis with diarrhea, calves with severe diarrhea had decreased milk replacer intake, average daily drinking speed, and number of rewarded visits to the feeder than calves with no diarrhea. Calves with respiratory disease had a lower milk replacer intake than calves without respiratory disease from 4 days prior to diagnosis until the day of diagnosis. These data suggest that decreases in all feeding
behaviors measured by automated milk feeders may aid in the detection of calves with severe diarrhea at onset of clinical signs, and decreases in milk intake may aid in earlier detection of calves with clinical respiratory disease.
Raising replacement dairy heifers is vital to the future of the dairy industry and represents a significant financial investment. Estimates for the average cost of raising a dairy heifer from birth to first calving at 24 months include $2,149 and $2,238 (Zwald, 2007; Karszes, 2014). Calfhood disease has a negative economic impact on raising dairy replacements. Common calfhood diseases include navel infection, sepsis, septic arthritis, diarrhea, and respiratory disease. Of these diseases, diarrhea and respiratory disease are the two most common diseases of dairy calves in the US, affecting an estimated 36.3% of preweaned calves across the country and causing 79% of all deaths in preweaned calves (USDA, 2010). In addition to increased treatment costs and death loss, economic losses can also be seen in the form of decreased productivity. Decreased growth has been observed in both diarrhea (Donovan et al., 1998b; Anderson et al., 2003) and respiratory disease (van der Fels-Klerx et al., 2002). Decreased growth can lead to a delay to first calving, which is not ideal as a negative correlation has been shown between age at first calving and productive life span (Silva et al., 1986). Increased age at first calving also increases replacement rearing costs (Tozer and Heinrichs, 2001), increases the risk of dystocia and metritis (Thompson et al., 1983) and decreases the odds of survival in the herd after 3 years (Syrstad, 1979). In addition to decreased weight gain, calves with a diagnosis of respiratory disease have been shown to be at risk for early culling and decreased milk yields in the first lactation (Schaffer et al., 2016).

Individual housing of dairy calves has been standard practice in the US for many years. The most recent survey of US dairy farms estimated that 75% of farms house
heifer calves in individual pens or hutches for at least part of the preweaning period (USDA, 2010). However, increased public concern over socially isolating calves and producer interest in labor reduction and savings have spurred a renewed interest in group housing calves in the US dairy industry. Still, group housing of dairy calves is not without its concerns and challenges. Although these findings have not been consistent throughout the literature, higher rates of disease (Webster et al., 1985; Curtis et al., 2016) and death (Gulliksen et al., 2009) have been observed in group housed calves. It has been suggested that these findings are the result of increased horizontal transmission of pathogens in group housing where calves share feeding equipment and have direct contact with each other (Curtis et al., 2016). Identifying diseased calves and treating them in a timely manner is another challenge in group housing. (LeBlanc, 1981) suggested that disease detection in individual housing is easier because it allows for monitoring feed intakes and fecal consistency of each calf individually. This benefit of individual housing is lost in most group housing and feeding systems.

Automated milk feeders are machines that are designed to deliver milk or milk replacer on-demand to group housed calves. Automated milk feeders consist of feeding stations located inside the calf pen. Each feeding station has a feeding nipple and a radio frequency identification (RFID) sensor mounted inside it. The feeding nipple is connected by rubber hoses to a machine located adjacent to the calf pen. The key components to this machine are a hot water hookup, a hopper to hold milk or milk replacer powder, a blender, and pumps that distribute milk or milk replacer to the nipples. When a calf enters that feeding station, it is identified by the RFID tag in its ear. As it begins to suckle the feeding nipple, the machine responds by either warming
milk to 38° C or blending milk replacer powder and warm water (38° C) and pumping the milk or milk replacer through the hose to the nipple where it is consumed by the calf. One of the advantages of automated milk feeders is that they can identify calves individually by their RFID ear tags and record data on several feeding behaviors, such as intake, average drinking speed, and number of visits to the feeder in a 24 hour period.

It has been hypothesized that these feeding behaviors change in the face of disease. This hypothesis has been investigated to better understand the relationship between disease and feeding behaviors measured by automated milk feeders and to evaluate the potential for feeding behavior data to be used as a predictor or detector of disease, a tool that could be very useful in a group housing environment. Maatje et al. (1993) were the first to investigate the effects of disease on feeding behaviors of veal calves as measured by automated feeders. This study found that 46% of sick calves had a negative deviation in drinking speed associated with disease, followed by 36% with a negative deviation in milk intake, 30% with a negative deviation in rewarded visits to the feeder, and 26% with a negative deviation in unrewarded visits to the feeder. (Svensson and Jensen, 2007) compared feeding behaviors in sick days to healthy days in calves fed a restricted milk intake by automated milk feeders and found only that calves averaged more unrewarded visits to the feeder on healthy days than on sick days (19.80 vs. 15.84; \( P < 0.01 \)). Borderas et al. (2009) were the first to compare feeding behaviors measured by automated milk feeders in sick calves and healthy calves over time. This study found no difference in daily milk intake between sick and healthy calves on the low milk allowance, but in calves on the high milk allowance, sick
calves drank less than healthy calves on days 0 to +3. There was no difference in daily
total visits to the feeder between sick and healthy calves on the low milk allowance.
However, in calves on the high milk allowance, sick calves had fewer total visits to the
feeder than healthy calves from days 0 to +3. Sick calves on the low milk allowance
averaged shorter duration of visits to the feeder than healthy calves from days 0 to +3.
The opposite was observed in the calves on the high milk allowance, where healthy
calves averaged shorter duration of visits to the feeder than sick calves from days +1 to
+3.

Although the methodology and statistical approach was different in all three of
these studies, they all demonstrated that feeding behaviors measured by automated
feeders do change in response to disease. However, none of these studies
investigated the effects of different diseases individually on feeding behaviors measured
by automated milk feeders. Small sample sizes were a commonality in all of these
studies, therefore they lacked the power to analyze the effects of individual diseases on
feeding behaviors. They could only make a clinical determination of sick or healthy and
evaluate to the differences between those two groups of calves. This leaves
unanswered the important question of whether all diseases effect feeding behaviors
measured by automated milk feeders similarly or whether different diseases have
different effects on these feeding behaviors. Answering this question is important in
understanding the relationship between diseases and feeding behaviors and a
necessary step in evaluating the potential of the feeding behaviors to serve as
predictors or detectors of disease in group housed calves fed by automated milk
feeders. Our hypothesis was that different diseases will have different effects on
feeding behaviors measured by automated milk feeders. The objective of this study was to investigate the effects of diarrhea and respiratory disease, the two most common diseases of dairy calves, on the feeding behaviors of preweaned dairy heifers fed a high allowance of milk replacer by automated milk feeders.
CHAPTER 2
BACKGROUND INFORMATION

Diarrhea

Diarrhea is characterized by an increased fluid content of feces, giving a bowel movement a loose or watery appearance. Diarrhea can result in dehydration, metabolic acidosis, electrolyte abnormalities, negative energy balance, and bacterial overgrowth in the small intestines (Smith, 2009). Calves with severe diarrhea may die from acidemia, sepsis, hyperkalemia, hypoglycemia, and hypothermia (Smith, 2009). Diarrhea occurring in calves during the first 28 days of life is commonly referred to as neonatal calf diarrhea (NCD). Incidence of NCD has been reported at 21.2-23.9% (USDA, 2010, Windeyer et al., 2014) in preweaned dairy heifers. In the US, NCD was found to be responsible for 56.5% of deaths in preweaned dairy heifers (USDA, 2010). Negative economic impacts caused by NCD have been observed in the form of decreased growth in beef (Anderson et al., 2003) and dairy (Donovan et al., 1998b) youngstock.

The pathogens most commonly associated with NCD are enterotoxigenic Escherichia coli (ETEC), Cryptosporidium parvum (C parvum), rotavirus, and coronavirus, either alone or in combination with each other (Foster and Smith, 2009). Studies in beef and dairy calves have shown ETEC to be the major cause of NCD within the first few days of life (Acres et al., 1977; Sherwood et al., 1983). Colonization of the calf’s gastrointestinal tract follows oral exposure to fecal coliforms soon after birth (Smith, 1965a, b). Enterotoxigenic E coli causes a secretory diarrhea by producing a toxin that binds to a brush border enzyme found on the intestinal epithelial cells and activates secondary messengers that increase chloride secretion into the
gastrointestinal lumen. Increased chloride secretion osmotically pulls water into the intestinal lumen faster than the villi are able to absorb it (Foster and Smith, 2009).

*C parvum*, a protozoal parasite of the gastrointestinal tract that has been documented in dozens of host species, is one of the most common causes of calfhood diarrhea worldwide (Mosier and Oberst, 2000). Infection occurs when the host ingests oocysts from the environment. Once inside the intestines, the organisms excyst and go through their life cycle, ending with the production of more oocysts that are shed in the feces. *C parvum* invades the epithelial cells of the intestines, inducing apoptosis of the enterocytes (Buret et al., 2003). The loss of enterocytes results in villous atrophy and subsequent retraction in an effort to maintain the integrity of the intestinal epithelial barrier (Heine et al., 1984). These villous changes cause a malabsorptive diarrhea. *C parvum* has been diagnosed in up to 100% of dairy calves in some studies (Xiao and Herd, 1994; O'Handley et al., 1999). Calves have been shown to begin excreting oocysts as early as 3 days postinfection with a shedding duration of up to 9 days (Fayer et al., 1998). In the same study, peak numbers of oocysts were shed from days 6-8 postinfection. Diarrhea was observed as early as day 3 postinfection with a duration of 4-16 days and severity that varied greatly between calves. *C parvum* infection and subsequent diarrhea and shedding of oocysts usually occurs in the neonatal period. Though adult cattle can shed *C parvum*, diarrhea caused by *C parvum* and oocyst shedding rarely occur after 3 months of age as previous exposure builds resistance to subsequent infection and increased age mitigates clinical signs in initial infections (Harp et al., 1990; Fayer et al., 1998; O'Handley et al., 1999). Oocyst shedding in beef calves
is much less common than in dairy calves (Ralston et al., 2003; Gow and Waldner, 2006).

Rotavirus is a common viral pathogen that typically infects calves within the first 3 weeks of life. Transmission occurs when the calf’s mouth contacts fecal contamination in the environment and the virus is ingested. One study done on dairy calves in California isolated rotavirus from 94% of calves (Chinsangaram et al., 1995). Another study done in Ohio isolated rotavirus from at least one calf on 63% of 47 dairy herds that participated in the study (Lucchelli et al., 1992). Rotavirus diarrhea has generally been thought to be caused by malabsorption. The virus attaches to mature villous enterocytes and invades the cells through an unknown mechanism. The virus replicates within the cell, leading to cell death and loss of enterocytes, resulting in a malabsorptive diarrhea (Foster and Smith, 2009). In the mid-1990s, a rotaviral enterotoxin, nonstructural glycoprotein 4 (NSP4), was discovered. NSP4 is produced during viral replication, is released upon enterocyte death, and acts on adjacent enterocytes in a paracrine manner to decrease their ability to digest carbohydrates and absorb water from the lumen. This maldigestion and malabsorption caused by NSP4 is likely as important in the pathophysiology of rotavirus as is villous loss (Foster and Smith, 2009).

Coronavirus is very similar to rotavirus in epidemiology and pathophysiology. Like rotavirus, it is introduced into the body through ingestion from environmental contamination, and most often affects calves in the first 3 weeks of life. Coronavirus titers have been shown to be widespread in cattle (Rodak et al., 1982), and the virus has been found in the feces of both healthy calves and calves with diarrhea (Snodgrass
et al., 1986). The virus attaches to and invades enterocytes via the S glycoprotein (Popova and Zhang, 2002). Inside the enterocyte, the virus replicates and is released via normal secretory mechanisms and cell death (Clark, 1993). Diarrhea actually begins when the virus enters the cell (Torres-Medina et al., 1985). The mechanism at this time is unknown, but 2 days after the onset of diarrhea, significant enterocyte loss and villous blunting can be found. Coronavirus primarily attacks mature villous enterocytes, but crypt enterocytes and colonocytes are also affected, resulting in a longer duration of clinical signs (Storz et al., 1978).

Infection with these enteric pathogens alone does not cause NCD. NCD is a multifactorial disease that occurs when there is an imbalance between the resistance of the calf and the pathogen burden. Risk factors that affect this balance and have been associated with NCD include type of housing and bedding, vaccination status of the dam against calf enteropathogens, nutrition, packed cell volume, serum total protein (STP) and immunoglobulin G concentrations, birth weight, hygiene, and dystocia (Pare et al., 1993; Wittum et al., 1994; Bendali et al., 1999; Al-Mawly et al., 2015). Prevention of, and appropriate handling of dystocia, successful passive transfer of immunity, and adequate nutrition are all key to appropriate immune function of the calf. Pathogen burden can be decreased through proper biosecurity protocols and adequate hygiene of maternity facilities, feeding equipment, and calf housing (Lorenz et al., 2011).

**Respiratory Disease**

Bovine respiratory disease (BRD) is a multifactorial disease of the lungs that can be found in cattle of all types and ages. Enzootic calf pneumonia (ECP), also known as dairy calf pneumonia, is a component of the BRD complex. Observable clinical signs include nasal discharge, lacrimation, cough, tachypnea, dyspnea, rough hair coat,
anorexia, and poor body condition. Additional clinical signs found on physical exam include fever, abnormal sounds on lung auscultation, and a cough response when compressing the cranial trachea. Though ECP can affect calves up to 6 months of age, epidemiological studies have shown ECP to occur as early as 2 weeks of age (Virtala et al., 1996), with peak incidence of observed at 5-6 weeks of age (Waltner-Toews et al., 1986a; Sivula et al., 1996). In the US, ECP affects 12.4% of preweaned dairy heifers and is responsible for 22.5% of deaths in preweaned dairy heifers (USDA, 2010). Mortality rates for ECP itself have been reported from 1.8-4.2% (Sivula et al., 1996; Virtala et al., 1996).

Enzootic calf pneumonia is a costly disease for the dairy industry. Economic losses occur in the form of death loss, treatment costs, poor growth, early culling, and reduced lifetime milk production. Calves that were identified as having ECP have been shown to be approximately 2-5 times more likely to leave the herd before first calving (Waltner-Toews et al., 1986c; Schaffer et al., 2016), to achieve first calving 6 months later (Correa et al., 1988), and to have a 233 kg lower 305-day mature equivalent milk yield in the first lactation (Schaffer et al., 2016) than calves that were never identified as having ECP. The delay to first calving is most likely due to decreased growth rates, which has been documented in beef and veal calves with lung lesions at slaughter (Thomas et al., 1978; Mei and Ingh, 1987). Age at first calving is important because a negative correlation has been shown between age at first calving and productive life span (Silva et al., 1986). Early calving heifers have a decreased risk of dystocia and metritis (Thompson et al., 1983) and a higher chance of survival in the herd after 3 years (Syrstad, 1979).
As previously mentioned, the causes of ECP are multifactorial. A variety of infectious agents and other risk factors play a role in the development of clinical disease. Common viral pathogens associated with ECP include bovine respiratory syncytial virus (BRSV), parainfluenza-3 virus (PI-3), bovine herpesvirus-1 (BHV-1), and bovine viral diarrhea virus (BVDV). BHV-1, BRSV, and PI-3 are transmitted by aerosols and direct contact and infect the epithelial cells of the respiratory tract. They cause epithelial cell destruction and apoptosis, inflammation, and decreased function of innate immune cells (Smith, 2009). The severity of clinical signs vary. BVDV can be acquired in utero or by ingesting or inhaling body fluids from an infected animal. BVDV is associated with a variety of clinical diseases besides BRD. BVDV can cause mild respiratory disease by itself (Baule et al., 2001), but the hallmark of BVDV is immunosuppression (Potgieter, 1995). It has been shown in experimental studies that clinical signs of respiratory disease caused by *Mannheimia haemolytica* (Potgieter et al., 1984b), BHV-1 (Potgieter et al., 1984a), and BRSV (Brodersen and Kelling, 1998) are more severe when cattle are co-infected with BVDV. It is believed that this synergistic effect is the result of the immunosuppression caused by BVDV, and that this is the most important role of BVDV in clinical respiratory disease. The relationship between these viral agents and clinical disease is not well understood. BRSV appears to be the most ubiquitous of these viruses and play the biggest role in ECP (Baker et al., 1986; Sivula et al., 1996), but seroconversion to all of these viruses in the first 4 months of life has been shown to be uncommon and not positively correlated with clinical disease (Sivula et al., 1996; Virtala et al., 1996).
Bacteria most commonly associated with ECP include *Pasteurella multocida* (*P multocida*), *Mannheimia haemolytica* (*M haemolytica*), *Histophilus somni* (*H somni*), and *Mycoplasma bovis* (*M bovis*). *P multocida*, *M haemolytica*, and *H somni* are commensal organisms of the bovine respiratory tract and are generally not considered to cause primary ECP. Instead, they are opportunistic organisms that cause disease in stressed or immunosuppressed calves or exacerbate disease initially caused by infection with one or more of the aforementioned respiratory viruses. *M bovis* is considered to be more pathogenic than the commensal respiratory bacteria, but still tends to play a secondary role, causing disease most commonly when the pathogen burden is very high or when the resistance of the calf is weakened.

Additional risk factors for ECP that have been identified are group housing and sharing of feeding equipment (Curtis et al., 2016), failure of passive transfer of immunity (Donovan et al., 1998a; Virtala et al., 1999), larger herd size (Waltner-Toews et al., 1986b; Donkersgoed et al., 1993), and previous diagnosis with diarrhea (Perez et al., 1990; Curtis et al., 1993).

**Individual vs. Group Housing of Dairy Calves**

Individual housing of dairy calves has been standard practice in the US for many years. The most recent survey of US dairy farms found that 75% of farms house heifer calves in individual pens or hutches for at least part of the preweaning period (USDA, 2010). However, increased public concern over socially isolating calves and producer interest in labor reduction and savings have spurred a renewed interest in group housing in the US dairy industry.

The main reason for adopting individual housing as common practice was to prevent transmission of infectious diseases through direct contact and to reduce the
poor performance and economic losses that follow disease. While some studies have shown higher rates of disease (Webster et al., 1985) and death (Gulliksen et al., 2009) in group housed calves, these findings are not consistent throughout the scientific literature. Other studies have found no difference in health outcomes between group and individually housed calves (Hanekamp et al., 1994) or even improved health outcomes in group housed calves (Hänninen, 2003; Babu et al., 2009).

Behavioral and cognitive benefits have also been observed in calves raised in some type of social housing. Socially housed calves have been shown to consume more solid feed during the preweaning period and have more consistent weight gain through weaning compared to individually housed calves (Vieira et al., 2010; Miller-Cushon and DeVries, 2016). Socially housed calves have also demonstrated the ability to cope better with novel events, such as showing less fear and more willingness to approach unfamiliar calves (Vieira et al., 2012) or show less neophobia towards new feeds (Costa et al., 2014). Calves raised in social housing during the preweaning period have shown improved postweaning ability to cope with competition for access to feed (Duve et al., 2012) and increased preference for social feeding (Miller-Cushon and DeVries, 2016), suggesting that group housed calves will be predisposed to fare better in social feeding scenarios as they grow and maintain intake when faced with routine social stressors.

It is well established in many species that social enrichment can improve cognition (learning). Cognition is commonly assessed experimentally through learning tasks, where the subject forms an association between a discriminative stimulus and a reward (initial learning), and then the ability of the subject to relearn the task with a
change in stimuli is assessed (reversal learning). The ability to relearn a task, or performance during the reversal learning stage, is most influenced by exposure to enrichment and is considered an indicator of behavioral flexibility. For example, a cognitive test has been used on this approach to assess cognition of socially housed calves, using color cues (black and white) as the discriminative stimuli and milk as the reward. In the initial learning stage of the task, the test calf was exposed to both color cues (black and white squares) and learned that approaching one of the color cues (e.g. white) was rewarded with milk. Once the calf consistently approached the white cue, which was associated with the milk reward, the reversal learning stage of the test began. In the reversal learning phase of the study, the reward was switched to the other color cue, or the black square in the previously given example, and the test subject must reverse what it has learned and choose the black square to get the milk reward. Socially housed calves have been shown to perform better in the reversal learning phase of cognitive studies (Gaillard et al., 2014; Meagher et al., 2015). The findings of these studies suggest that individually housed calves may have difficulty learning and coping with change, skills that would be useful as a calf grows and experiences the normal changes associated with being raised on a dairy farm, such as changes in feed, pen, or penmates. Differences in cognition may explain some behavioral differences between calves reared individually or in groups. For example, calves raised in social housing during the preweaning period are faster to begin feeding after grouping at weaning than calves housed individually prior to weaning (Vieira et al., 2010). It should be noted that behavioral and cognitive differences between socially and individually housed calves have only been observed during the pre- and immediate
postweaning period. Whether cognitive and behavioral impairments associated with individual housing as a preweaned calf persist into adulthood is not well understood.

One of the challenges of group housing calves is identification of diseased calves with subsequent treatment in a timely manner. It has been suggested that disease detection in individual housing is easier as it allows for monitoring of individual feed intakes and fecal consistency (LeBlanc, 1981). This benefit of individual housing is lost in most group housing and feeding systems.

**Automated Milk Feeders**

Automated milk feeders are machines that are designed to deliver liquid nutrition to group housed calves with less human labor than traditional bottle or bucket feeding of individually housed calves or mob feeding of group housed calves. The first automated milk feeder was patented in France in 1962. The use of automated milk feeders has been more popular in Europe than North America, and most manufacturers of automated milk feeders are still located in Europe, but at least one model is manufactured in the USA, where they have slowly gained some popularity in recent years. They can deliver milk or milk replacer to the calves, though milk replacer is more commonly fed through the automated feeders.

Automated milk feeders (Figure 2-1) consist of feeding stations located inside the calf pen with a feeding nipple and a RFID sensor mounted in them. The feeding nipple is connected by rubber hoses to a machine located adjacent to the calf pen. The key components to this machine are a hot water hookup, a hopper to hold milk or milk replacer powder, a blender, and pumps that distribute milk or milk replacer to the nipples. Calves that are fed from automated milk feeders must be fitted with an RFID ear tag. When a calf enters that feeding station, it is identified by its RFID tag. As it
begins to suckle the feeding nipple, the machine responds by delivering milk or milk replacer to the calf through the hose that connects it to the nipple. In the case where milk is fed through the feeder, the milk, which is agitated and kept refrigerated in the hopper, is warmed by a heat exchange coil to approximately 38\(^0\) C and delivered to the calf through the hose to the nipple. Where milk replacer is fed, a measured amount of warm water (approximately 38\(^0\) C) and milk replacer powder are deposited in the blender, mixed together, and delivered to the calf through the hose to the nipple. The feeders have the ability to purge unconsumed milk that has been sitting in the hoses and blender for too long and rinse the system with water as well as perform regular self-wash cycles with detergent. Most human involvement with the machine consists of monitoring the hopper and refilling it, recalibrating the machine to deliver the appropriate amounts of milk replacer and water and at the correct temperature, refilling the detergent tank, and other routine maintenance and monitoring.

One feature of the automated milk feeders to note is their flexibility to offer a customized nutrition program for each farm, and even for each calf individually if desired. Parts of the nutrition program that are programmable include the concentration at which the milk replacer is mixed, the volume and frequency that calves are allowed to drink, and the weaning schedule. Identification of each calf individually by its RFID ear tag allows the feeder to monitor the volume and frequency of feedings and to stop delivery of milk when a calf has consumed its entire allowance.

The display screens typically found on automated milk feeders are not large and do not allow easy access or visualization of the feeder data of an individual calf, much less so of multiple calves in the pen. However, the feeders can be connected to a
computer and a software package that allows a much better display of the feeder data with options such as to display the data of an individual calf or of many calves, or to display the data in spreadsheet form or in a graph. The computer and software can also record and store daily feeding data, such as daily intake, average daily drinking speed, and number of rewarded and unrewarded visits to the feeder per day. Rewarded visits are visits to the feeder when a calf is allowed to drink milk or milk replacer. Unrewarded visits are visits to the feeder when a calf is not allowed to drink, such as in cases where the calf is on a restricted feeding program and it has already consumed its allowance of milk or milk replacer. In this case, the machine will not release milk or milk replacer to the calf and the machine will record this visit as unrewarded.

One of the major concerns of automated milk feeders is that stocking densities (number of calves per feeding station) have to be quite high to justify their high cost. Automated milk feeder manufacturers claim that their product can support up to 35 calves per feeding station. Large numbers of calves per feeding station may increase competition between calves for time at the feeder and may increase horizontal transmission of pathogens (Curtis et al., 2016). Large groups of calves may also make disease detection more difficult, and large groups of calves have been associated with a higher incidence of disease (Svensson and Liberg, 2006).

Using Feeding Behavior Data to Detect Disease

Maatje et al. (1993) investigated the effects of disease on feeding behaviors of veal calves recorded by automated feeders. Clinical status was determined as sick or healthy. Feeding allowance was not mentioned, though it was most likely high since this study was done in veal calves. Cutoffs for negative deviations in feeding behaviors
were arbitrarily set and data from 7 days before diagnosis with disease to 3 days after diagnosis with disease were analyzed. Their findings were that 46% of sick calves had a negative deviation in drinking speed somewhere within the 11 day observation period, followed by 36% with a negative deviation in milk intake, 30% with a negative deviation in rewarded visits to the feeder, and 26% with a negative deviation in unrewarded visits to the feeder.

Svensson and Jensen, (2007) conducted a study on 2 farms where calves were fed by automated milk feeders and milk intake and feeding frequency were restricted. Calves were monitored daily by either a veterinarian or farm worker and each calf was given a daily clinical status of sick or healthy. Average drinking speed and rewarded and unrewarded visits were compared in sick days versus healthy days. The only statistically significant finding was that calves averaged 4 more unrewarded visits to the feeder on healthy days than on sick days.

Borderas et al. (2009) evaluated the effects of disease on the feeding behaviors of calves fed high (12 L/d- *ad libitum*) and low (4 L/d) milk allowances. This was a retrospective study using data from 4 previous experiments. Calves were identified only as sick or healthy. A repeated measures analysis was performed from day -2 to day +8 with day 0 being the day of disease diagnosis for sick calves. Every sick calf used in the analysis was paired with a healthy control calf from the same experiment, feed allowance, age, and similar birth weight. An equivalent day 0 to that of the sick calves was designated for the controls. Daily milk intake, total visits to the feeder, and average visit duration were the outcome variables of interest. There was no difference in daily milk intake between sick and healthy calves on the low milk allowance. In calves on the
high milk allowance, sick calves drank less than healthy calves on days 0-3. There was no difference in daily total visits to the feeder between sick and healthy calves on the low milk allowance. In calves on the high milk allowance, sick calves had fewer total visits to the feeder than healthy calves from days 0-3. Sick calves on the low milk allowance averaged shorter duration of visits to the feeder than healthy calves from days 0-3. The opposite was observed in the calves on the high milk allowance, where healthy calves averaged shorter duration of visits to the feeder than sick calves from days 1-3.

All three of these studies observed that feeding behaviors measured by automated feeders do change in response to disease. However, none of these studies investigated the effects of different diseases individually on feeding behaviors. Small sample sizes did not allow for the statistical power necessary to investigate the relationship between individual diseases and feeding behaviors measured by automated milk feeders. Understanding this relationship is important in evaluating the potential of the feeding behaviors to serve as predictors or detectors of disease in group housed calves fed by automated milk feeders. Our hypothesis was that different diseases will have different effects on feeding behaviors measured by automated milk feeders. The objective of this study was to investigate the effects of diarrhea and respiratory disease, the two most common diseases of dairy calves, on the feeding behaviors of preweaned dairy heifers fed a high allowance of milk replacer by automated milk feeders.
Figure 2-1. Illustration of an automated milk feeder (ID-TEK, Biotic Industries Inc.).
CHAPTER 3  
MATERIALS AND METHODS

This retrospective case-control study was conducted on a commercial dairy farm in north Florida and approved by the University of Florida Institutional Animal Care and Use Committee. All animals used in this study were pre-weaned Holstein heifer calves born from May 1, 2016 to December 31, 2016.

**Housing and Management**

All calves were born at a maternity facility where they were separated from their dams, weighed, identified with RFID and farm specific ear tags, had their navels dipped, and were fed colostrum. Birth weights were recorded in the dairy record keeping software in use on the farm (DairyComp 305, Valley Agricultural Software). While at the maternity facility, calves were housed in a group pen with a rubber mat floor. Twice a day, calves were moved from the maternity facility to the calf-rearing facility and placed in individual sand-bedded pens under an open-sided, fan-ventilated barn. While housed in the individual pens, calves were given water *ad libitum*, fed 3 quarts of milk replacer in a bottle twice daily, and had a venous blood sample obtained from the jugular vein at 2-3 days of age to measure neonatal STP concentrations as an indicator of passive transfer of immunity (Naylor and Kronfeld, 1977). Blood samples were collected in additive-free tubes, allowed to coagulate, centrifuged, and STP concentration was measured with a refractometer. STP values were recorded in DairyComp 305. As soon as calves were suckling a bottle vigorously, and if they had no signs of clinical disease, they were moved to group pens. The farm’s goal was to have calves moved to group housing between 3-5 days of age. All pen movements were recorded in DairyComp 305.
Group pens were housed under the same open-sided, fan-ventilated barn as the individual pens. Overall dimensions of the group pens were 13.7 X 7.3 m. A 1.8 X 7.3 m section in the front of the pen had a concrete floor, and this is where the automated feeder station, the calf starter bunk, and the water trough were found. The remaining 11.9 X 7.3 m area was sand bedded. Group pens held 20-25 calves. This number varied depending on expected calving rate and was adjusted higher when more calves were expected to be born or lower when less calves were expected to be born. Calves were moved from the individual pens to a group pen daily until it was filled. A group pen was always filled in less than a week. Calves remained in their group pens with their penmates until 1-2 weeks after weaning and were then moved all together to a postweaning barn. Calves were offered water and calf starter *ad libitum* in the group pens. The same milk replacer fed in the individual pens was fed in the group pens through automated milk feeders with one feeding station per pen. Milk replacer was fed at a concentration of 15% total solids, and was essentially fed free choice with the only restriction being that the calves could drink no more than 3 L in any 2 hour period. The free choice milk replacer was fed for the first 48 days the calves were in the group pens and drinking from the automated feeders. On day 49, a 13 day step down weaning protocol was begun. Calves were limited to 12 L of milk replacer on day 49. On each consecutive day, the limit was reduced by 0.85 L until the calves were only allowed to drink 1.8 L on day 61. On day 62 after being moved into the group pens, the calves were no longer allowed to drink milk replacer and were weaned.

Calves were monitored daily for disease by on-farm personnel that were trained to detect abnormal calves and diagnose and treat disease according to health care
protocols that were designed by veterinarians (defined below). All diagnoses and treatments were recorded in DairyComp 305.

**Diseases**

Diseases of interest for this study were diarrhea and respiratory disease. A case definition of dehydration is also provided as it is associated with diarrhea and, in this study, treatment with fluid therapy was used to categorize diarrhea according to severity. The case definitions for diarrhea, dehydration, and respiratory disease found in the health care protocols for the farm where this study was conducted are as follows:

- **Diarrhea**: Fecal scores of 2 or 3 from the following 4-point fecal scoring system; 0 = Normal; 1 = Semi-formed; 2 = Loose, stays on top of bedding; 3 = Watery, sifts through bedding (Figure 3-1).

- **Dehydration**: Sunken eyes, prolonged skin tent, and depression. Sunken eyes are detected by evaluating for a gap between the eyelid and the eye (Figure 3-2). No gap between the eyelid and the eye indicates euhydration. A 2-6 mm gap between the eyelid and the eye indicates moderate dehydration. A gap of more than 6 mm between the eyelid and the eye indicates severe dehydration. Skin tent is evaluated by pinching and twisting the loose skin on the side of the neck. Pinched skin that flattens back out in less than 1 second indicates euhydration. Pinched skin that remains tented for 2-4 seconds indicates moderate dehydration, and skin that remains tented for 5 seconds or longer indicates severe dehydration.

- **Respiratory Disease**: A calf with 2 or more of the 4 following clinical signs is considered to have respiratory disease; increased respiratory rate or effort; a rectal temperature of 40⁰C or greater; purulent nasal discharge; cough.

All disease data used in this study were taken from data recorded in DairyComp 305 by trained on-farm personnel.

**Measurement of Feeding Behaviors**

All automated milk feeders were connected to a computer with software (KalbManagerWIN, Förster Technik) that recorded daily milk feeding data on each calf individually. Calves were identified by the RFID sensor in the feeding station detecting
the RFID tag in their ear. Daily milk replacer intake (L), average daily drinking speed (mL/min), and number of rewarded visits to the feeder per day were the feeding behaviors of interest, and these data were collected from KalbManagerWin. Rewarded visits are visits to the feeder when a calf is allowed to drink milk or milk replacer. Unrewarded visits are visits to the feeder when a calf is not allowed to drink, such as in cases where the calf is on a restricted feeding program and it has already consumed its allowance of milk or milk replacer. In this case, the machine will not release milk or milk replacer to the calf and the machine will record this visit as unrewarded. In the present study, unrewarded visits data were not collected and analyzed because the calves were on a high allowance of milk replacer, and it was a very rare occurrence that a calf drank a full 3 L in a 2 hour period and returned to the feeder before the 2 hours had lapsed, resulting in unrewarded visits to the feeder.

**Case/Control Selection Criteria**

**Diarrhea**

Calves with a diagnosis of diarrhea between days 3-12 on the feeder were considered for enrollment as diarrhea cases. Only enrolling calves with a diagnosis of diarrhea after 3 or more days on the automated feeders was essential for allowing calves at least one day to acclimate to the automated feeders before data collection could begin. The day of diagnosis with diarrhea was designated as day 0. Calves with a diagnosis of another disease from birth to day +9 (9 days after day 0) were excluded from the final data set so as to not have concurrent diseases confounding the data.

Cases of diarrhea were split into two categories for analysis: moderate and severe. Moderate cases received a diagnosis of diarrhea and were treated according to health protocols but were not dehydrated and did not require fluid therapy on the day
diagnosis. Severe cases were diagnosed and treated for diarrhea as well as diagnosed as dehydrated and treated with an oral electrolyte solution, and potentially intravenous fluids as well, according to health protocols. Fluid therapy was chosen as the determining factor between moderate and severe cases because there was no other way to make this categorical determination in this retrospective study. Although the case definition of diarrhea on this farm is based on a fecal scoring system and the calf care personnel have been trained on the case definition and the fecal scoring chart, fecal scores are not recorded in DairyComp 305 on this farm. Therefore, fecal scores could not be used to categorize diarrhea according to severity.

For each severe case of diarrhea that was used in the data set, a moderate case of diarrhea from the same pen and as similar in age as possible was also included in the data set. For each pair of severe and moderate cases that were used in the data set, a healthy control calf was also included in the data set. Each control calf was from the same pen and as similar in age as possible to its severe and moderate cohorts. An equivalent day to the days of diagnosis for the cases was designated as day 0 for the controls. A calf was eligible for inclusion as a control if it had no history of disease from birth to day +9.

**Respiratory Disease**

Calves with a diagnosis of respiratory disease between days 15-41 on the automated milk feeders were considered for enrollment as respiratory disease cases. The lower limit of 15 days was set because respiratory disease in dairy calves has been found to occur at this age (Virtala et al., 1996). Also, respiratory symptoms detected earlier than this may be caused by neonatal septicemia (Smith, 2009). The upper limit of 41 days was chosen because the data collection period of a case of respiratory
disease diagnosed after day 41 would run over into the weaning period and the feeding behavior data would be confounded by the restrictions of the weaning protocol. The day of diagnosis with respiratory disease was designated as day 0. Calves with a diagnosis of another disease from day -8 to day +9 were excluded from the final data set so as to not have concurrent diseases confounding the data.

For each case of respiratory disease used in the data set, a healthy control calf from the same pen and as similar in age as possible was included in the data set. An equivalent day in which the case was diagnosed with respiratory disease was designated as day 0 for the control, and the control could not have a diagnosis with another disease from days -8 to day +9.

**Statistical Analysis**

**Sample Size Calculation**

Preliminary feeder data from a small sample of calves with and without diarrhea and respiratory disease was used to estimate sample sizes necessary to detect significant differences in feeding behaviors measured by automated milk feeders. SAS 9.4 (SAS Institute Inc.) was used to make the sample size calculations for daily milk replacer intake and average daily drinking speed. A full sample size calculation for daily rewarded visits to the feeder was not performed because this variable was of the least interest and preliminary review of the data concluded that the differences in means were too small and a sample size calculation would yield a sample size that was too large and not possible to achieve within a practical timeframe. Sample size calculations for daily milk replacer and average daily drinking speed yielded a larger sample size for average daily drinking speed. Therefore, collecting data on enough calves to satisfy the
sample size requirement for analysis of average daily drinking speed became the goal as this would also meet the requirement to analyze daily milk replacer intake.

Analysis of the preliminary feeder data from the calves with and without diarrhea showed that calves with diarrhea had an average daily drinking speed of 59.50 mL/min less than healthy calves the day before diagnosis with diarrhea with an overall standard deviation of 113.58 mL/min. With an expected difference of 59.50 mL/min, a standard deviation of 113.58 mL/min, 10 data points (days -2 to +7), alpha of 5%, and power of 80%, the resulting sample size from this calculation was 31 calves per group. With 3 groups to compare (none, moderate, and severe diarrhea), the goal was to identify at least 93 calves from the dataset to include in the analysis of the effects of diarrhea on feeding behaviors measured by automated milk feeders.

Analysis of the preliminary feeder data from the calves with and without respiratory disease showed that calves with respiratory disease had an average daily drinking speed of 26.94 mL/min less than healthy calves the day before diagnosis with respiratory disease with an overall standard deviation of 88.87 mL/min. With an expected difference of 26.94 mL/min, a standard deviation of 88.87 mL/min, 15 data points (days -7 to +7), alpha of 5%, and power of 80%, the resulting sample size from this calculation is 116 calves per group. With 2 groups to compare (respiratory disease and no respiratory disease), the goal was to identify at least 232 calves from the dataset to include in the analysis of the effects of respiratory disease on feeding behaviors measured by automated milk feeders.

**Diarrhea Analysis**

All data were analyzed using SAS 9.4. The total number of calves used in this analysis was 108 (36 severe, 36 moderate, 36 control). The outcome variables of
interest, milk replacer intake (L), average drinking speed (mL/min), and number of rewarded visits to the feeder were collected from day -2 to day +7 relative to day 0 (the day of diagnosis with diarrhea for the cases or an equivalent day for the controls). Other data collected for each calf were birthweight, neonatal STP concentration, pen number, feeder number, days of age at day of diagnosis, and days on feeder at day of diagnosis. PROC GLM was used to screen for normality of the residuals and outliers in the outcome variables. PROC CORR was used to evaluate the correlation of the additional data collected as a high correlation between pen number and feeder number, and between days of age at diagnosis and days on the feeder at day of diagnosis was suspected. The Pearson correlation coefficient between pen number and feeder number was 0.94, and the coefficient between days of age at day of diagnosis and days on the feeder at day of diagnosis was 0.84. Therefore, feeder number and days on the feeder at day of diagnosis were excluded from the model. PROC MIXED was used to analyze each outcome variable. Disease (severe, moderate, control), time (day -2 to +7), and disease X time interaction were forced into the models. Birthweight, neonatal STP concentration, and day of age at diagnosis were included in the model, and a backward stepwise elimination was performed to remove any variables from the model with a p value > 0.10. Calf ID was controlled for as a random variable and nested within pen number. Time was the repeated variable. First order autoregressive was the covariance structure chosen for the analysis.

**Respiratory Disease Analysis**

The total number of calves used in the analysis of effects of respiratory disease on feeding behaviors was 260 (130 cases, 130 controls), and data on the outcome
variables of interest was collected from day -7 to day +7. All other variables and the statistical approach were the same as previously described in the diarrhea analysis.

<table>
<thead>
<tr>
<th>Calf Fecal Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
</tr>
<tr>
<td>Semi-formed</td>
</tr>
<tr>
<td>Loose, stays on top</td>
</tr>
<tr>
<td>Watery, sifts through bedding</td>
</tr>
</tbody>
</table>

Figure 3-1. Calf fecal scoring system.

Figure 3-2. Evaluating sunken eyes for dehydration in calves.
CHAPTER 4
RESULTS

A total of 1079 heifer calves entered the calf barn during the study period. Diarrhea was diagnosed in 867 calves (80.35%), and respiratory disease was diagnosed in 401 calves (37.16%). Overall, 49 calves (4.54%) died during the study period. Of those 49 deaths, 13 (26.53%) were attributed to gastrointestinal abnormalities (diarrhea, clostridium infection, abomasal ulcer, etc.), and 6 (12.24%) were attributed to respiratory disease. The remaining deaths were attributed to Salmonellosis, congenital birth defects, calving trauma, sepsis, injury, and unknown causes. A summary of birthweight, neonatal serum total protein concentration, and age at day 0 can be found in Table 4-1.

Diarrhea

Intake

Birthweight \((P = 0.01)\) was the only additional explanatory variable that remained in the model after the backward stepwise elimination was performed. Overall, calves with severe diarrhea drank significantly less milk replacer per day than calves with moderate diarrhea or no diarrhea \((5.40 \pm 0.24 \text{ vs. } 5.96 \pm 0.24 \text{ vs. } 6.09 \pm 0.26 \text{ L/d}; P = 0.04)\). There was a significant effect of time \((P < 0.01)\), and there was a significant interaction between diarrhea and time \((P < 0.01)\). Milk replacer intake was similar in all three groups of calves in the days prior to diagnosis with diarrhea (Figure 4-1 A). Differences in milk replacer intake were observed between the different levels of diarrhea on days 0 to day +3. Specifically, calves with severe diarrhea drank significantly \((P \leq 0.05)\) less milk replacer than one or both groups of calves with moderate or no diarrhea from day 0 to day +3. The only day in which calves with
moderate diarrhea drank significantly less milk replacer than calves with no diarrhea was day 0 ($P = 0.02$).

**Drinking Speed**

No additional explanatory variables remained in the model after the backward stepwise elimination was performed. Overall, average daily drinking speed was similar in calves with severe, moderate, and no diarrhea (256.41 ± 11.99 vs. 272.09 ± 11.99 vs. 264.17 ± 11.99 mL/min; $P = 0.65$). There was a significant effect of time ($P < 0.01$), and there was a significant interaction between diarrhea and time ($P = 0.03$). Average daily drinking was similar in all three groups of calves prior to diagnosis with diarrhea (Figure 4-1 B). Differences in average daily drinking speed were observed between the different levels of diarrhea on days 0 and +1. Calves with severe diarrhea had significantly ($P \leq 0.05$) decreased average drinking speed on day 0 and +1. On day 0, there were no significant differences in average drinking speed between calves with moderate diarrhea and calves with severe or no diarrhea, but calves with severe diarrhea had a significantly ($P = 0.03$) lower average drinking speed than calves with no diarrhea. On day +1, calves with severe diarrhea tended to have a lower average drinking speed than calves with no diarrhea ($P = 0.06$) and had a significantly lower average drinking speed than calves with moderate diarrhea ($P = 0.04$).

**Rewarded Visits**

No additional explanatory variables remained in the model after the backward stepwise elimination was performed. Overall, calves with severe diarrhea had significantly fewer rewarded visits to the automated milk feeder per day than calves with moderate diarrhea or no diarrhea (4.93 ± 0.22 vs. 5.60 ± 0.22 vs. 5.6 ± 0.23 visits/d; $P = 0.05$). Time tended to have an effect ($P = 0.06$), and there was a significant interaction
between diarrhea and time ($P = 0.04$). Significant differences in number of rewarded visits to the feeder were found several days throughout the observation period (Figure 4-1 C). On day -2, calves with moderate diarrhea had a tendency for fewer rewarded visits to the feeder than calves with no diarrhea ($P = 0.1$), and calves with severe diarrhea had significantly fewer rewarded visits to the feeder than calves with no diarrhea ($P = 0.03$). On day 0, calves with severe diarrhea had significantly ($P = 0.03$) fewer rewarded visits to the feeder than calves with moderate or no diarrhea. On day +6, calves with moderate diarrhea had significantly ($P \leq 0.01$) more rewarded visits to the feeder than calves with severe or no diarrhea.

**Respiratory Disease**

**Intake**

No additional explanatory variables remained in the model after the backward stepwise elimination was performed. Overall, calves with respiratory disease had a significantly lower daily milk replacer intake than calves with no respiratory disease ($8.05 \pm 0.16$ vs. $8.55 \pm 0.16$ L/d; $P = 0.03$). There was a significant effect of time ($P < 0.01$), and there was a significant interaction between respiratory disease and time ($P < 0.01$). Milk replacer intake in calves with respiratory disease was significantly ($P \leq 0.05$) less than that of calves with no respiratory disease from day -4 to day 0 (Figure 4-2 A). Milk replacer intake was similar in both groups of calves after day 0.

**Drinking Speed**

No additional explanatory variables remained in the model after the backward stepwise elimination was performed. Overall, calves with respiratory disease had a significantly lower average daily drinking speed than calves with no respiratory disease ($398.28 \pm 11.64$ vs. $444.64 \pm 11.68$ mL/min; $P = 0.01$). There was a significant effect of
time ($P < 0.01$). However, there was no interaction between respiratory disease and
time ($P = 0.14$). Average daily drinking speed in calves with respiratory disease was
lower than that of calves with no respiratory disease throughout the observation period
(Figure 4-2 B). This decrease was statistically significant ($P \leq 0.05$) on all days except
for day -6 ($P = 0.16$) and day +1 ($P = 0.06$).

**Rewarded Visits**

No additional explanatory variables remained in the model after the backward
stepwise elimination was performed. Overall, number of rewarded visits to the
automated milk feeder per day was similar in calves with and without respiratory
disease ($6.52 \pm 0.15$ vs. $6.33 \pm 0.15$ visits/d; $P = 0.37$). There was no effect of time ($P =
0.36$), and there was only a tendency towards an interaction between respiratory
disease and time ($P = 0.09$). Calves with respiratory disease tended to have more
rewarded visits to the feeder than calves with no respiratory disease on days +1 ($P =
0.09$) and +6 ($P = 0.06$), and had significantly more rewarded visits to the feeder on day
+7 ($P = 0.05$) (Figure 4-2 C).

<table>
<thead>
<tr>
<th></th>
<th>Diarrhea</th>
<th>Respiratory Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Moderate</td>
</tr>
<tr>
<td>BW (kg)</td>
<td>42.27 (4.96)</td>
<td>41.51 (5.84)</td>
</tr>
<tr>
<td></td>
<td>39.91 (5.12)</td>
<td>40.19 (5.76)</td>
</tr>
<tr>
<td>STP (g/dL)</td>
<td>5.94 (0.57)</td>
<td>5.93 (0.64)</td>
</tr>
<tr>
<td></td>
<td>6.16 (0.69)</td>
<td>6.02 (0.57)</td>
</tr>
<tr>
<td>Age day 0 (d)</td>
<td>8.08 (1.12)</td>
<td>8.00 (1.29)</td>
</tr>
<tr>
<td></td>
<td>7.97 (1.07)</td>
<td>30.89 (7.73)</td>
</tr>
</tbody>
</table>

Table 4-1. Mean (standard deviation) birthweight (BW), neonatal STP concentration,
and age at day 0 for each category of diarrhea and respiratory disease.
Figure 4-1. Association between diarrhea and intake of milk replacer, average drinking speed, and number of rewarded visits to the automated feeder. A) Least squares means (± SEM) of milk replacer intake (L/day) in calves without diarrhea and calves with moderate and severe diarrhea. B) Least squares means (± SEM) of average daily drinking speed (mL/min) in calves without diarrhea and calves with moderate and severe diarrhea. C) Least squares means (± SEM) of rewarded visits to the automated feeder (visits/day) in calves without diarrhea and calves with moderate and severe diarrhea. Letters (abc) indicate statistically significant differences between least squares means in a single day. Means that share a letter have a $P$ value > 0.05. Means that are not marked with a common letter have a $P$ value ≤ 0.05.
Figure 4-2. Association between respiratory disease and intake of milk replacer, average drinking speed, and number of rewarded visits to the automated feeder. A) Least squares means (± SEM) of milk replacer intake (L/day) in calves with and without respiratory disease. B) Least squares means (± SEM) of average daily drinking speed (mL/min) in calves with and without respiratory disease. C) Least squares means (± SEM) of rewarded visits to the automated feeder (visits/day) in calves with and without respiratory disease. * denotes a $P$ value $\leq 0.05$. † denotes a $P$ value 0.06-0.10.
Diarrhea

In the present study, calves with severe diarrhea had decreased milk replacer intake from day 0 to day +3. These results are very consistent with the findings in Borderas et al. (2009), who also showed in their evaluation of calves on a high allowance of milk that sick calves had a lower milk intake from day 0 to day +3 than healthy calves. Although the analysis in Borderas et al. (2009) included multiple diseases and not only diarrhea, gastrointestinal illness was the most common disease observed. The present study took an additional step and evaluated two different severities of diarrhea. Calves with moderate diarrhea had a lower milk replacer intake than calves with no diarrhea only on day 0, indicating that calves with less severe diarrhea recover their appetites more quickly while calves more severely affected by diarrhea may need more supportive care to maintain nutrient balance.

Average daily drinking speed was significantly decreased in calves with severe diarrhea on days 0 and +1. Maatje et al. (1993) found decreased drinking speed to be the most common deviation in sick calves, though a direct comparison cannot be made because the methodology and statistical analysis in this study were very different from the present study. In Maatje et al. (1993), diarrhea was not the only disease that was analyzed, rather all diseases were analyzed together. Also, the cutoff for a significant decrease in average drinking speed was arbitrarily set and was counted as a deviation if it occurred anywhere from 7 days prior to 3 days after the day of diagnosis with disease. The relationship between time and disease and average drinking speed was not evaluated. Borderas et al. (2009) did not evaluate drinking speed as an outcome of
interest, but did find that sick calves on a high milk allowance drank less milk while spending more minutes per visit to the feeder on days 0 to +3. The decreased number of visits to the feeder per day from the sick calves certainly explains part of this decrease in milk intake, but a decreased average drinking speed may also play a part in this finding.

The effects of diarrhea on the number of rewarded visits to the feeder per day were inconsistent in the present study. Calves with severe diarrhea had a statistically significant decrease in number of rewarded visits to the feeder on days -2 and 0 when compared to calves with no diarrhea. When comparing calves with moderate diarrhea to calves with no diarrhea, the calves with moderate diarrhea had a tendency towards fewer rewarded visits to the feeder on day -2 and, surprisingly, had significantly more rewarded visits to the feeder on day +6. This is in sharp contrast to the findings in Borderas et al. (2009), where sick calves on a high milk allowance consistently had fewer total visits to the feeder per day from days 0 to +3. There are several differences between the present study and Borderas et al. (2009) that may explain this difference. In Borderas et al. (2009), all diseases were included in the analysis and total visits to the feeder was the outcome of interest. Gastrointestinal disease, which was defined only as diarrhea, was the most common disease observed in Borderas et al. (2009), and the calves were on a high allowance of milk replacer, resulting in numbers of total daily visits to the feeder similar to the numbers of daily rewarded visits to the feeder in the present study. This suggests that these two aspects of the aforementioned studies may be more similar than dissimilar. However, housing, group size, number of calves per feeding station, nutrition, climate, and age at diagnosis were different between the
present study and Borderas et al. (2009), and perhaps these dissimilarities may factor in the differences between the daily feeder visit results.

It should be noted that, although there were no differences in intake and average daily drinking speed between the three groups of calves, calves with no diagnosis of diarrhea had noticeable decreases in intake and average daily drinking speed from day -2 to day -1, similar to the calves with moderate and severe diarrhea. One possible explanation for this observation is that the calves with no diagnosis of diarrhea were also initially affected by gastrointestinal pathogens, but did not go on to suffer clinical signs severe enough to merit diagnosis and treatment, and their intake and average daily drinking speed recovered faster than calves with severe diarrhea. Another factor to consider is that after moving from individual housing to the group pens, calves were pushed to the feeding station (i.e. herded in groups or individually escorted to the feeding station by a calf barn employee) multiple times a day for several days to train calves to visit the feeder and drink milk replacer from the nipple. The frequency of pushing new calves toward the feeder decreased with time. The observation period for diarrhea began shortly after entering the group pens, as early as the second day in group housing for many calves. This practice of pushing the calves to the feeding stations for training purposes may have artificially increased milk replacer intake on day -2 for all groups, and the drop in milk replacer intake observed from day -2 to day -1 may be due to a decrease in pushing calves to the feeder instead of the onset of diarrhea. However, it does not make sense that helping calves to the feeder would also artificially increase average drinking speed for all groups on day -2. Also, it would make very good sense that pushing calves to the feeder would cause more rewarded visits to
the feeder on day -2, and yet the number of rewarded visits from day -2 to day -1 stayed the same or increased for all groups instead of decreasing as did milk replacer intake and average drinking speed. The theory that pushing the calves to the feeder in the days following the change to group housing artificially elevated milk replacer intake and average drinking speed on day -2 seems less plausible when also considering the number of rewarded visits to the feeder on day -2, but it cannot be ruled out.

It should also be noted that the results of calves with severe diarrhea on day 0 may be biased because of the treatment they received. These calves that were so severely affected by diarrhea that dehydration was detected in them were all treated with 2 L of an oral electrolyte solution administered through an esophageal tube. It is possible that placing this volume of fluids in the abomasum of the calves with severe diarrhea negatively impacted their milk replacer intake, average drinking speed, and number of visits to the feeder on day 0. Another potential bias that must be considered when interpreting the results of the diarrhea analysis is that the calves with a diagnosis of diarrhea that did not have a full data set because they died within 7 days of diagnosis were not considered for the analysis. Therefore, these results may not represent the calves most severely affected by diarrhea to the point of death.

The only difference observed between the three groups of calves prior to diagnosis was decreased rewarded visits to the feeder in the calves with moderate and severe diarrhea on day -2. Although this difference is statistically significant, it is not likely great enough to be used clinically to predict the onset of diarrhea. These results of the present study are similar to the results in Borderas et al. (2009) and suggest that
feeding behaviors measured by automated milk feeders have limited potential to predict diarrhea in calves on a high milk allowance before the onset of clinical signs.

Notable differences in feeding behaviors between calves with and without diarrhea were not observed until the day of diagnosis. The greatest differences were observed between calves with severe diarrhea and no diarrhea. Calves with moderate diarrhea had less drastic (intake and average daily drinking speed) or no (daily rewarded visits to the feeder) changes in their feeding behaviors compared to calves with diarrhea. These findings suggest that feeding behaviors measured by automated milk feeders may potentially be able to be used to detect diarrhea on the day of the onset of clinical signs, or perhaps the day after if a full day’s worth of data is necessary to make a clinical determination and intake does not deviate until the day of onset of clinical signs. Daily intake and average drinking speed appear to have more potential to be used in this manner than number of rewarded visits to the feeder because of their consistent decrease from day -2 to day -1. Calves that are more severely affected by diarrhea seem more likely to be detected using deviations in feeding behaviors. Feeding behaviors may not be able to distinguish between calves only moderately affected by diarrhea and calves with no diarrhea.

**Respiratory Disease**

In the present study, milk replacer intake of calves with respiratory disease was significantly lower than that of calves without respiratory disease from days -4 to 0. No previous study has demonstrated decreased milk intake in calves prior to the day of diagnosis with disease. These findings suggest that either daily milk replacer intake decreased before the onset of clinical signs of respiratory disease in the calves used in the present study, or clinical signs of respiratory disease were present before day 0 but
were not being detected on this farm until several days after daily milk replacer intake had decreased. If the latter is the case, then one must question whether the calf care employees are not adequately detecting clinical respiratory disease at onset, or whether the current and most commonly used method of diagnosing clinical respiratory disease (use of a clinical scoring system that involves monitoring for any combination of the following: increased respiratory rate, cough, mucopurulent nasal discharge, ocular discharge, ear droop, increased rectal temperature) is not adequate for detecting clinical signs at onset. Buczinski et al. (2015) concluded that the McGuirk Clinical Respiratory Scoring Chart can have acceptably high accuracy on average. However, Sivula et al. (1996) reported that only 56% of calves diagnosed with respiratory disease at necropsy had been correctly diagnosed by the producer before death, and Buczinski et al. (2014) reported that only 41% of calves with ultrasonographic evidence of lung consolidation had been treated previously with antimicrobials by the producer. These results call into question the sensitivity of producer diagnosis of respiratory disease in calves. The use of thoracic ultrasound to detect pulmonary abnormalities has been the subject of several recent studies, but the relationship between these abnormalities and clinical respiratory disease in calves is still not well understood. Unfortunately, there is no gold standard for antemortem detection of clinical respiratory disease in calves against which a decrease in milk intake measured by automated milk feeders can be validated. However, the results of the present study suggest that milk intake measured by automated feeders has potential to aid in earlier detection of respiratory disease in dairy calves, and perhaps combined with other diagnostic methods, such as a clinical scoring
system, monitoring milk intake can improve detection of clinical respiratory disease in calves by producers and farm employees.

Average daily drinking speed increased throughout the observation period in calves with and without respiratory disease along a similar slope, but calves had a significantly lower average drinking speed on day -7 (first day of data collection), and that difference remained consistent throughout the observation period. Maatje et al. (1993) found that a decrease in drinking speed was the most common change in feeding behavior between sick and healthy veal calves. However, the pattern of daily drinking speed changes observed in the present study has never been demonstrated before in the literature. The cause of this observation is unknown. Calves must pause suckling from time to time in order to breath, and it stands to reason that calves with respiratory disease would feel the need to take longer or more frequent breaks from suckling to breath more, which would decrease average drinking speed. However, it would be surprising to find this effect so consistently throughout the entire 15 day observation period (day -7 to day +7). Another possible explanation is that calves with lower average drinking speeds have some unknown predisposition to developing respiratory disease. Until the relationship between respiratory disease and average daily drinking speed is better understood, it is not likely to be a valuable aid in the prediction or diagnosis of respiratory disease in calves on a high milk allowance.

There was very little difference in the number of daily rewarded visits to the automated milk feeder between calves with and without respiratory disease, although it statistically tended to be increased for calves with respiratory disease on days +1 and +6 and was significantly increased on day +7. However, the clinical significance of
these increases is minimal as the difference in mean rewarded visits to the feeder on
days +1, +6, and +7 between calves with and without respiratory disease is less than
one. An increase in daily visits to the feeder of any kind (rewarded, unrewarded, total)
in sick calves has never been published in the scientific literature. Why calves with
respiratory disease in the present study had more rewarded visits to the feeder on some
days, however statistically significant or clinically insignificant, is unknown. Differences
between other studies and the present study in housing, group size, number of calves
per feeding station, age at diagnosis, or the fact that respiratory disease only was
specifically evaluated in this study may contribute to the contrasting results in number of
visits to the feeder. Regardless, the findings of the present study suggest that number
of daily rewarded visits to the feeder has little value in predicting or diagnosing
respiratory disease in calves on a high milk allowance.
The objective of this study was to investigate the effects of diarrhea and respiratory disease, the two most common diseases of dairy calves, on the feeding behaviors of preweaned dairy heifers fed a high milk allowance by automated milk feeders. Calves with severe diarrhea had lower milk replacer intake, average drinking speed, and number of rewarded visits to the automated feeder than calves with no diarrhea on the day of diagnosis. Differences in feeding behaviors between calves with severe diarrhea and no diarrhea before and after the day of diagnosis were inconsistent and less noteworthy. Calves with moderate diarrhea had a less drastic decrease in feeding behaviors on the day of diagnosis compared to calves with no diarrhea, and differences in feeding behaviors between calves with moderate diarrhea and no diarrhea before and after the day of diagnosis were minimal. Feeding behaviors do not appear to have much potential to predict diarrhea before the onset of clinical signs. However, they may have potential to be an aid in the detection of diarrhea on the day of the onset of clinical signs, especially intake and average drinking speed. Calves with moderate diarrhea may be more difficult to distinguish from healthy calves than calves with severe diarrhea using changes in feeding behaviors.

Calves with respiratory disease drank significantly less milk replacer than calves without respiratory disease from 4 days prior to diagnosis until the day of diagnosis, suggesting that daily milk intake may be used to detect clinical respiratory disease earlier or perhaps even predict the onset of clinical signs of respiratory disease in calves. Average daily drinking speed was consistently lower in calves with respiratory disease before, during, and after the onset of clinical signs, limiting its potential as a
predictor or detector of respiratory disease. There was only a small and inconsistent increase in number of rewarded visits to the automated milk feeder per day in calves with respiratory disease, suggesting that this feeding behavior also has little value as a predictor or detector of respiratory disease.

Further research on the sensitivity, specificity, and positive and negative predictive values of negative deviations in feeding behaviors measured by automated feeders is needed to determine the level of deviation most suitable for predicting or detecting diarrhea and respiratory disease in dairy calves. This study was performed in calves on a high milk allowance. The results and conclusions likely cannot be extrapolated to calves fed a limited milk allowance by automated milk feeders.
LIST OF REFERENCES


BIOGRAPHICAL SKETCH

Lincoln Judd Sims was born in Gainesville, Florida in 1982 and raised on his family’s farm in Marianna, Florida. Throughout his childhood, he was active in a variety of sports as well as raising and showing chickens, rabbits, pigs, and cattle. After graduating from Marianna High School in 2001, he lived in central Chile for 2 years while serving a mission for his church. He resumed his education after returning to the US, earning an AA in General Studies from Chipola College (Marianna, Florida) in 2006 and a BS in Animal Sciences from the University of Florida (Gainesville, Florida) in 2008. After graduating with his BS, Judd went to work for AgReserves, Inc. where he gained experience in agribusiness management and beef cattle husbandry. In 2009, Judd returned to Gainesville to pursue his veterinary degree at the University of Florida College of Veterinary Medicine (UFCVM). During his veterinary education, Judd was an active participant in the UFCVM Food Animal Club and served terms as its President, Treasurer, and Student Delegate to the American Association of Bovine Practitioners (AABP). Awards and honors that Judd received during his veterinary education include the Merial Veterinary Student Scholar Award, the AABP Bovine Veterinary Student Recognition Award, the AABP Foundation-Pfizer Animal Health Scholarship, and the Pfizer Animal Health Veterinary Student Scholarship. After graduating cum laude with his DVM in 2013, Judd remained at the UFCVM for 4 more years where he completed an internship and residency in Food Animal Reproduction and Medicine and an MS in Veterinary Medical Sciences. During his postgraduate training, he was awarded the Western Veterinary Conference Food Animal Incentive Award and the Southeast Quality Milk Initiative Continuing Education Dairy Award. Judd is married to Rachael Sims, and they have 3 children: Camila (8 years), Jim (3 years), and Gabi (2 years).
After finishing the residency and MS degree in the summer 2017 semester, Judd plans to move to south Florida and start his own veterinary practice with a focus on dairy production medicine.