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DRY COW DIET, MANAGEMENT AND ENERGY BALANCE AS
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presented by

Richard Edward Borthwick Cameron

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**DRY COW DIET, MANAGEMENT AND ENERGY BALANCE AS RISK FACTORS
FOR ABOMASAL DISPLACEMENT IN HIGH PRODUCING
DAIRY HERDS IN MICHIGAN**

By

Richard Edward Borthwick Cameron

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ABSTRACT

DRY COW DIET, MANAGEMENT AND ENERGY BALANCE AS RISK FACTORS FOR ABOMASAL DISPLACEMENT IN HIGH PRODUCING DAIRY HERDS IN MICHIGAN

By

Richard Edward Borthwick Cameron

A prospective study of 1170 multiparous Holstein cows, in 67 commercial herds, was conducted to determine risk factors for displaced abomasum (DA), in high producing dairy herds in Michigan. Each farm was visited four times within a six week period. At each visit, data on nutrition and management were collected and all multiparous cows within 35 days of calving were body condition scored (BCS) and a blood sample taken for plasma nonesterified fatty acids (NEFA) assay. A multivariate linear regression model was developed for lactational incidence of DA by herd, and a multivariate random-effects logistic model was developed for the occurrence of DA by cows. Significant risk factors for DA included a negative energy balance prepartum (as estimated from plasma NEFA), high BCS, suboptimal bunk management, prepartum diets with NEI > 1.65Mcal/kg dry matter, winter and summer seasons, high genetic merit and low parity.

To my parents, Jeanette and James Cameron.

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INTRODUCTION

Since the first reported case of left displaced abomasum by Ford in 1950, displaced abomasum (DA) has emerged as a common production disease in high producing dairy herds (Robertson, 1968; Grymer, 1980). The cost per case associated with treatment and lost production has been estimated to range from \$256 to \$406 in 1993 (Bartlett et al., 1994). An additional factor in considering the significance of this disease is that it is often associated with other production diseases such as hypocalcemia (Curtis et al., 1983), ketosis, and metritis (Curtis et al., 1985).

Epidemiological studies have identified breed, sex, age, season, concurrent diseases (Constable, 1992), and nutrition (Robertson, 1968; Coppock, 1974; Correa, 1990) as potential risk factors for DA. Nutrition is considered to have a significant impact on incidence and is perhaps the factor most feasible to control in a dairy. Yet a paucity of understanding still exists in the area of nutritional risk factors and research in the area has been relatively sparse and the results controversial.

The specific objective of this investigation was to identify potential risk factors for abomasal displacement that may operate on a herd level with special attention to nutrition and management and compare these results with those of an individual-cow model based on the same data set. The rationale for this two model approach is that in practice, the herd is the unit of concern and disease control measures are generally

applied at the farm level. However, as disease affects the individual it is useful to evaluate factors that are specific to the individual such as age, the presence or history of other disease, nutritional status, so that preventative measures can be instituted at this level.

This study was based on commercial, high producing herds in Michigan so that findings from the study would be directly pertinent to these high producing herds. This investigation offers the following advantages over several previous studies: a prospective design that allows for greater data accuracy and the establishment of temporal relationships between hypothesized risk factors and the outcome; a large size so that conclusions are less likely to be influenced by the peculiarities of a single herd, and finally, a consideration of a wide range of variables; all of which are necessary for the study of a multifactorial disease. In the setting of a large field study involving many herds, the study of the incidence of DA has a distinct advantage over other disease incidences. The occurrence of DA is usually heralded by a dramatic change in appetite and performance that is easily noticed by the farmer. In addition, it has a specific diagnosis that is highly repeatable by persons skilled in the clinical evaluation for the condition. Hence, the diagnosis of DA is not subject to the same owner- and veterinarian-variation in diagnosis as is hypocalcemia, metritis, mastitis and ketosis. This variation in diagnosis together with variation in management practices leads to increased or decreased reporting of disease relative to its true incidence which can have a major influence on the results and interpretation of a study (Kaneene and Miller, 1995). With DA being the primary focus of this study, it is not intended that the importance of these other periparturient diseases to health and production be ignored. Due to the association

between DA and other periparturient diseases, it seems reasonable to expect that measures that reduce the incidence of DA may have a beneficial impact on the incidence of other periparturient disorders.

LITERATURE REVIEW

Displaced Abomasum

Definitions

The abomasum's normal position is on the abdominal floor with the body of the abomasum positioned between the ventral sac of the rumen and the omasum (Habel, 1970). When it becomes distended, the abomasum can migrate or displace from its normal position. With distention, the abomasum bends in the middle and forms a loop between the omasum and the cranial duodenum. The greater curvature, with the line of attachment of the greater omentum, is on the outside of the loop. The lesser omentum is on the inside. The crest of the loop may slip under the rumen and come up along the left side where it is buoyed up by gas trapped at the top of the loop (left displacement of the abomasum, LDA), (deLahunta and Habel, 1986; Sack, 1968). Alternatively, the loop of abomasum may simply dilate and displace caudally in a sagittal plane on the right side with the pyloric part dorsal (right displacement, RDA). In some cases, the abomasum may undergo volvulus through 180 to 450 degrees, usually counterclockwise as viewed from the right side of the cow with the lesser omentum serving as the axis of rotation (Habel and Smith, 1981).

Incidence

In a New York survey, Coppock (1974) reported a DA incidence rate of 1.16% among the affected herds and .35% when expressed over the total number of lactations from all herds that reported in the survey. Various authors have reported that the incidence rate appears to be increasing: Robertson (1968) reported that the number of cattle with LDA admitted to the Large Animal Hospital of the University of Pennsylvania increased from 3% of total admissions in 1960 to 30% in 1963; Markusfield (1986) documented an apparent increase in lactational incidence rate from 0.8% during 1974-1976 to 1.7% during 1980-1984 in seven Israeli-Friesian herds.

Dohoo and Martin (1984) found a lactational incidence of 1.4% based on 2008 cows in 32 commercial herds in Ontario. Bartlett et al. (1986) reported a lactational incidence rate of 2.5% based on 2847 lactations in 21 Michigan dairy herds. Robb et al. (1987) reported an incidence rate of 4.36% in 50 dairy herds. Pehrson and Shaver (1992) in a study involving 71 herds in southern Wisconsin recorded an average incidence rate of 5.0%.

Non-nutritional risk factors

Sex, breed and phenotype

Female cattle are at higher risk of developing DA than are males (Constable, 1992). Abomasal displacement is found more frequently in dairy breeds than beef breeds (Constable, 1992). Pinsent et al. (1961), observed that Channel Island breeds are more susceptible than other breeds to the condition. Conversely, Robertson (1968) did not detect a difference among the breeds when the comparison was based on the population distribution. Constable et al. (1992) noted that within breeds, Guernsey cattle

are more frequently affected than Holstein-Friesians, which in turn are more frequently affected than Brown Swiss. Although the authors have given no explanation for difference in breed susceptibility, it may be possible that the susceptibility in Channel Island breeds may be related to their predisposition for hypocalcemia at parturition. The influence of hypocalcemia will be discussed later (page 18).

It has been observed that affected cattle are larger than the population average (Coppock ,1974). Fox (1965) noted that the depth of body of the dairy cow has increased markedly in the past 20 years, allowing potentially more room for abdominal viscera to become dislocated. Mahoney et al. (1986) compared health care needs of cows bred for large or small body size. Two groups were formed from a paired foundation population. The large group was mated to sires with extreme estimates of transmitting ability for tall height and deep and wide bodies, while the small group was similarly mated to extreme sires but to those transmitting short height and shallow and narrow bodies. They found that large cows required significantly more health care than small cows. Digestive disorders accounted for much of the group difference and displaced abomasums were more frequent among large cows, (6 of 220 large and 0 of 191 small cows had DA during first lactations and 10 of 220 large and 2 of 191 small cows had DA during their life times).

Martin (1972) cited evidence from a pedigree study which indicated genotype as a possible predisposing factor. The genetic factors were unknown but shape and size of abdomen were cited as possibilities. These factors appear plausible although there must indeed be more factors involved as a significant change in anatomical proportions of dairy cows is unlikely to have occurred so suddenly to explain the emergence of this

disease. Dairy cows do have deeper abdomens than beef breeds which in part may explain the difference in susceptibility between these two breeds.

Age

Many studies have shown an increased risk of DA with increasing parity (Martin, 1972; Erb and Martin, 1978). The incidence of DA increases with age with the highest risk between the ages of 4 and 7 years (Constable, 1992), however, high incidence rates in first parity cows have been reported (Willeberg et al., 1982). There is evidence that the disease is affecting younger cattle more commonly than previously reported (Pehrson and Shaver, 1992). Dohoo and Martin (1984) were unable to detect a trend with age in their study. A possible explanation for the commonly reported trend of increasing incidence with age may be that increasing age is associated with an increase in occurrence of other diseases such as parturient paresis which, as discussed later, may be risk factors for DA.

Parturition

The occurrence of abomasal displacement is closely associated with parturition. Based on 7,695 records of LDA cases from 17 North American veterinary schools, Constable (1992) reported that 57.0% of cases were diagnosed within 2 weeks and 80.2% of cases within one month of parturition. Approximately 10% of abomasal displacements occurred during pregnancy and were distributed equally in the second and third trimesters. Parturition heralds significant change to the dairy cow in terms of management and dietary changes, metabolic demands, and risk of disease. Thus the challenge of experimental and observational studies, to elucidate significant risk factors for DA, can be appreciated when it is realized that so many variables of importance are changing during this period of risk.

Season

Pinsent (1961), was one of the first authors to note a marked seasonal incidence with the great majority of cases occurring between October and April. This took into consideration seasonal calving patterns. A seasonal incidence was also reported by Robertson (1968) with 60% of cases occurring between November and May, and by Martin (1972) who reported a high incidence in spring and summer. Constable (1992) showed that the peak number of LDA cases develop in spring and the lowest number in autumn. As yet there is no proven explanation for the seasonal occurrence however, Constable (1992) theorized that seasonal changes in rumen volume secondary to seasonal variation in roughage intake may be involved with a full rumen constituting a moderately effective barrier for displacement. This theory has some merit although no documented proof exists that such a distinct change in forage intake occurs through out the population. It is possible that there may be factors associated with season that influence dry matter intake (DMI) in herds.

Twins

Markusfeld (1986) reported an association between DA and the birth of twins, an observation that has been repeated by Pehrson and Shaver (1992). The application of Constable (1992) and Svendsen's (1969) theory that a full rumen constitutes a moderately effective barrier for displacement would fit well in this situation. Twin fetuses in utero would severely compromise rumen capacity in the cow such that after calving the rumen volume may be even lower than usual. In addition cows with twins are more predisposed to common metabolic diseases due to the extra demands of the additional fetus.

Concurrent Diseases

Constable (1992) documented that 53.6% of 780 cattle with LDA and 30.4% of 280 cattle with abomasal volvulus had additional diseases.

Hypocalcemia

Hull et al. (1973), Curtis et al. (1983) and Massey et al. (1993) have presented evidence indicating hypocalcemia to be a potential risk factor for DA. Markusfeld (1986) could find no such association and suggested that previously described associations might have been the result of a tendency for a rising rate with parity, common to both diseases. Oetzel (1993) investigated the effects of prophylactic treatment with a calcium chloride gel on serum calcium concentration at calving, parturient paresis and displaced abomasum in Holstein cows ($n = 204$). Treatment decreased ($p < .05$) the incidence of parturient paresis (4.9 versus 11.8%), and decreased ($p < .01$) the incidence of subclinical hypocalcemia (29.4 versus 52.0%). Displaced abomasum during the first 3 weeks after calving was also decreased ($p < .05$) by treatment (1.0 versus 7.8%). The role of hypocalcemia in the etiology of DA will be discussed further (page 18).

Retained placenta and metritis

In both a study using a bivariate analysis (Coppock et al., 1972) and another using a multivariate analysis (Markusfeld, 1987), retained placenta has been indicated as a risk factor for DA. However, other multivariate studies did not show an association (Dohoo and Martin, 1984; Curtis et al., 1985). Erb and Grohn (1988) concluded that parturient paresis is a risk factor for LDA and that much of the association is mediated by retained placenta.

In the multivariate model put forward by Erb and Grohn (1988), metritis had an independent direct effect on the occurrence of LDA. An association was also reported by Markusfeld (1987) and Coppock et al. (1972). An earlier observation by Robertson (1968) was that 52% of cows with LDA also had concurrent metritis and 24% had metritis prior to the diagnosis of DA. This rate of metritis, one assumes, was higher than expected although no control data was listed. Apart from the relationship between parturient paresis, retained placenta and DA reported by Erb and Grohn, it is also conceivable that metritis fits into the possible association as well. Hypocalcemia, as discussed later, may reduce uterine involution which in turn may predispose the uterus to metritis, especially in the presence of a retained placenta. Apart from the effect of hypocalcemia causing abomasal atony, endotoxins from a metritis may also inhibit abomasal motility (Vlaminck et al., 1985). Poor abomasal motility is considered an important factor in the etiology of DA.

Ketosis

Curtis et al. (1985) in a path analysis based on 1374 lactations of multiparous cows, showed that clinical ketosis diagnosed prior to LDA had an effect on occurrence, increasing the odds ratio to 11.9. Conversely Dohoo and Martin III (1984) in a path analysis of 2711 lactations that included primiparous cows, were unable to detect a relationship. Curtis and co-workers (1985) did not offer an explanation for these different results. Possible reasons to be considered include that different populations were studied and that a large difference in lactational incidence rates for uncomplicated ketosis were reported, (7.4% in Dohoo and Martin's study versus 1.5% in the study of Curtis et al.) despite a similar lactational incidence rate for DA (1.2% versus 1.4%). Varden (1979)

reported that 30 out of 45 cows were treated for ketosis one to eight days before displacement could be demonstrated. Robb et al. (1986) in a case control study found that ketosis prior to diagnosis of DA was associated with an odds ratio of 38.8 (18.6 - 81.1) that was strongest for first lactation animals. A potential pathophysiological explanation for this association will be discussed later (page 19).

Milk Production

It has long been suggested that higher milk production is associated with increased risk of DA (Fox , 1965; Martin, 1972; Coppock, 1974; Grymer, 1981). In a bivariate comparison, Robertson (1968) found that herds reporting LDAs (as opposed to those herds with no LDAs) had a milk yield higher than the average for herds on DHI. Shanks et al. (1978) found in a pedigree study a non significant doubling of the rate of LDA in cows with a high pedigree for milk production. Martin et al. (1978) in a case control study found no indication that higher production cows had a higher incidence rate. Curtis et al. (1985) in a large multivariate analysis (n = 1347) which tested deviation from herd mate average in previous-lactation, mature-equivalent milk yield, found no association between milk yield and LDA. Dohoo and Martin (1984) found no association between previous milk production and the occurrence of DA in a discriminant analysis applied to 817 cows that had completed two lactations. If one is to interpret the significance of the opposing results in the above mentioned studies, attention has to be drawn to the design and type of analysis applied to the different studies. The studies by Dohoo and Martin (1984) and Curtis and workers (1985) are superior to the others in terms of their prospective design, large sample size and better control for confounding variables in a multivariate analysis. Hence the weight of evidence seems to indicate that

milk production is not a risk factor for DA. Erb and Grohn (1988) stated that it is unlikely that high cow milk yield is a risk factor for LDA, however, high previous-lactation herd yield but not high previous cow milk yield was a significant risk factor.

Husbandry Factors

It has been suggested that lack of exercise associated with tethering or housing in winter increased the incidence of DA, however Martin (1972) observed that twice as many affected herds as unaffected herds (28/66 versus 4/26) used loose housing as opposed to tie stalls or a combination. Furthermore, LDA has been observed in cows that are exclusively pastured (Jubb et al. 1991) indicating that exercise is unlikely to be protective or that restricted exercise is a significant risk factor for DA.

Nutritional risk factors

A number of nutritional factors have been speculated upon as risk factors for DA over the past 40 years; however, there are 3 main factors that have featured predominantly in the literature. These are:-

- the level of concentrate feeding
- dietary fiber levels
- dietary calcium levels and more recently, the dietary cation-anion (DCAD) difference

Concentrate Feeding

The issue of concentrate feeding was the first to receive attention. It is interesting historically that after the first reported case of LDA by Ford in 1950, the number of clinical reports showed a steady increase as reviewed by Pinsent (1961). The question had to be asked what changes were occurring in the dairy industry that may have brought about the emergence of this disease? Significant changes were occurring. Research by Huffman

(1961) had shown that conditions in the dairy industry made it economically worthwhile to feed dairy cows higher levels of grain than had been previously practiced. Thus, the trend in the dairy industry since the early '60s has been to feed more grain. This has been speculated to be responsible for the increased occurrence of DA (Pinsent, 1961). Later it was further specified that lead feeding (the feeding of grain to cows in the late dry period) was associated with a high incidence of DA (Robertson, 1968; Coppock, 1974; Correa et al., 1990).

Lead feeding allows the rumen microorganisms to adapt to a higher grain diet prior to parturition and, perhaps more importantly, induces elongation of the rumen papillae. Several researchers including Robertson (1968), Coppock (1974), and Correa et al., (1990) have concluded that lead feeding is associated with a higher incidence of DA. Unfortunately, in the reports of Robertson and Correa the level of grain feeding was not defined. Conceivably, cows could have been receiving anywhere from a pound of grain to an all grain diet. Robertson used a case-control study involving 30 herds reporting the occurrence of DA, that were matched with 30 herds without any occurrence of the disease. He reported a statistically significant difference in the two groups in the mean amount of grain consumed in the last month of pregnancy. No correlation, however, was found between the level of concentrate feeding and the incidence of LDA within herds. It could be argued that Robertson's conclusion that lead feeding predisposes to the occurrence of DA is not substantiated by his data. It is interesting that, contrary to the findings of Robertson and Correa, Curtis and workers (1985) came to the opposite conclusion in a study of individual cows using the same data set as Correa. In Correa and co-workers' study, the data were analyzed at the herd level and the association evaluated was between

DA incidence and whether or not the farm's stated policy was to lead feed. In Curtis and co-workers' analysis of individual cows, the specific diet fed on each farm was classified with respect to energy and assigned to one of three energy levels. Curtis concluded that the higher tercils of estimated energy were equated with the practice of lead feeding, which decreased the risk of LDA.

Svendson (1969) investigated the link between DA and high concentrate diets and concluded that high concentrate diets lead to high concentrations of volatile fatty acids (VFAs) in the abomasum, resulting in abomasal atony - an important prerequisite for displacement. However, Breukink and De Ruyter (1976) could not demonstrate elevated abomasal VFAs in cows on high grain diets. Another explanation for the potential effect of high grain diets on the incidence of DA is that these types of diets lead to ruminal acidosis. Ruminal acidosis results in the release of histamine and endotoxin (Dunlop, 1972) which has been shown to decrease abomasal emptying (Vlaminck et al., 1985).

Fiber Level

Fiber can be conceived as having two overlapping functions in the prevention of DA. In the dry cow, a high fiber diet, as opposed to one high in concentrates, will lead to greater dry matter intakes (Coppock, 1972; Nocek, 1983). Furthermore, due to the fibrous nature of the diet, feed has a longer residence time in the rumen, leading to a greater rumen volume. Both Svendson (1969) and Constable (1992) have hypothesized that the normal rumen volume constitutes a moderately effective barrier against LDA. Postpartum cows have a significantly reduced rumen volume after calving as the fetus in utero occupies a large space in the abdomen that restricts rumen capacity. After calving, rumen volume will increase with time in relation to increasing dry matter intake. Constable (1992) considered

that evidence for the importance of normal rumen volume is reflected in the findings that proportionately fewer cases of abomasal volvulus, compared with LDA, develop in the immediate postpartum period indicating that rumen volume may directly influence the direction of abomasal displacement. Furthermore, Constable considered that seasonal variation in LDA incidence may in part be explained by a potential seasonal variation in rumen volume if the high incidence in spring is related to a smaller rumen volume which in turn may be related to lower forage intakes in late winter or early spring accompanying depletion of farm hay stores. Constable (1992) surmised that the high incidence of LDA in lactating dairy cattle results from the additive effects of: decreased rumen volume, increased abdominal void immediately after parturition and increased exposure to factors that induce abomasal atony.

Grymer's report (1981) is the only journal publication located in which the relationship between fiber levels and DA was investigated, in an epidemiological manner. He concluded from a case control study that lactating rations less than 16 to 17% crude fiber were associated with increased risk of DA.

The physical nature of the fiber appears important. A ration may have a high fiber content but have little effect on rumination if it is finely processed. Dawson et al. (1992) documented that cows ($n = 46$) fed an experimental diet in which ground alfalfa hay was the principal roughage source were 10.8 times more likely to develop LDA as compared to those fed a normal alfalfa hay.

Apart from its physical affect on rumen volume, fiber also serves as a stimulus for the cow to ruminate. When the cow is placed on a high concentrate diet rumination becomes vital for a supply of bicarbonate rich saliva to prevent ruminal acidosis.

Obviously the levels of fiber and concentrate feeding are inversely correlated to each other and are not necessarily separate issues. Robertson (1968) reported that non-affected herds showed a trend of consistently consuming more nutrients in the form of roughage and that affected herds consistently fed rations having significantly higher grain content. However, a correlation was not evident between the level of grain feeding and the incidence of LDA within herds. Nocek et al. (1983) divided 289 cows into 3 groups during the dry period and fed diets of 100% hay, 50:50 hay:corn silage, or limited corn silage plus liquid protein supplement. The LDA incidence was 3, 4.3, and 6.3% respectively, which although not significantly different, indicated a trend of increasing incidence as the diets declined in hay content. In an earlier experiment Coppock (1972) assigned 40 Holsteins to four complete diets of 75:25, 60:40, 45:55 and 30:70 forage to concentrate ratios 28 days before parturition. During 25 days following parturition, 0, 2, 4, and 4 cases of LDA occurred in the four ration groups respectively. Conversely, Johnson and Otterby (1981) reported that in a trial evaluating 3 dry period diets ranging from all hay to a complete ration of 47% grain and 53% ensiled forage, there was little effect on feed consumption and no cases of DA recorded.

Based on the conflicting reports in the literature, it would appear that the issue of concentrate and fiber levels is an important area in need of further research. A large number of references that are often quoted in reviews of this issue have no statistically significant results and weight is placed on mere potential trends.

Dry cow dietary calcium levels and DCAD

The effect of dry cow nutrition on the occurrence of clinical and sub-clinical hypocalcemia has been well documented (Oetzel et al., 1988; Oetzel, 1991). There have

been reports by Hull et al. (1973), Curtis et al. (1983) and Massey et al. (1993) that show hypocalcemia as significant risk factor for DA. Recent research has shown that the dietary cation-anion difference is more important in preventing hypocalcemia than dietary calcium concentration (Oetzel, 1991).

Pathogenesis of abomasal displacement

Mechanical Theory

Beg and Whiteford (1956) postulated that the uterus in late pregnancy elevates the rumen and pushes the abomasum cranially and to the left of midline. After parturition the rumen drops back and traps the abomasum between the body wall and the rumen, according to their theory. Constable (1992) showed that the incidence of LDA did not increase substantially from the second to third trimester giving little support for the theory of Beg and Whiteford. The fact that DA is reported in bulls, steers, and calves, and that a number of nutritional and metabolic risk factors have been identified, makes it likely that the mechanical theory plays a minor, if any role in most cases of DA.

Abomasal Hypomotility or Atony

There is general agreement that abomasal hypomotility is an important prerequisite for abomasal displacement to occur (Pinsent, 1962; Svendsen, 1969; Breukink and de Ruyter, 1976). The hypomotility results in the accumulation of ingesta and gas leading to distention and displacement. In looking at etiologies for abomasal hypomotility several factors have been considered:-

Volatile Fatty Acids (VFAs)

Svendson (1969) considered that the possible role of large amounts of concentrates in the etiology a DA may be mediated by the effect of VFAs on abomasal

motility and gas production. In experiments involving the infusion of ruminal contents from an animal fed a high concentrate diet into the abomasum of other cows, Svendsen was able to demonstrate a reduction in abomasal motility. This could be repeated using solutions of VFAs similar in composition to what was found in ruminal fluid from a cow on a high concentrate diet. However, Breukink and De Ruyter (1976) compared a high grain diet with an all hay ration and found that there was no difference in abomasal VFA concentrations between the two diets. Madison et al. (1993) studied the effects of a change from a diet composed primarily of forage to a diet composed primarily of concentrate on abomasal antral and duodenal motility of 5 multiparous lactating Holstein cows. Their results suggest that rapid change from a low to a high concentrate diet alone is not sufficient to cause disruption of abomasal antral or duodenal motility that would induce abomasal displacement.

Hypocalcemia

The vital importance of calcium for muscle function, especially smooth muscle function, is well known. Hypocalcemia can effect the motility of the gastrointestinal tract including the abomasum resulting in hypomotility or atony. Hull and Wass (1973) postulated on the possible role hypocalcemia played in the etiology of DA. This was based on observations that many cases of DA can be temporarily corrected by administration of calcium preparations, that some cows with DA also had a history of milk fever, and that the role of hypocalcemia in impaired uterine involution may be the link between the association between metritis and DA. Reports by Curtis et al. (1983) and Massey et al. (1993) indicate hypocalcemia as a significant risk factor for DA. However, the fact that DA can be a significant disease in primiparous cows, which

reportedly are less affected by hypocalcemia than older cows, means that there are likely additional factors involved in the etiology of abomasal hypomotility.

Endotoxin

The association of DA with concurrent disease has stimulated research into possible roles mediators and products of inflammation might play in the etiology of abomasal hypomotility. Vlaminck et al. (1985) in an experimental study with three duodenal fistulated cows, showed a marked inhibition of abomasal emptying after the intravenous administration of endotoxin.

Normal periods of inactivity

Kuiper et al. (1988) studied the myo-electric pattern of the abomasum and found that there were long periods of inactivity which may play a role in the pathogenesis of DA. These periods may last for up to several hours and can occur less than once a day or even once a week and are independent of the cow's position.

Negative-energy-balance associated metabolic disease

Speculation has been raised over the possible association between disorders of energy metabolism (hepatic lipidosis and ketosis) and the occurrence of abomasal displacement (Holtenius and Niskanen, 1990; Breukink, 1991). As discussed, an association between abomasal displacement and ketosis diagnosed prior to displacement has been indicated by some workers (Curtis et al., 1985; Varden, 1979). Although a pathophysiological explanation for this association has yet to be proven, there is evidence for the possible explanations that have been advanced.

Meirhaeghe et al. (1988) found that animals with abomasal displacement showed higher basal blood glucose levels than control animals, independent of their blood ketone

body concentration. They also observed a delay in glucose clearance from the blood of cows with DA, despite elevated insulin levels that point towards the possibility of an insensitivity of body tissues to insulin. The same authors found in a study of four fistulated heifers, that endogenous insulin, secreted after intra venous glucose infusion, as well as exogenously injected insulin, caused a marked decrease of abomasal emptying rate lasting several hours. They suggested that insulin itself, independent of hyper- or hypoglycemia, might be the major cause of inhibition of abomasal emptying. They noted that infusions of some volatile fatty acids (butyrate, iso-valerate, valerate) induced an insulin response greater than that produced by the infusion of glucose. It is possible that these and other insulinogenic substances are involved in the regulations of abomasal emptying and that disturbances in volatile fatty acid metabolism may play a role in the pathogenesis of abomasal displacement. DeCupere et al. (1991) reported that cows ($n = 38$) with left displaced abomasum exhibited insulin resistance which differed both with non-ketotic ($n = 33$) and ketotic ($n = 7$) control animals. This is further supported by Holtenius and Traven (1990) who showed impaired glucose tolerance and heterogeneity of insulin responses in studies with 36 cows with abomasal displacement, indicating insulin resistance and signs of non-insulin-dependent diabetes mellitus. Causes for the insulin resistance are not clear but lipolysis and ketone bodies may play a role.

The potential importance of disorders of energy metabolism in the pathogenesis of DA makes it pertinent to review energy metabolism and associated disorders in the ruminant and this will comprise the second section of this review.

Energy Metabolism in Ruminants

Introduction

An understanding of metabolic disease in ruminants related to disorders of energy metabolism would be facilitated by a brief review of ruminant energy metabolism. This can be achieved by highlighting the fundamental differences in energy metabolism between ruminants and the commonly understood models based on humans and rats.

The first point is that the majority of carbohydrate (CHO) digestion in ruminants occurs in the rumen by fermentation to yield 3 major volatile fatty acids - acetate, propionate and butyrate. Of these products of CHO digestion only propionate can be metabolically converted to glucose (Bruss, 1993). Other sources of glucose can be obtained from certain amino acids entering the Krebs cycle. Thus, an important point to appreciate is that the ruminant is in a constant state of gluconeogenesis (Herdt, 1992, 1988a).

In monogastric species such as the rat, CHO digestion results in glucose absorption. After digestion in these species, the liver has to cope with rising levels of blood glucose. In order to prevent excessive blood glucose levels, the liver has to convert the glucose into alternative forms. Glucose can be converted to glycogen (which can reach a concentration limit) and to fatty acids. Hence, rat and human livers are important sites of fatty acid synthesis, in contrast to ruminants which synthesize essentially no fatty acids in their liver. It follows on that in species where fatty acid synthesis is a significant feature of hepatic metabolism, that they are able to secrete the fatty acids from hepatocytes, in the form of triglyceride (TG), in an efficient manner. The TGs that are produced are packaged into very low density lipoprotein (VLDL), which is TG

surrounded by an envelope of protein, phospholipid, and cholesterol. The VLDL are secreted into the circulation (Herdt, 1992). Pullen et al. (1990) compared liver slices from 8 different species and concluded that the ability of liver to secrete TG as VLDL is proportional to the livers capacity for lipogenic fatty acid synthesis. Thus, it is thought that because ruminant livers are not a site of fatty acid synthesis that in turn the metabolic machinery to package TG into VLDL for secretion out of the hepatocyte is limited. It is probable that it is the secretory process itself, not the synthesis of triacylglycerol, which is responsible for the limited hepatic secretion (Emery et al., 1992). Fatty acid synthesis in the ruminant occurs in adipocytes from acetate - the most abundant energy source for ruminants (Herdt, 1992).

Metabolic response to negative energy balance

The term negative energy balance implies that the animal is expending more energy in a day than is being supplied from the diet. The result is a decline in blood glucose which causes a decline in the insulin/glucagon ratio. This stimulates glycogenolysis from glycogen stores and gluconeogenesis from glucogenic amino acids. However, the major energy source, especially in prolonged periods of energy deficit, is fatty acids. Fatty acids can be utilized directly by the tissues for energy or can be converted to ketone bodies in the liver. Ketone bodies are water soluble molecules that serve as a substitute for glucose in nearly every tissue. During prolonged negative energy balance, there is a shifting of peripheral fuel utilization from glucose and amino acids to ketone bodies and fatty acids (Herdt, 1992).

Fatty acids that are released from lipolysis circulate in the blood bound to albumin and are referred to as plasma nonesterified fatty acids (NEFAs) to distinguish them from

triglyceride fatty acids in lipoproteins and chylomicrons. NEFAs can be utilized by tissue for energy. However, as NEFAs circulate bound to albumin, a more effective transport system is necessary as albumin can become saturated with NEFA. Hence, the liver actively takes up NEFAs. The latter can be metabolized via 3 possible pathways - complete oxidation, incomplete oxidation or re-esterification. Complete oxidation of the fatty acids to carbon dioxide and water is possible but of minor significance. Some of the fatty acids are transported into the mitochondria and undergo β oxidation to ultimately produce ketone bodies. The passage of fatty acids into the mitochondria is a point of regulation. This prevents excess ketone body formation or hyperketonemia. In cases of ketosis there is compromise of this regulatory process (Herd, 1988a).

Hepatic uptake of NEFAs is proportional to plasma levels. When high levels of fatty acids accumulate in the hepatocyte they are re-esterified to form TG. The TG thus formed has to be packaged into VLDL in order to be secreted into the circulation. The secretion of VLDL in ruminants is limited and may be even further compromised by high levels of accumulated TG. Large amounts of hepatic TG lead to fatty liver (Grummer, 1993).

What is relatively new in the understanding of fatty liver is the appreciation of the chronology of the condition. Fatty liver has often been considered a disorder developing in the postpartum. Results from investigations by Gerloff (1986), Bertics (1992) and others have shown that cattle with severe hepatic lipidosis may have high hepatic TG concentrations accumulating during late gestation and may be more susceptible to severe TG accumulation developing near the time of parturition (Grummer, 1993).

A note on normality - there is a normal rise in NEFA levels in the last week or more of gestation and especially so around parturition (Grummer, 1993; Vazquez-Anon et al., 1994). As mentioned, some degree, possibly less than 20% triglyceride (dry matter basis) infiltration of the liver is normal (Grummer, 1993) with no adverse results occurring. However, in certain circumstances the mobilization of NEFAs is excessive or occurring earlier than anticipated. The result is an overload of NEFAs to the liver and to a greater extent than normal, with respect to parturition.

Two potential means for the control of hepatic lipidosis are evident:-

- 1) Reduction of adipose mobilization
- 2) Enhanced hepatic VLDL output

As there is currently not much that can be done about the latter, attention needs to be focused on the former point and this is the direction in which the review will proceed.

Assessment of energy balance

Appreciating that a negative energy balance is the starting point in the pathogenesis of disorders of energy metabolism, variables that could be used to assess energy balance would be of great value. Furthermore, they would allow an evaluation between possible associations between negative energy balance and the occurrence of disease such as DA.

Variables used in assessing energy balance

There are several variables that can be used in assessing the energy balance in ruminants.

Body condition score

This is widely used in dairy herds. A potential disadvantage of the system is that it may not be sensitive enough. One body condition score unit approximates 54 kgs of body weight (Garnsworthy, 1988). Detecting a loss of half a point on the frame of a 600 kg cow that is expanding with advancing pregnancy and perhaps complicated with prepartum edema can be difficult. Body condition scoring may detect significant weight loss occurring through out the dry period, but might not be sensitive enough to pick up condition loss occurring in the late dry period.

Plasma glucose concentrations

This variable was employed in metabolic profile testing widely used in the United Kingdom and elsewhere (Cote and Hoff, 1991). The disadvantage of this is that glucose concentrations are maintained via homeostatic mechanisms that could hide mild or early stages of energy imbalance. In addition this variable is influenced by stress (Lindsay, 1977).

Plasma ketone bodies

This variable is not well correlated with energy balance (Kunz and Blum, 1985). It may fail to indicate mild degrees of energy imbalance and is possibly more indicative of the starch concentration of the ration than its caloric sufficiency. Ketone bodies also exhibit a marked diurnal variation in concentration, possibly linked to feeding, which comprises a major proportion of total variance (Gaal et al., 1983).

Plasma nonesterified fatty acids (NEFA)

This is possibly the most sensitive indicator of the caloric sufficiency of a diet (Kunz and Blum, 1985) but there are potential sources of variation in concentrations in

addition to caloric sufficiency that will be considered later. Annison in 1960 (cited in Bowden, 1971) was the first to suggest that plasma NEFA levels could serve as an indicator of energy balance in ruminants. A lot of the research in the '60s and '70s involved with NEFAs was concerned with nutritional studies in sheep, looking at the effect of dietary energy levels on a wide range of body metabolites including plasma NEFA concentrations. These nutritional studies were extended to cattle and in the '80s attention was given to lactating dairy cows. It should be appreciated that there is relatively limited information in the literature as to normal values in dairy cattle. Gerloff et al. (1986) were one of the first groups to investigate NEFA levels in the development of fatty liver. Further studies have been published by Studer et al. (1993) and Grummer (1993).

Plasma NEFA assays have been typically a research tool and one of the questions to be addressed in this field investigation is whether this variable has potential for use in general field investigations of negative energy balance, hepatic lipidosis and their sequelae of periparturient problems including abomasal displacement.

Normal pattern of NEFA concentrations in the dry period

Based on the limited data available there appears to be a standard pattern in the NEFA profile for cows in late gestation and the periparturient period. Typically cows have levels that are under 300 uEq/l through the dry period. In the last week of gestation NEFA levels start to rise possibly indicating the increased caloric demands of the fetus and amplified by the usual decline in DMI that occurs prior to calving. In the 24 to 48 hours prior to calving there is a dramatic rise in NEFA levels up to 800 uEq/l followed

by a precipitous drop over the next 48 hours. This trend is documented in different studies (Blum et al., 1983; Vazquez-Anon, 1994; Simmons, 1993; Yousif, 1995).

More research is needed to clarify what levels are associated with abnormalities. NEFA levels above 300 uEq/l in the dry period are considered to be indicative of a negative energy balance. This is based on data from different studies (Blum et al., 1983; Vazquez-Anon, 1994; Simmons, 1993; Yousif, 1995; Herdt, personal communication) in which cows generally have NEFA concentrations below 300 uEq/l until approximately 48 hours before parturition when concentrations start to increase. Gerloff et al. (1986) showed that cows that were classified as having severe hepatic lipidosis had NEFA levels above 400 uEq/l greater than 3 weeks from calving.

Pathological factors that affect plasma NEFA concentrations

The three factors of importance include: (1) mass of fat stores, (2) energy imbalance (starting sooner with respect to calving or of greater magnitude than normal) and (3) stress.

Mass of fat stores

Generally, fatty liver is associated with fat cows and hence the name fat cow syndrome. It is known that epinephrine is the most potent lipolytic agent in ruminants while norepinephrine is about 80% as potent as epinephrine (Brockman and Laarveld, 1986). It has been demonstrated that increased beta-adrenergic receptors per adipose cell appear to be associated with the mobilization of greater amounts of glycerol and free fatty acids to meet energy needs associated early lactation (Jaster and Wegner, 1981). It seems possible that the amount of fat mobilized may be proportional to the mass of fat present (Bruss, 1993). Another possible reason for this syndrome being particularly associated

with fat cows is the fact that fat cows (BCS >3.5) have been shown to eat less in the post partum period than thinner animals (Garnsworthy and Topps, 1982), but research is still required to see if this applies to the prepartum period. It is interesting that Zamet et al. (1979) indicated that either predisposition or possibly pre-clinical signs for peripartum disease may be reflected in reduced dry matter intake (DMI) prepartum.

The degree of energy imbalance

Fat cow syndrome, although rare in thin animals, has been observed in animals not necessarily classified as obese. An explanation for high NEFA levels in these animals is that they may have been in a greater degree of negative energy balance or for longer than is normal (Bruss, 1993).

Explanations are - inadequate rations or rations that do not get into the animal e.g. competition at the feed bunk, illnesses - lameness. The significance of adequate dietary energy is highlighted in a study that showed that prepartum diets even more nutrient dense than recommended by National Research Council (NRC) reduced fat mobilization prepartum (VandeHaar, 1995). Other factors not related to disease include - twin pregnancies:- there is greater energy demand in late pregnancy and these cows experience an earlier and greater drop in DMI as calving approaches (Van Saun and Sniffen, 1995) possibly related to reduced rumen capacity. Season - e.g. severe heat stress in June/July is associated with significant fall off in DMI (Zamet et al., 1979).

Finally there is a large variation in the degree of DMI depression seen amongst cows in the last 2 weeks or so of gestation (Grummer, 1993). Generally a gradual decline in feed intake starts about 3 weeks prepartum becoming pronounced in the final week of gestation (Bertics et al., 1992; Zamet et al., 1979). An experimental study reported by

Bertics et al. (1992) illustrates the impact variation in DMI can have on the degree of hepatic lipidosis. In this study there were 2 groups of cows - 11 cows which had ad lib intake (control), and 11 cows maintained at the same level of DMI recorded during day 21 to day 17 prior to calving by force feeding refusals via rumen cannulas. In the control cows DMI decreased by 28% over final 17 days and liver lipid increased 227% in the control cows versus 75% in the force fed group when comparing levels on day 1 postcalving to levels 17 days prior to calving.

Stress

Finally, the third reason for elevated NEFAs is stress. Understanding the critical role of the sympathetic nervous system in fat mobilization (Frohli and Blum, 1988) allows an appreciation of the impact of stress on NEFA levels. Gerloff et al. (1986) mentioned the importance of stress in the periparturient period and common examples are dystocia, new grouping, lack of calving pen, high environmental heat stress. In a genetics experiment that studied the lipolytic adaptations of bovine adipose tissue during late pregnancy, lactation, and dry period in Holstein heifers, there was indication of a genetic component in adrenergic regulation of lipolysis in adipose tissue, independent of energy balance in supporting lactation. Basal glycerol release in high genetic merit heifers was consistently higher than in low genetic merit heifers. In addition the same results were obtained in response to norepinephrine and epinephrine (McNamara and Hillers, 1986). This would indicate that stress would have a greater effect on fat mobilization in cows of higher PTAmilk.

Temporal factors that affect plasma NEFA concentrations

Time period relative to calving

As discussed earlier, cows sampled very close to calving will have dramatically elevated plasma NEFA concentrations which may be normal.

Diurnal fluctuations

Earlier research has demonstrated the significant effect feeding time has on plasma NEFA concentrations. This effect is more pronounced when animals are fed once a day, compared animals having continual access to feed. What is seen is that NEFA levels may drop by more than 50% in 2 to 4 hours after feeding and then rise steadily back over six hours or more (Radloff et al., 1966; Bines and Hart, 1977). In a study looking at the effect of three rations of different energy density on plasma NEFA levels it was found that diurnal variation in plasma concentrations was of greater importance than the variation resulting from a 76% difference in DM intake and a 71% difference in energy status (Coggins and Field, 1976). Hence cows should not be sampled soon after feeding; this should rather be delayed by several hours and taken at a fixed time after feeding (Coggins and Field, 1977).

Effect of stress

Researches have pointed out that NEFA levels are very stress sensitive (Lindsay, 1977). A 50 to 150% increase in NEFA levels has been associated with excitement from handling (Holmes and Lambourne, 1976).

Sample handling

Blood samples taken for plasma NEFA assay have to be handled correctly. This involves placing the samples on ice for transport to the lab. At warm temperatures

significant hydrolysis of TG in VLDL can occur elevating NEFA levels (Herdt, personal communication).

Hepatic lipidosis and disease sequelae to negative energy balance

Hepatic lipidosis is commonly called fatty liver or fat cow syndrome. As the latter name states, this is a clinical syndrome usually observed in the immediate postpartum period and is associated with severe fat infiltration of the liver (Morrow, 1976). As a syndrome it can present in a number of different ways. Typically an obese cow is presented for one or more of the typical periparturient disorders that are common in dairy cows - milk fever, mastitis, metritis, DA. However, in these cows there is typically a poor response to treatment, and the cow is more depressed and anorectic than expected for the given disorder. There is always ketosis present, and the prognosis is guarded to poor (Morrow, 1976; Herdt, 1988).

The significance of hepatic lipidosis to the dairy industry

This can be addressed by studying the disease incidence and outcome in dairy herds. There are limited references in the literature on this point and reference will be made to three in this area. Reid (1980) looked at the incidence of fatty liver in a 109 high yielding Freisian cows in the United Kingdom (UK) and Gerloff et al. (1986) examined 80 cows in 9 herds that were investigated for possible fatty liver problems in Michigan.

Reid evaluated, by quantitative morphology, the percentage (%) fat in liver cells one week after calving. Gerloff et al. (1986), using gravimetric methods, looked at maximum triglyceride concentrations in liver samples between one month before to one month after calving. In both studies they classified the cows into 3 groups - mild, moderate and severe based on the degree of hepatic lipidosis. The three classifications of

mild, moderate and severe hepatic lipidosis are fortunately comparable across the two studies as liver fat content determined histologically as done by Reid is correlated with liver TG content measured chemically as done by Gerloff. Of the 109 high-yielding cows Reid examined, 37% were classified with mild hepatic lipidosis, 48% were moderate and 15% had severe fatty infiltration. In Gerloff's study of 80 cows 65% were mild, 20% moderate and 15% were severe. Gerloff went further in his study and looked at death and cull rates due to disease in the 3 groups of cows. In the mild group 15%, in the moderate group 31%, and in the severe group 42% died or were culled due to disease. In a study involving 49 pluriparous cows van Dijk et al. (1989) found 16 cows (33%) with severe hepatic lipidosis, 13 cows (26%) moderate, and 20 cows (41%) with mild hepatic lipidosis. They found the severe group to be related to impaired fertility and a high incidence of periparturient disease. Reid and Roberts (1983) estimate that about one-third of high yielding cows in the UK are affected by subclinical fatty liver.

Thus, based on these and other studies in the literature, there is a relatively high incidence of the disease in dairy herds and that the risk of morbidity in general, including DA, appears proportional to liver TG levels.

Prevention of Hepatic Lipidosis

The treatment of hepatic lipidosis is aimed at decreasing fat mobilization, decreasing ketone formation, stimulating appetite and treatment of concurrent disease. As mentioned earlier, cows with clinical fatty liver generally have a poor response to therapy which is usually prolonged, labor intensive and expensive. Hence it is sensible to focus ones attention more on prevention than treatment. From the above review, a number of preventative measures can be drawn and are listed as follows:-

- 1) Maximize DMI throughout late gestation
- 2) Proper ration formulation
- 3) Close monitoring of health
- 4) Avoid over-conditioned animals
- 5) Avoid stressful environmental conditions
- 6) Propylene glycol (PG) administration in late gestation
- 7) Assessment of energy balance for early correction of a negative balance

A study by Studer et al. (1993) illustrates the potential benefit of one therapy that could be instituted in the dry period. In this experiment there were 2 groups of cows - one group of 13 cows were given 1 liter oral drench of PG once daily starting approximately 2 weeks prepartum until the day of calving; the other group of 11 cows formed the control group and received a 1 liter water drench. The average NEFA concentrations (uEq/l) in the week prepartum were 403 for the control group and 234 for the treated group. At day one after calving the liver TG% in the control group was 14.5 and for the propylene glycol group 5.0 ($p < .01$). In conclusion, this study illustrates how an understanding of the pathogenesis of hepatic lipidosis with an appreciation of the chronology and the importance of plasma NEFA levels, opens up opportunity for early intervention that may avoid or reduce the severity of the condition and its sequelae.

Hepatic lipidosis - a potential risk factor for abomasal displacement

The literature suggests an association between hepatic lipidosis and abomasal displacement (Holtenius and Niskanen, 1985; Breukink, 1990). It is now understood that a negative energy balance is the initiating factor in the development of both ketosis and fatty liver disease and that this imbalance may frequently start in the prepartum period

(Gerloff et al., 1986; Grummer, 1993). It seems logical to consider that a negative energy balance in the prepartum period, as determined by elevated plasma NEFA levels, may show an association with the occurrence of abomasal displacement. Further investigation of this association in the field may determine its significance as a risk factor and underscore the importance of the practical, preventative measures discussed for hepatic lipidosis when considering preventative measures for abomasal displacement.

MATERIALS AND METHODS

The Data

Selection of farms

Selection of farms was based on two criteria - being a member of the Michigan Dairy Herd Improvement Association (DHIA) and having a current herd average above the Michigan DHIA average of 8760 kg (19300 lb) of milk per cow per year. Three hundred farms met these criteria of which 118 responded to a questionnaire sent out soliciting involvement in the study. Of the 118 farms that responded, 104 farms were visited between October 27, 1993, and January 25, 1995.

A total of 67 farms (1170 cows) were used in this study. The reasons for deleting the farms (37) included incomplete data (20) (failure to complete the health sheets (6), inadequately defined rations (7), incomplete management data (7)) and inadequate cow numbers (13). A total of 1737 cows (465 primiparous and 1272 multiparous) were sampled in the 67 herds. Primiparous cows and cows that gave birth to twins were deleted from the analysis.

Farm visits

Responsibility for collecting and recording data on the assigned farms was done by 4 investigators among which the 104 farms were divided. Each farm was visited 4 times within a 6 week period with a minimum of 6 days between each visit.

Herd data

On the first visit, nutrition and management data were recorded on standardized sheets and at the second, third and fourth visit, changes in nutrition or management were recorded.

A TMR is defined as a total mixed ration such that all the dietary components being fed are mixed together before being fed. In this study, if any dietary component was fed separately then the ration was not classified as a TMR. A transition diet was defined as a ration that is fed to dry cows for at least the last week of gestation and which differed in content from what the cows were fed in the earlier part of the dry period.

It was not feasible in this study to conduct feed analysis of the rations on each farm. Hence reliance was placed on ration data supplied by the farmer. In cases where there was no feed analysis available, book values (NRC) were used to describe the feed examined. Estimates of feed intake were available on some farms but in the majority of cases this was difficult to predict with accuracy. In cases where intakes were unknown it was assumed that the average cow's dry matter intake (DMI) in late gestation was 10kg per day. When the amount of concentrate fed was known, the amount of forage consumed was estimated by the difference between the concentrate dry matter and the potential DMI.

Bunk management with respect to late gestation cows was evaluated. Length of bunk space, how frequently the bunks were cleaned and for how long feed was available was recorded. A penalty score (0-2) was devised for bunk management and is described in the Appendix.

An estimate of herd ME milk production was obtained from the mean of herd ME milk production on DHIA test days between 1 and 150 days after the first visit to the farm. This variable was collected as an indicator variable as opposed to a risk factor.

Cow data

On the first visit and subsequent visits the following was collected from all Holstein cows and heifers within 5 weeks of calving:- identification number, body condition score and a blood sample collected in an EDTA tube from a coccygeal vessel. No effort to classify the animal with regards to parity was done at this stage as these data along with the animal's PTAmilk index were to be obtained from DHIA records once the animal had calved. PTAmilk is a value derived from the animal model which predicts genetic merit of each animal in a population from the animal's own performance (if available) and the production records of all related animals. The Predicted Transmitting Ability (PTA) is a one-half breeding value, adjusted so that cows born in 1985 average 0 (Wiggans and van Raden, 1989).

At the second, third and fourth visit all animals within 5 weeks of expected date of calving were identified, body condition scored and blood sampled, including animals from the previous visit that had not yet calved.

Before the start of the field investigation, the investigators standardized their body condition scoring technique using a chart from Elanco Products Company (Indianapolis, IN, USA). Body condition scoring was done on a scale of 1 to 5 (1/2 point increments), with 1 being emaciated to 5 being severely obese (Wildman et al., 1982).

The blood samples for plasma NEFA analysis were put into ice within 15 minutes, transported back to the laboratory, centrifuged at 3000 rpm for 15 minutes and the plasma then placed into labeled plastic tubes and stored at - 20 °C. The plasma samples obtained were analyzed for NEFA using a commercial kit (NEFA-C kit, Wako Chemicals USA, Richmond, VA) with modifications by McCutcheon and Bauman (1986), Sechen et al. (1993), Johnson and Peters (1993), Dyk (1995).

Collection of DA incidence data

Heifers were excluded from the analysis because they represented another population which in addition often differed in management from the other cows in the herd. Cows that gave birth to twins were excluded from the analysis as in terms of NEFA levels, abomasal displacement and other diseases, they represented another subset of the population.

Cow model

A health sheet was left with the farmer at the end of the first visit to record health information on the cows sampled after they had calved. From this sheet the occurrence of DA in each animal sampled was determined.

Herd model

In this model a lactational incidence rate for DA at each farm was calculated based on the animals sampled at the farm visits. However, as heifers were excluded from the analysis in both models, the number of multiparous cows initially identified was limiting in the smaller herds and in herds that had few cows over the study interval. One approach would be to eliminate herds with small numbers but this would bias the study in

favor of larger herds. The minimum number of multiparous cows that had to be considered in assessing the occurrence of DA was chosen after considering that the National Animal Health Monitoring System (NAHMS) uses a minimum of 10 animals for their herd disease estimates (Kaneene and Hurd, 1990). The inclusion criteria set for this study were that a minimum of 20 consecutive multiparous cows with no DA had to be considered for a zero occurrence to be assigned to the herd. A herd could be included if one or more DAs were reported for less than 20 cows (9 cows was the lowest number) but not if no DAs had been reported. This was done to improve the confidence in classifying herds as low incidence. It is appreciated that the incidence estimate between herds may be affected in some cases by the difference in population size but this concern diminishes when differences in incidence between herds is large. It is accepted that the estimate of incidence in this dry cow population sampled may differ significantly from the annual incidence rate obtained for the same herd, however, the estimate obtained is not being used for this inference.

In order to increase the number of cows on which the DA frequency estimate for the herd was based, 44 of the herds in this study were approached retrospectively to create an expanded data base on which DA incidence rates could be calculated. This will be referred to as the expanded data set as opposed to the original data set. Using DHIA records, additional cows that calved directly following those that were sampled, were identified. The farmer supplied data on whether the cows experienced a DA during the lactation and, in addition, if the cow had a DA, whether the cow had had twins.

Statistical analysis

The analysis was done at two levels - a herd level and a cow level. The cow-model considered risk factors for abomasal displacement specific to the individual and used a logistic regression analysis. The herd model considered potential risk factors operating at the herd level and involved a multiple regression analysis.

Herd level variables

The risk factors considered in the herd model are listed in Table 1. Where applicable a further description of these variables can be found in the Appendix.

The outcome variable was the herd incidence rate of abomasal displacement in the expanded data set. Each herd's DA incidence rate (DAIR) was calculated as in equation 1.

Equation 1:

$$\text{DAIR} = \frac{\text{No. affected with DA}}{\text{No. recorded calvings}}$$

Cow level variables

The risk factors considered in the cow model are listed in Table 2. The outcome variable was categorical (1/0) - the presence or absence of DA - in each cow. Table 3 shows the outcome variables for both models and their coding.

Table 1
Herd-based risk factors used in analysis of DA

Risk Factor	Coding	Description
season of visit	1-4	months (1-12) categorized: 1) 3 4 5 2) 6 7 8 3) 9 10 11 4) 12 1 2
bcs 1	1-5	herd average body condition score 35 to 1 day prepartum
N3001	0-.93	herd incidence of NEFA concentrations above 300 uEq/ l in cows sampled 35 to 3 days prepartum
hdmilk	20351-30296	mean of herd ME milk from first visit to 150 days (lb)
lac	2-4.6	average lactation number of cows sampled
ptamilk	430.3-1795.8	average PTAmilk index (PTAmilk < -200 coded as missing values) for herd, based on cows sampled
Feed Management Risk Factors		
bunk	0-2	combined score for bunk space and feed availability and freshness (0-2)
d_trat	0-30	days transition ration fed - continuous
tmr	0/1	total mixed ration fed precalving (1 = yes, 0 = other)
trat	0/1	transition ration fed (1 = yes, 0 = no)
Feed Risk Factors		
cmcpr	0/1	precalving ration energy density categorized: if >1.65 NEI Mcal/kg DM cmcpr = 1, if = or <1.65 NEI Mcal/kg DM then cmcpr = 0
denerg	1-5	change in concentrate feeding before & around calving, categorical : 1(mild) - 5(severe)
dforage	1-5	change in forage type & relative amount around calving, categorical: 1(mild) - 5(severe)
dnfcb	-5-20	difference in non fiber carbohydrate (NFC) % between ration precalving and postcalving
hay	0-79	% hay in ration precalving
mcd	1.21-1.61	NEI Mcal/kg DM of dry cow ration
ndfl	15-46	forage - neutral detergent fiber % of lactating ration
ndft	16-53	forage - neutral detergent fiber % of prepartum diet
Disease risk factor		
mf	0-.33	herd incidence of milk fever based on cows sampled

Table 2
Cow -based risk factors used in analysis of DA

Risk Factor	Coding	Description
Descriptive and NEFA Factors		
bcs 1	1-5	average body condition score 35 to 1 day prepartum for individual cow
lac	2-9	lactation number
ptamilk	-151-2770	pta milk index (pta < -200 coded as missing values)
N3001	0/1	if cow had a NEFA concentration above 300 uEq/ l sampled 35 to 3 days prepartum then N3001 = 1
Disease risk factors		
dyst	0/1	case of dystocia
mf	0/1	case of milk fever
rp	0/1	case of retained placenta

Table 3
Outcome variables used in analysis of DA

Variable	Coding	Contents
DA	0/1	Displaced abomasum in observed cow
DAIR	-2.94 - -0.49	Logit transformed DA incidence rate (herd)

Cow model

This was approached by first generating univariate random effects logistic regression models for each of the risk factors using the variable DA (coded as yes or no) as the outcome (Statistics and Epidemiology Research Corporation and Cytel Software Corporation, 1991). All risk factors were included in the multivariable logistic regression model with random effects. This approach of using the random effects accounts for possible lack of independence of individual animals in the same herd. A backwards model building procedure was used to develop the final reduced model in which risk factors had to have a significant association with the outcome at $p < .05$. The correlation matrices for both the initial data set and the final model were checked for potential collinearity among the independent variables by means of evaluating the correlation coefficients between the independent variables. Based on an acceptable limit of .6 ($p < .05$) for a correlation coefficient, no collinearity was detected.

Herd model

The risk factors that were initially selected from the complete data set were chosen to reflect factors which had previously been associated with the occurrence of DA. In addition, management factors were also considered. As the outcome variable DAIR was not normally distributed, a logit transformation was performed to improve the distribution. The formula for the logit transformation is seen in equation 2.

Equation 2:

$$\text{logit transformation} = \log \frac{\text{DAIR} + 0.05}{1 - (\text{DAIR} + 0.05)}$$

Univariate regression models were developed for each of the risk factors.

Collinearity diagnostics were run during the regression process (Statistical Analysis Systems Institute Inc., 1985) by means of evaluating the correlation coefficients between the independent variables. Based on an acceptable limit of .6 ($p < .05$) for a correlation coefficient, no collinearity was detected. A multivariable linear regression model was developed using a backwards model building procedure in which the remaining variables had $p < .05$. Collinearity within this model was evaluated by inspection of variance inflation factors and Eigenvalues. No collinearity was detected. The plot of residuals for the final model showed the residuals to be normally distributed, hence indicating that the normality requirement for linear modeling was upheld.

Results

Lactational incidence rate for DA

Lactational incidence rate for DA based on lactation number for all cows sampled in the study is shown in Table 4. The DA incidence rate for individuals with twins is shown in Table 5.

Table 4

DA incidence for all cows (excluding those cows with twins)

Lactation No.	Number of cows	Number with DA (%)
1	456	29 (6)
2	509	37 (7)
3	325	26 (8)
4	171	10 (6)
5	82	5 (6)
6	53	2 (4)
2 and greater	1170	80 (7)

Table 5
DA incidence for cows with twins

Lactation No.	Number of cows	Number with DA (%)
1	9	1 (11)
2 and greater	102	12 (12)

Cow-based analysis

Table 6 shows a break down of risk factors based on cows' DA status and Table 7 shows the final cow-based multivariate model.

Significant factors in the cow-based model associated with an increased risk of DA included increased body condition score, winter season and a plasma NEFA level greater than 300 uEq/l between 35 to 3 days prepartum. An increasing lactation number brought about a reduction in risk of DA.

Herd-based analysis

Table 8 shows the herd-based multivariate model for the logit transformed incidence rate of DA. Significant factors which were associated with increased risk of DA in herds included increased PTAmilk, increased body condition score, winter, summer, and rations with energy densities higher than 1.65 Mcal/kg NEI DM fed before calving. Having adequate bunk space together with fresh feed always available was significantly associated with a reduced risk of DA.

Table 6
Breakdown of risk factors based on cows' DA status

Risk Factor	Mean observations for cows grouped by DA status	
	With DA	Without DA
herd size	260.67	253.96
lactation number	2.91	3.11
body condition score	3.54	3.32
NEFA concentration above 300 uEq/l 35 to 3 days prepartum	.53	.35
PTAmilk index	1141	1114
bunk management penalty score (0-2)	1.07	.93
days transition ration fed	13.05	13.09
total mixed ration (0/1)	.68	.59
transition ration (0/1)	.83	.85
change in concentrate feeding (1-5)	2.75	2.78
change in forage type and amount (1-5)	2.99	2.77
difference in non fiber carbohydrate (NFC %) between ration precalving and post-calving	2.40	3.25
% hay in ration precalving	11.85	14.75
NEI Mcal/kg DM of dry cow ration	1.44	1.41
forage - neutral detergent fiber % of transition diet	27.41	29.30
forage - neutral detergent fiber % of lactating ration	20.14	20.57
post calving		
occurrence of dystocia	.037	.034
occurrence of milk fever	.099	.093
occurrence of retained placenta	.123	.113

Table 7

Cow-based multivariate random effects logistic models for the occurrence / non-occurrence of DA

Variable	Coefficient	P	Odds ratio	95% CI
Grand Mean	-5.694	<.001	.3365E - 02	.497E - 03 - .228E-01
Body condition score	.8777	.001	2.405	1.41 - 4.10
Winter season	1.087	.002	2.967	1.48 - 5.96
Elevated NEFAs	.7139	.007	2.042	1.22 - 3.42
Lactation number	-.2138	.045	.8075	.66 - 1.0
%SCL	.6524			

Overall model deviance with 1077 degrees of freedom: 519.530

Likelihood ratio statistic for random effects term: 10.9 (p <.283)

Table 8

Herd-based multivariate linear regression model using logit transformed DA incidence rate

Variable	Coefficient	F	P
Intercept	-5.30	25.06	.0001
PTAmilk	.0006	7.27	.0091
Optimal bunk management	-.343	4.69	.0343
Summer season	.339	4.67	.0347
Winter season	.632	10.28	.0022
NEI > 1.65Mcal / Kg DM	.388	4.13	.0465
Body condition score	.650	5.21	.0260
Model $R^2 = .344$, $F = 5.25$ with 66 d.f. ($p < .002$)			

DISCUSSION

Lactational incidence rate

The lactational incidence rate for DA in this study was 7% for the 1170 multiparous cows. Although primiparous cows were excluded from the data analysis, it is interesting to note that the incidence rate in this parity based on 465 animals was 6.4%. These rates are higher than what is reported in the literature. The highest lactational incidence rate previously reported in the observational studies reviewed was 5.0%. This was also the most recent report (Pehrson and Shaver, 1992).

Care must be exercised in interpreting these rates relative to those in the literature as in the majority of literature reports it is the lactational incidence rate reported over a year or more. As has been reported and observed in this study, there is a distinct association between season and incidence of DA. Hence it is quite probable that the incidence rate reported here is higher partly as a result of the time of year when the incidence rates were recorded. Furthermore, the herds studied in this investigation had the state average or higher level of milk production which will likely contrast from the average population on which some studies were based. However, the trend in the literature of increasing incidence with each new report is supported by these results. The trend of increasing incidence with increasing parity that has been reported (Martin, 1972;

Erb and Martin, 1978; Constable, 1992) is not supported by this study and in fact an opposite trend is observed. This issue is addressed later in the discussion.

Cow model

Elevated plasma NEFA concentrations prepartum

In the cow-based model increased plasma NEFA levels prepartum were significantly associated with the occurrence of abomasal displacement. Increased plasma NEFA concentrations in the prepartum period have been demonstrated to be important in the development of hepatic lipidosis (Gerloff et al., 1986; van Dijk et al., 1989; Grummer, 1993). There are in turn studies that have shown the degree of hepatic lipidosis to be associated with the occurrence of periparturient problems (Gerloff et al., 1986; van Dijk et al., 1989), including DA (Holtenius and Niskanen, 1990). Research indicates an association between the occurrence of ketosis and the presence of hepatic lipidosis (Grummer, 1993). Ketosis (diagnosed prior to DA occurrence) has been implicated as a risk factor for DA in several studies (Curtis et al., 1985; Varden, 1979; Robb et al., 1987). These findings support the opinion of Holtenius and Niskanen (1985) and Breukink (1991) that hepatic lipidosis may have a significant role in the pathogenesis of DA.

Two different reports in the literature, one by Meirhaeghe and co-workers (1988) the other by Holtenius (1992), put forward another possible explanation that may link the occurrence of DA to hepatic lipidosis. Meirhaeghe and co-workers (1988) found that animals with abomasal displacement showed higher basal blood glucose levels than control animals, independent of their blood ketone body concentration. They also

observed a delay in glucose clearance from the blood of cows with DA, despite elevated insulin levels, pointing towards the possibility of an insensitivity of body tissues to insulin. The same authors found in a study of four fistulated heifers, that endogenous insulin, secreted after intravenous glucose infusion, as well as exogenously injected insulin, caused a marked decrease of abomasal emptying rate lasting several hours. They suggested that insulin itself, independent of hyper- or hypoglycemia, might be a major cause of reduced abomasal motility and inhibition of abomasal emptying. DeCupere et al. (1991) reported that cows ($n = 38$) with left displaced abomasum exhibited insulin resistance which differed from both non-ketotic ($n = 33$) and ketotic ($n = 7$) control animals. This is further supported by Holtenius and Traven (1990) who showed impaired glucose tolerance and heterogeneity of insulin responses in studies with 36 cows with abomasal displacement, indicating insulin resistance and signs of non-insulin-dependent diabetes mellitus. Causes for the insulin resistance are not clear but lipolysis, ketone bodies and the degree of body fatness may play a role. Holtenius (1992) made the observation that various degrees of insulin resistance are associated with moderate to severe fatty livers.

Another factor to consider is that ketosis is recognized as having a negative effect on DMI. It is possible that poor DMI may reduce motility of the forestomachs due to reduced stimulation of stretch receptors and in turn lead to a reduction in abomasal motility.

Body condition score

In both the cow-based and herd-based models there was a significant association between body condition score and displaced abomasum with increased body condition score associated with increased risk. To my knowledge, this is the first time this association has been observed in a field study. In a study of 429 Holstein cows, body condition at calving was not associated with an increased incidence of disease (Ruegg and Milton, 1995). However, there are other reports that indicate an association between high body condition score and periparturient disease in general. In trials involving cows that belonged to either a control ($n = 22$) or overconditioned ($n = 22$) group, the total number of cases of periparturient diseases were 31 in the overconditioned and 21 in the control during the first 11 weeks postpartum (Fronk et al., 1980). Treacher et al. (1981) reported that cows calving in very good condition (Body condition score 4 or greater), developed more severe fatty liver, lost more weight and were more susceptible to disease and produced less milk than leaner cows. Shirley (1994) reported that in 35 heifers fed to a body condition score of 4.0, on a 1 to 5 scale, and maintained at that condition for the last 60 days before calving experienced a high incidence of subclinical ketosis and abomasal displacement. Of the 35 primiparous cows, 17 experienced a displaced abomasum within the first 30 days after calving.

A pathophysiological explanation for this association between BCS and DA is likely based on a negative energy balance. There is evidence that fatter animals eat less (Garnsworthy and Topps, 1982), and have greater negative energy balance in early lactation that is supported by high NEFA concentrations (Fronk et al., 1980). Elevated

NEFA concentrations increase the degree of hepatic lipidosis (Bertics et al., 1992; Studer et al., 1993; Grummer, 1993). Researchers (Gerloff et al., 1986; van Dijk et al., 1989) have shown the impact of hepatic lipidosis on increased periparturient disease. Further support for this association is shown in this study by the significant association between elevated NEFA levels prepartum and the incidence of DA in the cow-model. The large sample size and controlling for many variables may have allowed the detection of an association between BCS and DA, in contrast to previous studies.

Season

Season was a significant risk factor in both models and their results will be discussed together. Winter (December, January, February) in the cow-model and winter and summer (June, July, August) in the herd model were associated with an increased occurrence of DA. Similar findings for a seasonal association with DA incidence have been reported (Robertson, 1968; Pinsent, 1961; Constable, 1992). Although no theory to explain this association has been proven it is interesting to consider whether a negative energy balance may be involved. It is known that high temperatures reduce dry matter intake in summer (Zamet et al., 1979), which may possibly lead to a greater degree of hepatic lipidosis and a smaller rumen volume at calving. Cold temperatures in winter increase the energy maintenance requirements of cows and extreme temperatures are likely a period of increased stress. A negative energy balance in the cow model is associated with DA occurrence. Management and dietary factors which restrict energy intake in late gestation will have an even more profound affect in winter when maintenance energy requirements are increased. In addition feed intake may be further

compromised especially in herds with exposed bunks due to feed being frozen or covered in snow and the cows may have been less willing to stand to eat in full exposure to the elements.

Increasing lactation number

Increasing lactation number was associated with a reduction in risk for the occurrence of DA. This finding is opposite those reported in the literature (Martin, 1972; Erb and Martin, 1978; Constable, 1992), while Dohoo and Martin (1984) were unable to detect a consistent trend. There are several aspects to consider for the different trend seen in this study. First of all, primiparous cows were excluded from this analysis and had they been included a different result may have been obtained. Secondly, although heifers were not included in either model, a very high incidence of DA in the primiparous cows was present in this study which contrasts sharply with the low incidence in most of the previous studies. A cow that has had a DA surgically corrected is generally unlikely to redisplace in subsequent lactations. Thus, the population at risk in higher parities is reduced by the presence of previously treated cows and this change in population at risk, not accounted for in this investigation, may have had a significant impact especially since differences in incidence rate between parities is small. In addition it would be interesting to compare the age distribution of the population in this study with those in previous observational studies. The impression from looking at the distribution of cows among parities in our study, compared to other published reports, is that herds in our study were made up of younger animals. Thus, it is possible that there was a higher degree of culling in our herds which may also have a significant effect on the population at risk, when one

considers that cows predisposed to problems are removed earlier leaving behind a more 'resistant' population.

Herd model

PTAmilk

PTAmilk is a value derived from the animal model which predicts genetic merit of each animal in a population from the animal's own performance (if available) and the production records of all related animals. In the herd-based model, a higher average PTAmilk was found to be positively associated with the incidence of DA. This association has not been reported in other observational studies. However, support for this association in the literature can be found in Shanks et al., (1978), and Jones et al., (1994).

Shanks et al. (1978) in a study with 43 pairs of heifers found that high pedigree cows produced more milk but had a higher incidence of disease compared to low pedigree cows. It is interesting to note that, although not statistically significant, the high pedigree group in their study had twice the number (6 vs. 3) displaced abomasums as did the low group. Similar findings were reported in a selection experiment conducted over 16 years that compared one group of cows that were bred to the highest PTAmilk sires to another unselected control group. Single-trait selection for milk yield resulted in increases of health expenses as a correlated response. Increases in total health costs during the 16 year study were primarily due to reproduction, digestion and ketosis (Jones et al., 1994).

Care should be taken in the interpretation of the association between PTAmilk and DA occurrence. Although herds with higher average PTAmilk were associated with

a higher incidence of DA it may not necessarily mean that the higher PTAmilk cows with in herds were the ones that experienced DA. As herd PTAmilk is influenced by management selection of sires and dams with greater milking potential, it is possible that the occurrence of DA may be associated with some correlated aspects of management, possibly concerned with maximizing milk production, undefined in this study.

The significance of PTAmilk may indicate that increased milk production is a risk factor for DA. However, no association between DA occurrence and the mean herd ME milk production (between the first visit and 150 days later) considered in the initial herd model was found. A similar lack of association was found in multivariate analysis by Curtis and co-workers (1985) and Dohoo and Martin (1984). Caution must be given to the lack of association between DA incidence and herd ME milk in our study as a much larger population is considered in the herd ME milk production compared to the population on which the DA incidence estimate was based in this study. Given all the numerous factors that can potentially influence herd ME milk production, perhaps mean herd PTAmilk is a more legitimate estimate of a herd's potential milk production and, as this study reveals, this might be where a significant association between DA occurrence and milk production is present. Further evaluation of this association is indicated. It is interesting to consider that, with the extensive use of AI, the average herd PTAmilk is likely to have shown a steady increase over time and this in part may explain the comparable trend of increasing incidence of DA observable in the literature.

One has to be cautious of applying PTAmilk at the individual cow level as our models give no support for this application. However, if PTAmilk operates at the

individual cow level there is research that may give an explanation for this. A report by McNamara and Hillers (1986), indicated a genetic component in adrenergic regulation of lipolysis in adipose tissue, independent of energy balance, in supporting lactation. Cows with high genetic merit showed higher rates of lipolysis measured at 30 and 15 days before parturition and this higher rate was maintained independent of energy balance during lactation. Apart from a genetic component, it also seems probable that the amount of fat mobilized may be relative to the mass of fat stores present (Bruss, 1993).

If having a higher PTAmilk is associated with a greater ability to mobilize fat in the prepartum, then an association between PTAmilk and elevated NEFA levels seems logical. Furthermore, if higher PTAmilk is combined with heavier body condition score and suboptimal bunk management there is reason to expect even higher prepartum NEFA levels. This is not supported by the results of this study but it is an area worthy of further research.

The aim of most dairy herds is to produce replacement animals of higher genetic merit than the parent herd. Thus it seems likely that PTAmilk would be increasing in the direction of lower parity numbers and in turn earlier parities may be more predisposed to metabolic disorders initiated by a negative energy balance especially if they are well conditioned. PTAmilk is associated with age, with younger parities having a higher index. In the cow-model lower lactation numbers were associated with greater risk of DA. If indeed lower parities are at greater risk this may give support to the association between DA incidence and PTAmilk. Primiparous cows were excluded from the models constructed in this investigation so applying the results of our models to this group of

animals is not legitimate. However, if they do in fact share factors in common with multiparous cows, a negative energy balance will have a greater effect on NEFA concentrations in these animals.

Optimum bunk management

In the herd model there was a significant association between having optimum bunk management, and a reduced incidence of DA. These features of bunk management (adequate bunk space and continuously available fresh feed) would be conducive to optimum dry matter intake (DMI) and even consumption of feed throughout the day, allowing for a better nutritional status and greater rumen fill at calving. The significant positive association between elevated NEFA levels and the occurrence of abomasal displacement shown in the cow-based model gives added weight to the importance of nutritional status. Svendsen (1969) and Constable (1992) discuss the importance of rumen fill as a moderately effective barrier against displacement of the abomasum. It seems likely that optimum bunk management would be conducive to maximizing rumen volume.

It has been shown that cows exhibit a decline in DMI in the final days of gestation that may be the result of the effect of placental estrogens (Forbes, 1987). In an experiment (unpublished) cited by the later author in which the feeding behavior of four ewes was monitored from midpregnancy, it was found that meal size decreased and meal frequency increased with advancing pregnancy. This change in feeding behavior may be a consequence of decreasing functional rumen capacity as the uterus enlarges. If this is applicable to cows, then the importance of having fresh feed readily available throughout

the day can be appreciated. Management of herds that feed restricted amounts to dry cows, especially in late gestation, may seriously reduce the DMI of cows in advanced pregnancy. This situation could be further compounded by competition for limited bunk space.

Prepartum diets greater than 1.65Mcal NEI per kg

In this investigation it was found that prepartum diets greater than 1.65Mcal NEI per kg were associated with increased risk of abomasal displacement. A possible explanation for this association may be that cows on a high concentrate diet, compared to a low concentrate diet have a greater decline in DMI before calving as has been observed in other studies (Coppock et al., 1972). A possible reason for this decline may be palatability. There is indication that estrogen, which increases in the final days of gestation, affects dietary selection in ruminants causing a reduction in concentrate intake but not in forage intake (Forbes, 1987). Hence this might explain the lower intake of rations high in concentrate and the benefit of rations high in forage. A decreased DMI compounded by a low forage component may have resulted in a reduced rumen volume post calving. As discussed, a small rumen volume offers less resistance for abomasal displacement to occur (Constable, 1992).

There is another explanation to be considered for the relationship between excessively high energy density and DA occurrence. Cows on a very high plane of nutrition through out the dry period may become overconditioned. Such animals have been shown to have a greater degree of negative energy balance in early lactation possibly as a result of lower DMI. The higher postpartum plasma NEFA levels in these

animals can result in hepatic lipidosis (Van Den Top et al., 1995). The association between hepatic lipidosis and the occurrence of DA is discussed later on.

Comparison of findings between both modeling approaches

The two models complement each other as the cow-based study allows for risk factors within herds to be studied which may explain the variation in herd incidence rate more clearly than between-herd risk factors. This may be particularly true of variables that apply to the individual, such as plasma NEFA concentrations. The cow-model treats each animal as a separate observation and hence will be more sensitive to these risk factors than the herd-based model. However, the herd-based model complements the cow-based model as it is better at evaluating herd-level management practices. This is an area of weakness in the cow-level model because even though it groups observations by herd, the larger herds with more observations will have a greater influence in the model.

The impact of optimum bunk management, herd average PTAmilk, prepartum rations greater than 1.65 Mcal NEI per kg dry matter, and summer on the occurrence of DA would have been missed if only a cow model was studied. Similarly the cow model added the importance of negative energy balance to the occurrence of DA. The combined findings of these two models appear to reinforce each other as discussed, with a common line through several of the factors of significance.

Other dietary factors

No significant association was found between prepartum fiber levels and the incidence of DA in both the herd and cow based models. A significant shortcoming in a field investigation of this magnitude is the inability to accurately estimate the DMI on the

farms investigated. Hence, as cows eat kilograms of forage as opposed to proportions, which were estimated in this study, variations in DMI between and within herds likely introduced significant error in the estimate of forage NDF consumed. Furthermore, selective feeding by cows in herds in which ration components were fed separately would further increase the potential error of the DMI estimate. In as much as dietary energy density is negatively correlated with fiber levels, it could be stated that this study shows that dry-period diets that are extremely high in concentrates (and hence low in forage) are associated with increased risk of DA.

No other significant associations between diet and the occurrence of DA were found in this investigation. No association with dietary factors was found in studies by Dohoo and workers (1984), and Martin (1972). The difficulty of estimating DMI in field based investigations makes comparisons between herds, with respect to diet, potentially inaccurate. This, in part, is likely responsible for the absence and, in some cases, the presence of controversial significant findings.

Twins

Twins were excluded from the analysis as, in terms of NEFA levels, abomasal displacement and other diseases, they represented another subset of the population. Reasons for this may be a feature of a greater and earlier drop in DMI together with the greater prepartum energy needs that they experience before parturition that lead to elevated NEFA concentrations (Van Saun and Sniffen, 1995). These authors suggest that much of the observed health and production problems associated with twin pregnancy may result from inadequate nutrition in the prepartum period to meet fetal needs resulting

in severe maternal nutrient depletion. The high ME requirement for twin pregnancy and the weight loss experienced by dams is also reported by Koong et al. (1982). It seems logical to state that the tendency of twin pregnancies to be associated with the occurrence of DA gives support to both the association of negative energy balance prepartum and the occurrence of DA and also the theory advanced by Constable (1992) and Svendsen (1969) that rumen volume constitutes a moderately effective barrier to displacement. However, it cannot be stated if one or both factors are involved in this tendency for DA.

Limitations in the study

In the herd-based model it has to be appreciated that in some herds the average body condition score was based on a smaller number of cows than used to estimate DA incidence. This may have led to an inaccurate assessment of the herd average. However, the fact that the same association is detected in the cow model, where only cows with BCS were used, indicates the significant influence of this risk factor. The same concern is applicable for the herd average PTAmilk and the average incidence of elevated plasma NEFA concentrations.

Cows that had had a DA previously and were surgically corrected were not accounted for in the analysis. This may have had an impact on incidence especially if the sample for the herd was small.

Although special effort was given to the accurate recording of feeding practices on the farms, a potential short fall was an accurate analysis of the rations themselves. Due to the size of the investigation it was not feasible to chemically analyze individual feedstuffs. Reliance for these data was placed on the farmer. No doubt this information

was accurate in some cases, but not in others. In retrospect, additional inquiries on the questionnaire may have given a greater appreciation of the potential accuracy of the ration evaluation. Such questions could include:- Which ration components have been analyzed and when was this done? How were samples collected? How often is the DM of ensiled feeds checked and by what method? How are ingredients weighed and amounts of forage obtained?

An effort was made to evaluate prepartum rations with respect to their DCAD value. However, as this factor was not assessed accurately in a number of herds it was left out to maintain the sample size. A trend of higher DCAD diets being associated with higher incidence of DA was observed. This is a potential risk factor worthy of further study.

Summary and Conclusions

Significant risk factors for DA included a negative energy balance prepartum (as estimated from plasma NEFA), high BCS, suboptimal bunk management, prepartum diets with NEI > 1.65Mcal/kg dry matter, winter and summer seasons, high genetic merit and low parity. The results of this study give support to the theory that hepatic lipidosis may be an important risk factor for DA given the significance of a negative energy balance in the prepartum. The significance of suboptimal bunk management and overconditioning give further support to this theory. The importance of ensuring optimum nutrition is highlighted in both models. The potential affect of seasonal influence on the energy balance of cows in late gestation offers, in part, an explanation for the seasonal incidence that is commonly observed.

Herds with higher average PTAmilk are associated with a higher occurrence of DA. This association is a new finding and is worthy of further investigation. Although this may be a factor that has to be accepted in the drive to improve herd genetics, its importance, if indeed significant, is that it will need to be considered in further investigations into risk factors of DA. Furthermore, as improving PTAmilk is desirable, the trend for a continued increase in DA incidence is apt to continue, making the need for effective control measures more pressing.

Practical recommendations

DA occurrence in a herd is likely to be reduced by the avoidance of a negative energy balance prepartum, overconditioned animals and by providing optimal bunk management to cows in late gestation. Prepartum rations excessively high in energy (NEI >1.65 Mcal/kg DM) are also to be avoided. In addition, if it were feasible, a seasonal calving pattern in either the spring or fall may avoid the higher risk periods of the year. If this is not feasible, at least an effort could be made to avoid calving cows in the hot summer months when it is known that dry matter intakes can be significantly reduced.

The importance of ensuring optimum nutrition is highlighted in both models. Improving bunk management is a recommendation that can be readily implemented on most farms and the beneficial impact of maximizing dry matter intake in late pregnancy can only help improve the energy balance of cows in late pregnancy. Negative aspects of bunk management that were frequently encountered in the analysis included restricted bunk space, infrequent cleaning of the bunk and restricting feed such that feed was not continuously available. As has been reported by VandeHaar and co-workers (1995), a prepartum diet more nutrient dense than recommended by NRC may be a feasible way of improving the nutritional status of peripartum cows. However, there must be caution that the energy density is not raised excessively (>1.65 Mcal NEI/kg DM).

The results of this study give support to the theory that hepatic lipidosis may be an important risk factor for DA given the significance of negative energy balance in the prepartum as assessed by plasma NEFA concentrations. Thus, it may be worthwhile to

consider a number of preventative measures discussed for the prevention of hepatic lipidosis and are listed as follows:-

- 1) Maximize DMI throughout late gestation - this may best be achieved by having a 'close up' or 'transition group' into which cows are moved 3 weeks before anticipated calving date. This group of animals can be fed a more nutrient dense ration and together with optimum bunk management will reduce the likelihood of a negative energy balance occurring in the prepartum period.
- 2) Proper ration formulation to avoid potential errors
- 3) Close monitoring of health including conditions such as lameness that may impact on nutrient intake
- 4) Avoid over-conditioned animals
- 5) Avoid stressful environmental conditions. The hot summer months are at least easy to predict and calving animals at this time should be avoided if possible.
- 6) Propylene glycol administration in late gestation. This could be considered as a final measure to reduce fat mobilization in late gestation especially in individual animals that are off feed.
- 7) Assessment of energy balance for early correction of a negative balance. The use of plasma NEFA assays may prove useful in field investigations where problems in energy balance are considered.

The influence of negative energy balance, overconditioning and suboptimal bunk management in late gestation on the occurrence of DA is an important concept to be taken from this study when considering preventative measures for DA. This is an

important contribution to the understanding of this disease and is a facet absent in the common literature when preventative recommendations are considered.

APPENDIX

APPENDIX

Description of variables

Change in Energy Level (denerg)

This categorical variable was formulated to describe the temporal change in dietary energy density in the periparturient period (3 weeks before to 3 weeks after parturition) on a scale of 1 (mild) to 5 (severe).

- 1) more than 20 days on a transition ration (or a gradual change over from basal ration to high ration) and an intermediate ration post calving for 7 days or more prior to high ration
- 2) 20 days or more on a transition ration or a gradual change over from basal to high ration
or:
14 days transition ration and then intermediate ration 7 days post calving
- 3) 14 days transition ration then high ration
or:
7-10 days transition ration then intermediate ration 7 days post calving
or:
14 days intermediate ration post calving
- 4) 7-10 day intermediate ration straight to high ration
or:
basal ration to intermediate ration postcalving or basal diet with exposure to some concentrate prior to calving
- 5) Basal ration to high ration

Change in forage type and relative amounts (dforage)

This variable was formulated to consider the change in forage types and amounts in the periparturient period (3 weeks before to 3 weeks after calving) and to classify this on a scale of 1 (mild) to 5 (severe)

- 1) little change in type and proportion
- 2) no change in type, minor change in relative amounts
- 3) a greater than 50% changes in relative amounts
- 4) a greater than 50% changes in relative amount when corn silage decreases relative to haylage
or:
introduction of a new forage type
- 5) severe changes in types (excluding hay) and amounts

Individual bunk management factors

1) Bunk Space (b sp) -

- a) if $< \text{ft/cow}$
or 1-2 ft/cow and TMR limited or cows clean up entire TMR
Then $b \text{ sp} = 1$
- b) if $> 2 \text{ft/cow}$
or 1-2 ft/cow and feed available all the time
Then $b \text{ sp} = 0$

2) Feed availability and freshness (f&f)

- a) if bunks not cleaned at least once a day
or if cows clean it up
Then $f\&f = 1$
- b) if cleaned at least once a day
Then $f\&f = 0$

Bunk management penalty score (BUNK)

Penalty score (BUNK) is calculated in equation 3.

Equation 3:

$$\text{BUNK} = b \text{ sp} + f\&f$$

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