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RELATIONSHIP OF BODY CONDITION SCORE WITH MILK YIELD AND CONCEPTION IN DAIRY CATTLE

By

Joseph John Domecq

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ABSTRACT

RELATIONSHIP OF BODY CONDITION SCORE WITH MILK YIELD AND CONCEPTION IN DAIRY CATTLE

By

Joseph John Domecq

The goal of this project was to investigate the relationships between body condition scores, milk yield and conception in high producing Holstein dairy cows. Three specific objectives were investigated: 1) determine if body condition scores are a valid and consistent measure of subcutaneous fat, 2) determine the relationship between body condition scores and milk yield, and 3) determine the relationship between body condition scores and conception to first service. Data was collected from a commercial dairy farm (1,000 cows) during an 18 month long period. All multiparous cows entered the study at dry-off, while all primiparous cows began the study at parturition. Cows were assigned a body condition score weekly by one individual throughout the study, continuing until 120 DIM. Milk yield, health, and reproductive data was also collected. Ultrasound measurements of subcutaneous fat were compared to body condition scores of 50 cows evaluated during three separate sessions. Ultrasounnd measurements validated that body condition scores were valid and consistent measures of subcutaneous fat. Lower body condition scores at dry-off, and a gain of condition during the dry period were associated with increased milk yield in the first 120 days of lactation. A loss of body condition in the first month of lactation

was associated with a decreased likelihood of conception. A lower body condition score at dry-off and increasing body condition during the dry period were associated with an increased likelihood of conception. Results of this research suggest that body condition scores are more strongly associated with milk production and the probability of conception than the occurence of health disorders or other management risk factors. This research confirmed that body condition scores during the dry period and early lactation are an important dairy herd monitoring tool.

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LIST OF ABBREVIATIONS

$\bar{x}$ = Mean.
μ = Mean.
ΔDBCS = Change in body condition score during dry period.
ΔPBCS = Change in body condition score in first month of lactation.
% = Percent.
BCS = Body condition score.
bST = Bovine somatotropin.
cells/ml = Cells per milliliter.
CFS = Conception to first service.
cm = Centimeter
d = Day.
DA = Displaced abomasum.
DD = Days dry.
DD^2 = Days dry squared.
DBCS = Body condition score at dry-off.
DIM = Days in milk.
DYST = Dystocia.
FCM = Fat corrected milk.
GN_i = Group number.
hr = Hour.
IND = Index.
k = Estimate.
kg = Kilogram.
kg/yr = Kilogram per year.
LAC = Lactation.
LLUM = Left lumbar.
LTHD = Left tail head.
LTRL = Left thurl.
LUM = Mean lumbar measurement.
MET = Metritis.
MF = Milk fever.
MHZ = Megahertz.
mo = Month.
MYA = Milk yield acceleration.
n = Number.
no. = Number.

NDD = New days dry.
p = Probability.
PBCS = Body condition score at parturition.
PCA = Principal component analysis.
R^2 = Coefficient of determination.
RLUM = Right lumbar.
RP = Retained placenta.
RTHD = Right tail head.
RTRL = Right thurl.
SD = Standard deviation.
SE = Standard error.
SPR = Spring.
SUM = Summer.
TRL = Mean thurl measurement.
UM_j = Ultrasound measurement.
US = United States.
WIN = Winter.
wk = Week.
Y_{ijk} = Body condition score.

INTRODUCTION

Dairy cows experience a period of negative energy balance in early lactation when the energy demands for body maintenance and milk production are not being met by the diet. To meet the energy demands of milk production, cows will utilize body fat and protein as an energy source. As milk production decreases during lactation, the demand for energy becomes less, and lost body fat and protein will be replaced.

Monitoring and understanding the relationship between milk production, feed intake, and mobilzation of body reserves is needed when formulating management decisions for early lactation cows. Monitoring milk production of an individual cow is usually conducted on modern dairies. However, monitoring an individual cow's feed intake is not typically done on most large dairy farms. Methods to monitor and evaluate body condition could give insight to the energy status of cows. Body condition scores (**BCS**) are a subjective visual evaluation of the amount of body fat of cows and can be used to monitor negative energy balance as well as the return to positive energy balance in later lactation.

Results of previous studies have suggested that BCS are associated with the nutrition, reproduction, milk yield, and health of cows. Much of the research has been done in the United Kingdom, making inference of results to the United States difficult.

The United Kingdom dairy industry utilizes different feedstuffs and management practices than the United States. Data from dairy cows producing greater than 10,500 kg of milk annually are also limited. The magnitude and duration of negative energy balance may be greater with higher production levels. If this is true, there is a need for BCS research of high producing dairy cows in the United States. Current United States BCS studies utilize small numbers of cows with relatively low production levels and provide conflicting results.

Changes in BCS during the dry and early lactation periods may be more important to production and reproduction than absolute BCS. Body condition score changes during these periods reflect the energy status of cows. Previous research indicates that the absolute BCS at dry-off or parturition may not be as important to milk production as changes in BCS. However, extremes in BCS, cows which are too thin or too fat at parturition, have been associated with health and production problems.

Body condition loss in early lactation has been associated with reproductive problems and conception failure in some studies, while other studies are inconclusive. Energy balance during early lactation may alter the cows' hormonal status, which in turn may delay the initiation of estrous cycles after parturition. Follicular and luteal function may also be negatively altered, which could contribute to reproductive and conception failure. By utilizing and monitoring BCS in early lactation, management practices could be implemented to improve reproductive performance.

Because of the possible relationships between BCS, milk production, reproduction, and health, previous statistical procedures may not have yielded reliable results. If correlations with other variables are not reduced, a reliable association of one variable with another cannot be determined. By utilizing statistical procedures that reduce collinearity, or the association between independent variables in statistical models, not only can the contribution of a specific variable to a particular outcome be determined, but the relative importance of that variable in comparison to all other variables measured can be determined without the effects and problems of collinearity.

Charts to aid in assigning BCS have been developed and are widely used. However, because of the subjective nature of BCS, the validity and consistency of BCS have been questioned and may limit the usefulness of BCS, particularly in interpretation of research results and comparison of BCS among cows, herds, and scorers. Techniques for validating BCS are needed.

The goal of this research project was to determine relationships between BCS, milk production, and conception to first service in Holstein dairy cows producing greater than 10,500 kg of milk annually. Specific aims were:

1) Determine if BCS are a valid and consistent measure of body fat.

2) Determine if BCS, or changes in BCS, during the dry period and early lactation are associated with milk yield or the rate of increase in milk yield.

3) Determine if BCS, or changes in BCS, during the dry period and early lactation are associated with first service conception.

A review of literature is presented in Chapter 1. The BCS validation procedure is reported in Chapter 2. The investigation of the association between BCS and milk yield is presented in Chapter 3. Chapter 4 includes the investigation of BCS and conception. A summary of results from the research project is presented in Chapter 5.

CHAPTER 1

Literature Review

BODY CONDITION SCORING TECHNIQUES

Body condition scores (**BCS**) represent a subjective visual or tactile evaluation of the amount of subcutaneous fat in a cow. Lowman et al. (43) developed a BCS technique for dairy cattle. It was based upon experience with sheep, which allowed for assessment of subcutaneous fat in a simple, quick, and repeatable method. A BCS between 0 (thin) and 5 (obese) was assigned by feeling the amount of subcutaneous fat over the spinous processes and around the tail head. Garnsworthy (24) reviewed the methods and techniques for body condition scoring across species of livestock and regions of the world. Scores typically range from 0 (thin) to 12 (obese), depending on the system of evaluation.

Wildman et al. (66) developed a system by which cows were assigned a BCS ranging from 1 (thin) to 5 (obese) based on a subjective tactile and visual evaluation of the tail head and lumbar regions of the cow. Braun et al. (4) proposed the addition of tenth-, quarter-, or half-point increments to the 1 to 5 range to better characterize the amount of subcutaneous fat carried by cows. More recently, Edmonson et al. (15) proposed a system by which cows were visually evaluated at the lumbar, thurl and tailhead regions and an overall score from 1 to 5 was determined. A chart was developed to aid in assigning BCS to specific body regions. The lumbar, rump, and tail head regions were evaluated to determine an overall BCS utilizing quarter point increments. A chart was developed that included descriptions for 8 specific body locations within the lumbar, rump, and tail head regions.

Ferguson et al. (20) clarified and simplified the BCS system of Edmonson et al. (15) and developed a decision chart for assigning BCS based upon simple descriptions of several specific body regions, including the thurls, lumbar vertebrae, coccygeal ligament and sacral ligament. The simple descriptions developed for the seven body regions were sufficient to categorize cows by quarter point increments between a BCS of 2.25 and 4.0. Half-point increments were needed for BCS less than 2.00 and greater than 4.0.

VALIDATION OF BODY CONDITION SCORES

Garnsworthy and Topp (26) reported a range of correlations from .60 to .76 between ultrasound measurements of subcutaneous fat over the 10th and 13th ribs and BCS. Garnsworthy and Jones (25) reported similar correlations. These correlations suggest that BCS are positively associated with the actual amount of subcutaneous fat.

According to a review by Garnsworthy (24) the original scale developed by Lowman et al. (43) in 1973 was from 1 to 4. However, the Lowman scale (43) was revised in 1976 and ranged from 0 to 5, thus there is some confusion as to what scoring scale was used in United Kingdom research. Regardless of the scoring system used Garnsworthy (24) concluded that BCS were positively correlated with subcutaneous fat.

Neilson et al. (49) used a series of ultrasound measurements over the 10th and 13th ribs and 3rd lumbar vertebra to develop a backfat area index for each cow. The backfat area index was based upon the length and width of the subcutaneous fat layer over the area. Correlations for BCS and the backfat area index were over .80.

Ultrasound has been used extensively in other species of livestock to measure subcutaneous fat and carcass characteristics. Houghton and Turlington (35) reviewed the use and accuracy of ultrasound in swine, sheep, and beef cattle. Correlations from .45 to .94 for ultrasound measurements of subcutaneous fat at various body regions to actual measurements obtained at slaughter indicated that ultrasound measurements were associated with subcutaneous fat. Faulkner et al. (18) concluded that ultrasound was an accurate method of measuring 12th rib thickness in beef cattle based upon comparison to ultrasound measurements obtained after slaughter.

Otto et al. (51) investigated the relationship of BCS and composition of the 9th to 11th rib of dairy cattle and found that BCS was an accurate indicator of the fat composition of a cow. The ether extract content of the 9th to 11th rib section was highly correlated with BCS. They reported that a one point change in BCS was associated with a 56 kg change in live weight. Wright and Russel (67, 68) reported similar results.

The consistency and repeatability of BCS within and across scorers were investigated by Edmonson et al. (15). Body condition score did not differ between scorers with various levels of training during a single scoring session, indicating that BCS could be repeated consistently. All scorers utilized the chart developed by

Edmonson et al. (15) and received some training prior to the study. Ferguson et al. (20) also investigated the repeatability of BCS across scorers and concluded that BCS were repeatable. Four scorers independently assigned BCS to 225 cows and agreed with the modal BCS calculated for each cow 58% of the time, or were a quarter point different from the modal BCS 33% of the time. The BCS obtained in both studies were compared between scorers but not to any objective measurements of subcutaneous fat. Because all scores were obtained during one scoring session, consistency of BCS between scorers and within scorers across time was not investigated.

ENERGY BALANCE AND MILK PRODUCTION

After parturition, dairy cows increase milk production. Peak milk production occurs between 6 and 8 weeks after parturition (6, 21, 24, 32). After peak production, milk production declines at a rate of 2.5% per week for most cows (32). Dry matter intake, which is an indicator of appetite, also begins to slowly increase after parturition, but maximum feed intake occurs 4 to 8 weeks after peak milk yield (6, 21, 24, 32). During this time period, cows experience negative energy balance where the amount of energy needed to support body maintenance and milk production exceeds the amount of dietary energy consumed (6, 24, 32). Several researchers indicated that 80% of cows experience negative energy balance in early lactation (6, 64).

The nadir of negative energy balance occurs 1 to 2 weeks after parturition (6). Energy intake becomes greater than energy output and a positive energy balance occurs 3 to 4 months after parturition (6). Cows meet the energy demands of body maintenance through different combinations of increased energy intake, mobilization of body fat, and as a last resort, by decreasing milk production (6, 24, 32, 46). As energy intake exceeds energy output in mid to late lactation, body reserves lost in early lactation will be replaced.

Garnsworthy (24) offered an explanation for the difference in the rate of increase in milk production and feed intake in early lactation. Mammals generally have a regulatory mechanism which reduces feed intake as body reserves (fat) increase in order to prevent excessive fatness. Cows that are fatter at parturition have lower feed intakes and take longer to reach maximum feed intake than thinner cows (24, 26). Cows may have excessive body reserves at parturition, thus decreasing feed intake at a time in early lactation when feed intake should be increased, leading to the state of negative energy balance. Therefore, cows must mobilze body fat to maintain production during this period of reduced feed intake.

Ferguson and Otto (21) concluded that there is a minimum BCS needed at parturition to support peak milk yield because the increase in feed intake is slower than the increase in milk production in early lactation. If feed intake is not ad libitum, the need for body reserves becomes more important.

BODY CONDITION SCORE AND MILK YIELD

Much of the information concerning BCS and milk yield is based upon studies conducted in the United Kingdom utilizing small numbers of cows. Also the breeds of cows, management strategies and BCS scoring scales were different from those found in the US. These factors make inference to conditions in the United States difficult.

Frood and Croxton (23) indicated that cows with a BCS of 2 or less at parturition produced 400 kg more milk during their lactation than cows with a BCS greater than 2.0. Several studies (3, 37, 41) found no significant relationship between BCS at parturition and daily milk yields. Results of a study by Garnsworthy and Topps (26) and research from Treacher et al. (62) suggest a negative relationship between BCS at parturition and mean daily milk yield in early lactation. Cows with lower BCS generally produced more milk than cows with higher BCS. A positive association between BCS and milk production has also been shown to exist; cows with higher BCS at calving produced more milk (42). In a review of United Kingdom research, Garnsworthy (24) suggested that the relationship between BCS at parturition and milk yield was variable and concluded that other factors must be involved. Cows with a higher BCS at calving generally lost more body condition during lactation, which negatively influenced milk yield.

Conclusions of more recent studies investigating BCS and milk yield in the United States are also variable. Holter et al. (34) reported no relationship between BCS at calving and mean daily milk yields in the first 12 weeks of lactation for 30 cows. Daily milk yields or cumulative milk yields at 80 DIM between cows calving above or below a BCS of 3.5 (five-point scale) did not differ in a 66 cow study (55). Mean daily milk production was not influenced by the amount of condition loss. The amount of BCS loss was related to BCS at calving. Ferguson and Otto (21) reported no significant influence of BCS at parturition on milk yield of 1300 cows on one dairy farm. Results from Italy (52) indicated that BCS at parturition is not important to total milk yield. However, losses in BCS decreased peak production and the persistency of the lactation curve. Waltner et al. (65) suggested that both BCS at parturition and the change in BCS during lactation were related to the total milk yield of 3.5% FCM at 90 DIM. Ruegg (54) reported no differences in 305 d FCM or peak milk yield among 429 cows in 13 Canadian herds based upon BCS at parturition. Based upon the conclusions of these studies, the relationship between BCS at parturition and milk yield is unclear.

The BCS during the dry period prior to parturition may be important. However, the influence of BCS at dry-off or during the prepartum dry period has not been extensively researched, and may have a more direct influence on changes in BCS and milk production. This may be due to the reduced feed intake and greater losses of BCS in early lactation associated with BCS at parturition. The influence of obesity, or overconditioning, has been investigated (22, 27, 47, 63) and suggested to be a problem in production, reproduction and health of dairy cows.

ENERGY BALANCE AND CONCEPTION

Butler and Smith (6) reviewed studies conducted prior to 1987 and concluded that higher milk yield may have a negative influence on conception. More recently, Nebel and McGilliard (48) concluded that higher levels of milk production were associated negatively with reproductive performance, but indicated that data from cows producing greater than 13,000 kg/yr is limited. Hillers et al. (33) concluded that conception was not influenced by production and that it is difficult to separate the confounding effects of management from the possible biological effects of higher levels of milk yield. They further suggested that dry matter intake and mobilization of body fat may be more important to conception and reproductive performance than milk yield.

In a review of the literature, Butler and Smith (6) concluded that negative energy balance was directly correlated to the postpartum interval to first ovulation and lower conception rates. Their study found that the number of estrous cycles is reduced prior to insemination because of a delay in the initiation of estrous cycles during a state of negative energy balance. Fewer estrous cycles prior to insemination may be related to conception failure (6). The follicle may not be as responsive to luteinizing hormone or other gonadotropins because of reduced amounts of glucose and insulin during the state of negative energy balance. Butler and Smith stated that "once estrous cycles were initiated, they continue regardless of energy balance". They concluded that negative energy balance may have reduced the pulsatile secretion of luteinizing hormone which is needed for ovarian activity. Butler et al. (5) reported that energy balance during the first 20 d of lactation is important in determining the onset of ovarian activity following parturition. Canfield and Butler (7) concluded that negative energy balance influences the initiation of estrous cycles by reducing luteinizing hormone pulsatility and responsiveness of the ovary to luteinizing hormone.

Canfield et al. (8) indicated that the correlation was .75 between days to first ovulation and days to energy balance nadir. As the energy balance becomes less negative, the hypophyseal-ovarian axis becomes more active followed by ovulation and formation of a corpus luteum. The mean nadir of negative energy balance occurred 15 d postpartum. First postpartum ovulation occurred at 29 d. The increase in luteinizing hormone pulsatility was also observed by Canfield and Butler (7) around the energy balance nadir.

Villa-Godoy et al. (64) reported that mean daily negative energy balance over the first 100 days of lactation was not associated with a delay in the initiation of estrous cycles postpartum. Mean days to first postpartum ovulation was 23.9, regardless of mean daily energy balance over the first 100 d of lactation. Cows with the lowest mean daily energy balance in the first 100 d reached the nadir of negative energy balance at day 12 postpartum, which was sooner than other cows in the study. First postpartum ovulation for all cows occurred during a state of negative energy balance. Mean daily negative energy balance over the first 100 days of lactation is a longer time period than used by Canfield et al. (7, 8), which may have contributed to the lack of relationship between energy balance and initiation of estrous cycles seen by Villa-Godoy (64). Canfield et al. (8) concluded that first ovulation occurred when most cows are still in negative energy balance, but after the negative energy balance nadir and during the return to positive energy balance.

Butler and Smith (6) concluded that negative energy balance could be monitored by BCS and that days to first postpartum ovulation were associated with BCS. Cows which lost more BCS in the first 5 weeks of lactation required greater days to first service than cows losing less BCS. Their data support the conclusion of Canfield et al. (7, 8) that delayed initiation of estrous cycles postpartum may be due to negative energy balance. Cows may regulate the effects of negative energy balance through the increased mobilization of body fat and increased feed intake.

Negative energy balance may influence the secretion of progesterone by the corpus luteum. Villa-Godoy (64) indicated that progesterone secretion from the corpus luteum of the second and third postpartum estrous cycles was adversely affected by negative energy balance, but the first corpus luteum postpartum was not affected. During the first and second postpartum estrous cycles, Spicer et al. (61) observed higher levels of progesterone in cows with positive energy balance than in cows with negative energy balance.

Based on the research of Lucy et al. (44) energy balance influences the number of ovarian follicles. An increase in the number of large follicles was associated with an increase in energy balance. They concluded that an increased number of large follicles leads to earlier ovulation for cows in higher states of energy balance.

After reviewing literature pertaining to the role of negative energy balance and reproduction in dairy cattle, Nebel and McGilliard (48) concluded that the magnitude and duration of negative energy balance is associated with reduced conception rates. They concluded that negative energy balance alters the secretion of gonadotropin releasing hormone, which effects the secretion of gonadotropins, which in turn influences the secretion of progesterone. They also indicated that BCS may be a way to monitor negative energy balance and make management decisions to improve reproductive performance.

BODY CONDITION SCORE AND REPRODUCTIVE PERFORMANCE

The relationship between BCS and reproductive performance is somewhat unclear. The reproductive performance of 202 cows was not associated with BCS at parturition in a study conducted in Italy (52). Butler and Smith (6) reported that first service conception rate was not different between a group of control cows and a group of overconditioned cows at parturition. Waltner et al. (65) found no relationship between days to first service, or services per conception with BCS at parturition. In a study conducted by Ruegg et al. (56) BCS at parturition was not related to services per conception for 66 Holstein cows. Ruegg and Milton (57) conducted a multi-herd trial and found no relationship between BCS at parturition and reproductive performance.

In a review of research from the United Kingdom, Garnsworthy (24) concluded that BCS at the time of insemination is not related to conception success or failure, but changes in BCS between calving and insemination may influence conception. Butler and Smith (6) grouped cows based on BCS loss between parturition and insemination and reported that losses of one point or two points of BCS resulted in conception rates of 53 and 17%, respectively. Ferguson and Otto (21) reported similar results; cows losing one point of BCS conceived at a rate of 34%, while cows losing two points of condition had a conception rate of 21%. Ruegg and Milton (57) found no significant differences in days to first breeding or days to conception for cows grouped by condition loss between parturition and insemination. However, condition loss in early lactation and increased number of services per conception was identified in this multi-herd trial. In contrast, Ruegg et al. (56) indicated that loss of BCS in early lactation was not related to services per conception for 66 cows, but cows with a BCS of 3.5 or greater at parturition, or cows that lost greater than .75 BCS in early lactation required more days to conceive.

BODY CONDITION SCORE AND COW HEALTH

Van Saun (63) concluded that investigating the relationship between BCS and health is difficult because health problems are not totally independent events. Several researchers (9, 10, 16, 17) used path analysis and odds ratios to show that most periparturient health problems are a series of complex disorders that are related. In addition, there is a wide variation in how health problems are defined and diagnosed, thus making comparison of results difficult. Gearhart et al. (27) also concluded that small sample size and the lack of power to detect significant associations contribute to the difficulty in determining relationships between BCS and health. Because of these factors, the relationship between BCS and specific health disorders is not clear.

Gearhart et al. (27) investigated BCS and changes in BCS on health and concluded that BCS was related to health. Overconditioned cows (BCS > 3.75) at dry-off were at increased risk for reproductive and lameness problems during lactation. Cows overconditioned at 30 d postpartum were 290 times more likely to have metritis compared to cows with average BCS. Retained placenta, metabolic disorders, and mastitis were not associated with BCS. The authors concluded that the small occurrence of health problems in the 9 herds included in the study may make it difficult to identify relationships.

In another multi-herd trial, Ruegg and Milton (57) found no relationship between BCS and health. No significant association between BCS and health were found to exist in several single herd studies (34, 52, 65). Although overconditioning has been identified as a risk factor for health problems, the relatively low number of overconditioned cows in these studies may have contributed to the lack of an association.

AREAS FOR FURTHER RESEARCH

Body condition scores within and across scorers have been determined to be consistent during a single scoring session. The influence of time between scoring sessions on consistency of BCS has not been investigated. Although BCS have been found to be similar among scorers, ultrasound measurements have not been used to validate BCS over time. Although BCS were similar among scorers, BCS may not have been as valid and consistent as ultrasound measurements of subcutaneous fat over time. ***The first objective of this research was to validate and determine the consistency of BCS over time by comparing BCS to ultrasound measurements of subcutaneous fat.***

Dairy cows experience a period of negative energy balance in early lactation, when feed intake cannot meet the demands of production. During early lactation a cow mobilizes body fat and protein as an energy source to support lactation. As lactation progresses, milk production decreases, feed intake increases and body fat lost in early lactation is replaced. Body condition scoring can be used to monitor the changes in body fat during lactation.

Results of research investigating the influence of BCS on milk production are mixed. Research from the United Kingdom may not be similar to the US because of different breeds of cows and management conditions. Extremes in BCS are associated negatively with milk yield. Based upon the studies conducted in the US, BCS at parturition appears to have little influence on milk yield. However, changes in BCS early in lactation have been associated with milk yield. There has been very limited research investigating BCS and milk yield for cows producing over 10,500 kg/yr.

Because of the biological changes experienced by cows, total milk yield at a specific point in time may not be an adequate method of evaluating the association of BCS with milk yield. The rate of increase in milk yield may be influenced by BCS and changes in BCS and may reflect the biological changes experienced by cows. ***The second objective of this study was to investigate the associations of BCS and changes of BCS during the dry period and early lactation with total milk yield and the rate of increase in milk yield in early lactation.***

Associations between BCS and reproductive performance are unclear. Increased milk yields have a slight negative association with conception. Association of changes in BCS between parturition and insemination and conception success is equivocal. Further investigation of the role of BCS and milk yield on conception in cows producing greater than 10,500 kg/yr is needed. ***The third objective of this study was to investigate the associations of BCS and changes of BCS during the dry period and early lactation with conception to first service.***

CHAPTER 2

Validation of Body Condition Scores with Ultrasound Measurements of Subcutaneous Fat of Dairy Cows

ABSTRACT

This research validated body condition scores with ultrasound measurements of subcutaneous fat. Fifty Holstein cows were evaluated during three sessions in 1993. Cows scored during each session were divided into three groups of fifteen or twenty cows. Body condition scores were assigned by one trained individual utilizing a five-point (1 = thin, 5 = fat) visual scoring technique. Cows were scored to the nearest quarter point. Ultrasound measurements of subcutaneous fat were obtained by another individual at the lumbar, thurl, and tailhead areas of both sides of the cow. Body condition scores and ultrasound measurements were collected on the same day, but obtained independently. Correlations between ultrasound measurements were determined and ranged from .36 to .86. Regression models were developed to validate the body condition scoring technique across the three cow groups. Group number and different combinations of ultrasound measurements were independent variables, and body condition score was the dependent variable. Ultrasound measurements were significantly associated with body condition scores. The coefficients of determination for the models ranged from .36 to .65, depending on which ultrasound measurements

were included in the model. These results suggest that the body condition scoring technique used in this study was as valid as ultrasound techniques in measurement of subcutaneous fat.

INTRODUCTION

Body condition scores (BCS) represent a subjective visual or tactile (or both) evaluation of the amount of subcutaneous fat on a cow (15, 20, 21, 24, 51, 66). Methods and techniques for body condition scoring differ across species of livestock and region of the world and have been reviewed by Garnsworthy (24). Scores typically range from 0 to 12, depending on the system of evaluation being used by the scorer. Low scores usually represent thin cows, and higher scores represent cows with more subcutaneous fat.

Two BCS systems have been developed in the US for dairy cows (15, 66). Wildman et al. (66) developed a system by which cows were assigned a BCS ranging from 1 to 5 based on a subjective tactile and visual evaluation of the tailhead and lumbar regions of the cow. Edmonson et al. (15) proposed a system by which cows were visually evaluated at the lumbar, thurl and tailhead regions to determine an overall score from 1 to 5. Ferguson et al. (20) explored and analyzed the work of Edmonson et al. (15) and Wildman et al. (66), which clarified and expanded the usefulness of BCS.

Regardless of the scoring system used, the subjectivity, repeatability, and validity of BCS have been questioned. Studies in the United Kingdom (24, 25, 26, 49) have related BCS to ultrasound measurements of subcutaneous fat at the 9th, 10th, or 11th rib of dairy cows. Correlations between BCS and ultrasound measurements ranged from .59 to .81, suggesting that BCS reflected the actual amount of subcutaneous fat. However, cows in those studies were scored on a four-point scale and were from breeds not normally found in the US; thus, those results may not represent the subcutaneous fat level of cows in the US. Further, the 9th, 10th, and 11th rib are not normally evaluated using the BCS techniques developed in the US.

The consistency and repeatability of BCS within and among scorers were investigated by Edmonson et al. (15). There was no difference in the BCS assigned to cows between scorers with various levels of training, indicating that BCS could be repeated consistently. Since the work of Edmonson (15), the use of BCS as a herd management tool has increased. However, its validity has been questioned by academia and industry, even though data collected from slaughtered animals suggests that BCS and carcass fat are related (18, 51).

Because of the increased role of BCS in dairy herd management and the questions of the validity of BCS, this research investigated the association between BCS and ultrasound measurements of subcutaneous fat. To achieve this goal, the following objectives were addressed: 1) to determine the relationship of ultrasound measurements across specific body locations, 2) to determine the relationship between BCS and ultrasound measurements of fat at specific body locations of the cow, and 3) to validate the relationship between ultrasound measurements and overall BCS over time.

MATERIALS AND METHODS

Data Acquisition

In 1993, 50 Holstein cows located on a commercial dairy farm were assigned a BCS and evaluated via ultrasound. The herd (1,000 cows) was milked three times a day, and mean milk production was over 10,500 kg /yr. Three different groups of cows were evaluated in March (group 1), April (group 2), and December (group 3). Fifteen cows were randomly selected for each group during the first two sessions and twenty for the group in the third session.

The BCS and ultrasound measurements were obtained independently for the same cows on the same day. Throughout the study, cows were assigned a BCS by one individual, utilizing the visual technique developed by Edmonson et al. (15). Cows were scored to the nearest quarter point.

An Aloka 500 (Corometrics Medical Systems, Inc., Wallingford, CT) ultrasound machine with a 5-MHz linear array transducer was used to determine the amount of subcutaneous fat at six different locations in three areas on each cow. Body locations for ultrasound were selected based upon body areas evaluated during body condition scoring and ease of obtaining and reading ultrasound measurements.

One individual operated the machine and obtained ultrasound measurements throughout the study. The hair coats of cows were not clipped because cows were housed in a cold free-stall barn on a commercial dairy. Measurements were obtained by freezing the image on the screen of the ultrasound machine and then measuring the layer of subcutaneous fat in the center of the screen to the nearest .10 cm.

The first ultrasound location was the lumbar area. The transducer was oriented parallel to the midline over the transverse processes of the lumbar vertebrae midway between the midline and ends of the transverse processes. The thurl area, the second area, was located midway between the tuber coxae (hooks) and the tuber ischiae (pins), 2 to 3 cm above the greater trochanter of the femur. The third area was near the tailhead, 4 cm off midline, parallel to the sacral vertebrae, and midway between the tuber coxae and the tuber ischiae. Ultrasound measurements were obtained and recorded for the right and left side in each area.

Statistical Analysis

Ultrasound measurements for right and left sides were used to determine a mean measurement for each area. The mean lumbar, thurl, and tailhead area measurements were used to calculate an overall mean for the areas. Pearson correlation procedures were used to determine associations between ultrasound measurements of the six different locations, and correlations were considered to be significantly different from zero at $P < .05$.

The relationship between BCS and ultrasound measurements were investigated using regression models. To validate BCS with ultrasound measurements, group number 1, 2, or 3 was included in the models. The following general model was used.

$$Y_{ijk} = \mu + GN_i + UM_j + E_{ijk}$$

where:

Y_{ijk} = BCS,
μ = mean,
GN_i = group number (i = 1, 2, or 3),
UM_j = ultrasound measurement j, and
E_{ijk} = error i j k.

Each location was modeled and analyzed separately. Three models were selected for presentation. Model 1 includes the mean lumbar measurement, Model 2 includes the mean thurl measurement, and Model 3 includes the mean ultrasound measurement for the lumbar and thurl regions.

RESULTS

A clear ultrasound image for measurement could not be obtained for 1 cow with a BCS of 4.5, and data for that cow was omitted from the analysis. The tailhead location was discarded after the first group because of low correlation with BCS and difficulty in obtaining a clear ultrasound image for measurement. In addition, a clear ultrasound image for measurement could not be obtained for 2 cows on both the right and left sides of the thurl region, so a mean ultrasound measurement could not be calculated.

Means, standard deviations, and ranges of BCS and ultrasound measurements are presented in Table 1. The number of cows evaluated with ultrasound at each location is also indicated. The BCS ranged from 1.00 to 4.25, mean was 2.94, and standard deviation was .62.

The mean ultrasound measurements of the lumbar for the right and left sides of the cow were 2.30 and 2.35 cm., respectively. Right and left thurl means were 1.95 and 1.96 cm, and right and left tailhead measurements were 1.71 and 1.43 cm. Ultrasound measurements ranged from 0 to 4.20 cm across all three areas and both sides of the cow. Standard deviations of ultrasound measurements were near .5 cm for all six sites. A scatter plot of BCS and the mean ultrasound measurement of the right and left lumbar area is shown in Figure 1.

Pearson correlation coefficients for comparison of the six locations evaluated with ultrasound are shown in Table 2. Correlation coefficients ranged from .36 to .86 and were all significantly different from zero ($P < .05$). The lowest correlation, .36, was between the right or left side thurl with the left lumbar. Correlation was highest between the right and left side thurl measurement, .86. The correlation for the left and right lumbar was .53. These Pearson correlation coefficients were numerically but not statistically different from one another ($P > .05$).

Results from three different regression models are shown in Table 3. The number of cows included in models varies because of the difficulty in obtaining ultrasound measurements at various locations for cows in each of the three groups. The BCS was the dependent variable for all models. Model 1 includes the mean lumbar measurements for 47 cows and group number 1, 2, or 3 as independent variables. Model 2 includes the mean thurl measurement for 29 cows and group number 1 or 2; the independent variables for model 3 were the mean ultrasound measurements for the lumbar and thurl regions for 29 cows and group number 1 or 2.

Results shown in Table 3 are similar for all combinations of ultrasound measurements included in the other models analyzed but not in Table 3. The R^2 ranged from .36 to .65, depending on the ultrasound measurement included in the model. All models were significant ($P < .05$) in explaining the variation in BCS. Ultrasound measurements from all six locations evaluated were significantly associated with BCS ($P < .05$). Means of lumbar and thurl measurements as well as the overall mean of both locations, were also significant ($P < .05$). Group number did not influence BCS in any model ($P > .3$).

DISCUSSION

In this study, the lumbar, thurl, and tailhead locations were selected for evaluation for several reasons. These locations are the general areas that are evaluated when a cow is assigned a BCS using the technique developed by Edmonson et al. (15). United Kingdom studies (24, 25, 26, 49) have used ultrasound measurements from the 9th, 10th, or 11th rib for correlations to BCS. However, this rib area is not evaluated when a cow is assigned a BCS and may not be the ideal body location for comparison and validation of BCS with ultrasound measurements.

The range of standard deviations of .49 to .73 cm for all six locations evaluated suggests that some variation is associated with ultrasound measurement. Houghton and Turlington (35) and Faulkner et al. (18) reported similar standard deviations of ultrasound measurements of the rib area of beef cattle and concluded that ultrasound measurements could be altered by the location of the transducer, the angle the transducer was held to obtain a measurement, and the amount of hair coat. The hair coat was not clipped in this study because the cows were housed in a free-stall barn, and the farmer preferred not to have the hair coat clipped. Lack of clipping may have contributed to the variation in measurements. The layer of subcutaneous fat is not uniform in a given location and could also contribute to measurement error and increased standard deviation.

Ultrasound measurements have been shown to represent amounts of subcutaneous and carcass fat in studies with slaughtered beef and dairy cattle (18, 35, 51); correlations as high as .90 were achieved. If BCS are significantly associated with ultrasound measurements, the BCS technique can be assumed as valid as ultrasound measurements to quantify the amount of subcutaneous fat carried by a cow.

Results from all regression models indicated that all six locations were significantly associated with BCS and much of the variation associated with BCS is explained by the models, indicating that BCS is a valid measure of subcutaneous fat. Similar associations for BCS and ultrasound measurements, which utilized data from the 9th, 10th or 11th rib, have been reported for dairy cows in the United Kingdom (24, 25, 26, 49). The R^2 ranged from .36 to .65 and did not change when ultrasound measurements from only one side of the cow were included in the model, suggesting that only one side or location of the cow needs to be evaluated with ultrasound.

This study was not designed to identify an ideal area or location or a combination of areas and locations to validate BCS with ultrasound measurements, but results suggest that one location might be adequate because combining ultrasound measurements from the lumbar and thurl areas did not improve the R^2 of any model. Variation in BCS that is unexplained by these models might be due to variation in technique of the ultrasound technician or to variation in BCS technique.

Group number had no effect on BCS in any model, regardless of the location used as an independent variable. The association between ultrasound measurements and BCS did not change during the study and was always statistically significant. The technique for obtaining ultrasound measurements was assumed to be consistent for the three groups. These results suggest that BCS are valid measures of subcutaneous fat over time and that BCS technique is as valid and as consistent as ultrasound measurements over time. If the BCS technique was not consistent, group number would have had a statistically significant effect on the BCS.

A criticism of BCS has been that an individual scorer or group of scorers may not be accurate in BCS technique over time, suggesting that the variation in BCS over time may not be due to actual changes in the cow, but to inaccuracies associated with scorer technique because BCS have not been validated over time with a quantitative measurement of subcutaneous fat. Comparisons of BCS and ultrasound measurements in the United Kingdom did not address this question (24, 25, 26, 49). Edmonson et al. (15) developed a BCS system and indicated that BCS were consistent among scorers utilizing the BCS technique, which became widely accepted as an important tool for dairy herd management. The accuracy of BCS over time was not investigated. Although Edmonson et al. (15) found that BCS were consistent, or precise, among scorers, BCS may not be an accurate measure of subcutaneous fat of the cow. In other words, BCS were consistent but may not reflect the actual levels of fat carried by the cow. Results of this study indicate that BCS is a valid measure of subcutaneous fat over time.

This study investigated the relationship between BCS and ultrasound and determined whether BCS would be valid over time. In commercial dairy herds, BCS are assigned regardless of stage of lactation or milk production. Therefore, in this study, stage of lactation, production, and other management considerations were not evaluated. The BCS technique should be valid across all cows and all BCS, regardless of other management factors. This study was not designed to investigate differences in BCS or ultrasound related to stage of lactation, milk production, or other management factors that may be important in the relationship between BCS and ultrasound. A possible limitation of this study was that only 50 cows in one herd were used. The techniques and models developed in this study can be used by other individuals to determine the validity of BCS they obtain.

CONCLUSIONS

The relationships between BCS and ultrasound measurements obtained in this study validate that BCS adequately reflect the subcutaneous fat of cows. The ultrasound measurements of thurl, lumbar, and tailhead regions had a statistically significant relationship with BCS, and BCS were as valid as ultrasound over time. Future investigation can use the approaches developed in this study to validate BCS from many herds and cows.

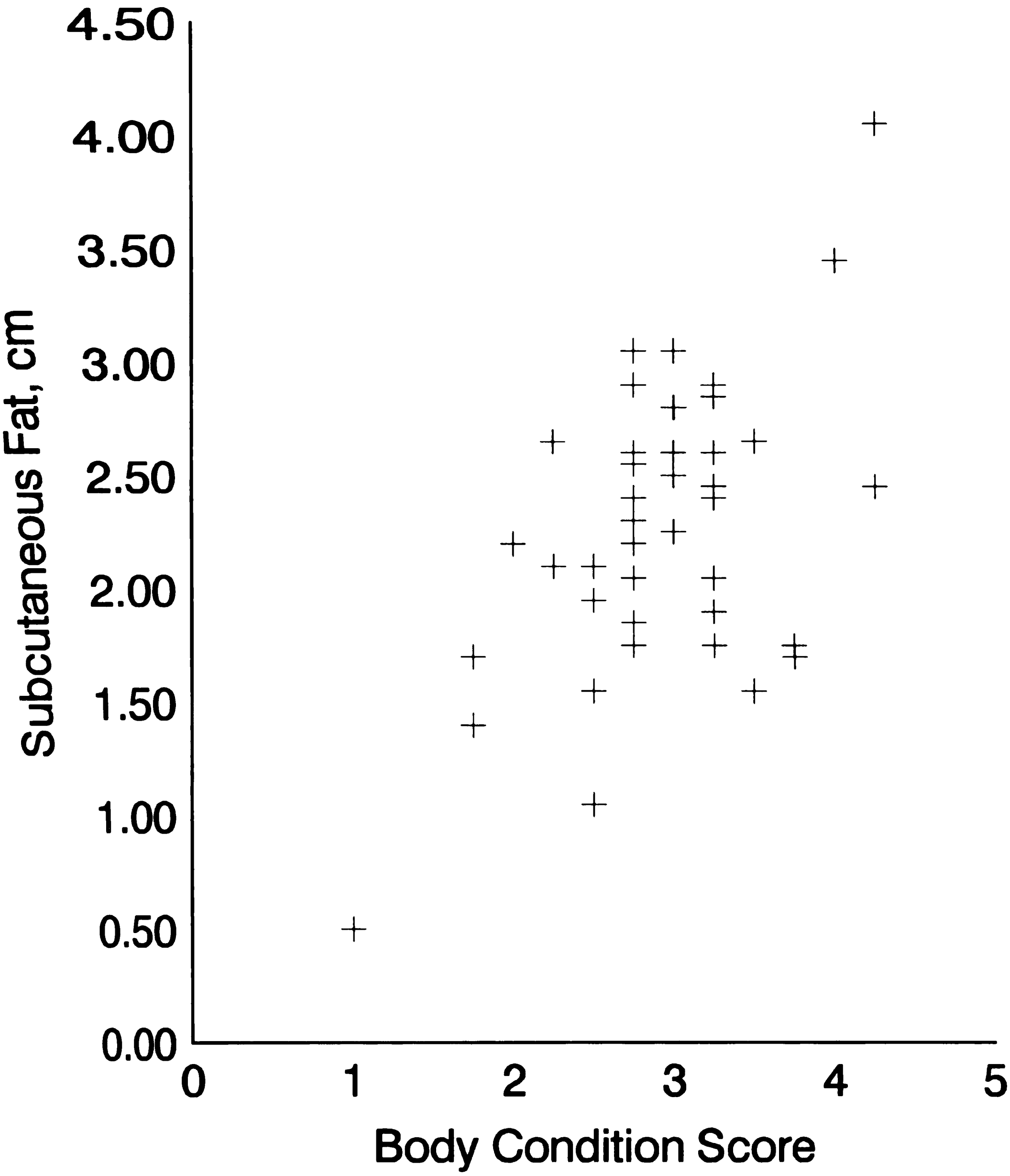

Figure 1. Scatter plot of body condition scores and mean ultrasound measurement of right and left lumbar area.

Table 1. Number of cows, means, standard deviations, minimum, and maximum body condition scores and ultrasound measurements.

Variable	Cows	$\bar{x}$	SD	Minimum	Maximum
	(no.)				
Body condition score[1]	49	2.94	.62	1.00	4.25
Right lumbar, cm	47	2.30	.64	.30	4.20
Left lumbar, cm	48	2.35	.69	.60	3.90
Right thurl,cm	31	1.95	.49	0	2.50
Left thurl, cm	31	1.96	.54	0	2.70
Right tailhead, cm	15	1.71	.63	.40	2.70
Left tailhead, cm	15	1.43	.73	0	2.70

[1] Body condition score 1 = thin, 5 = obese.

Table 2. Pearson correlation coefficients for ultrasound measurements of specific locations.

	RLUM[1]	LLUM	RTRL	LTRL	RTHD	LTHD
RLUM	1.00	.53	.60	.54	.50	.56
LLUM		1.00	.36	.36	.53	.42
RTRL			1.00	.86	.65	.51
LTRL				1.00	.66	.63
RTHD					1.00	.65
LTHD						1.00

[1] RLUM = Right lumbar.
LLUM = Left lumbar.
RTRL = Right thurl.
LTRL = Left thurl.
RTHD = Right tailhead.
LTHD = Left tailhead.

Table 3. Comparsion of regression models investigating the relationship and validity of body condition scores with ultrasound measurements.

	Model		
	1[1]	2[2]	3[3]
R^2	.36	.65	.57
F	8.15	23.62	16.46
p	.0002	.0001	.0001
n	47	29	29
Independent variables			
		P	
GN[4]	.75	.325	.81
LUM	.0001		
TRL		.0001	
IND			.0001

[1] BCS = Lumbar plus group number.
[2] BCS = Thurl plus group number.
[3] BCS = Index plus group number.
[4] Group number (1,2, or 3).
LUM = Mean lumbar measurement.
TRL = Mean thurl measurement.
IND = Mean of lumbar and thurl measurement.

CHAPTER 3

Relationship of Body Condition Scores and Milk Yield in High Producing Holstein Dairy Cows

ABSTRACT

The relationship between body condition and milk yield of dairy cows was investigated in this study. Holstein cows (n = 779) on a commercial dairy farm were scored for body condition weekly beginning at dry-off and continuing until 120 DIM. Multiple linear regression and principal component analysis were used to investigate relationships. Mean body condition scores were 2.77 and 2.66 at dry-off and parturition, respectively. Principal component analysis was used to reduce the collinearity among independent variables, calculate new parameter estimates, and rank the relationship of each variable with milk yield. Body condition change in the dry period was ranked first, followed by lactation number, and then body condition score at dry-off for multiparous cows. Increased body condition score of one point between dry-off and parturition was associated with 545.5 kg more milk in the first 120 DIM than for cows which did not gain one point of BCS. However, each additional point of body condition at dry-off was associated with 300 kg less milk at 120 DIM. Cows with lower body condition at dry-off, and that gained condition in the dry period, produced more milk in the first 120 DIM and had increased rates of milk yield

compared to cows with more body condition at dry-off and cows which did not gain condition in the dry period.

INTRODUCTION

Body condition scores (**BCS**) represent a subjective, visual or tactile evaluation of the amount of subcutaneous fat on a cow (1, 15, 66). Two BCS systems for US dairy cattle have been reported in the literature (15, 66). Scores range from 1 (thin) to 5 (obese), with scoring increments of a tenth-, quarter-, or half-point utilized (3). Ferguson et al. (20) clarified and expanded both BCS systems' usefulness.

Much of the information relating BCS and milk yield is based upon studies conducted in the United Kingdom (24). These studies utilized small numbers of cows of breeds and with management strategies that were different from those in the US, and were scored on a 4-point scale, which is not used in the US. These factors may make extrapolation of results to conditions in the US difficult. In a review of United Kingdom research, Garnsworthy (24) suggested that the relationship between BCS at parturition (**PBCS**) with milk yield was variable, and that cows with higher BCS at calving generally lost more body condition during lactation, which negatively influenced milk yield.

Fat or overconditioned cows at calving may be at risk for lower yield and increased reproductive and health problems (2, 22, 27, 47). However, the fat or overconditioned cows may represent extremes in BCS that are not typically seen in high producing dairy herds. Two studies (2, 4) have found no difference in health or reproductive problems based on BCS.

Conclusions of more recent studies investigating BCS and milk yield in the US are also variable. Daily milk yields or cumulative milk yields of cows above or below a BCS of 3.5 on a 5-point scale did not differ in a 66 cow study (55). Mean daily milk yield in early lactation was not influenced by the amount of condition loss in the first weeks of lactation. Ferguson (19) reported no signficant influence of BCS at parturition on milk yield of 1300 cows. Reseachers from Italy (52) indicated that BCS at calving was not important to total milk yield, but change in BCS influenced peak yield and the shape of the lactation curve. In contrast, Waltner et al. (65) stated that BCS at parturition and change in BCS during lactation were related to total milk yield of 3.5% FCM at 90 DIM. Ruegg (54) reported no differences in 305-d FCM milk yields or peak milk yield among 429 cows in 13 Canadian herds based on BCS at parturition.

Body condition score at calving appears to have little influence on milk yield. However, changes in BCS, when related to BCS at calving, influenced milk yield. The effect of BCS at dry-off (**DBCS**) or changes in BCS during the prepartum period were not included in previous studies and could influence milk yield. The rate of increase in milk yield in early lactation is important to total yield and may more accurately record the biological changes experienced by cows. The rate of increase in milk yield may be associated with body condition or changes in body condition.

The goal of this study was to investigate the relationship between BCS and milk yield in high producing Holstein dairy cows. The research hypothesis tested was that BCS or changes in BCS during the dry period and early lactation are associated with milk yield. Specific objectives were 1) to describe BCS and changes in BCS in the dry period and early lactation; 2) to quantitate and rank the associations of BCS and changes of BCS during the dry period and early lactation with total milk yield up to 120 DIM, and 3) to quantitate and rank the associations of BCS with the rate of increased milk yield between 1 and 15 DIM.

MATERIALS AND METHODS

Cow Selection

A commercial dairy farm (1,000 cows) located in south central Michigan was utilized. The herd was housed in a curtain-sided, six-row, free-stall barn, fed a total mixed ration, and milked three times a day. Lactating cows were grouped based upon production and lactation number into four groups. First lactation cows were kept in the same group throughout their lactation. Dry cows were housed in two groups: an early dry group consisting of cows from dry-off to 3 wk prior to expected calving and a close-up group from 3 wk prior to calving.

Cows entered the study at dry-off. All cows that were dried off during 1993 were included. All heifers that calved for the first time between February 15, 1993, and February 15, 1994, entered the study prior to first parturition. Data collection on all cows terminated at 120 DIM or when they were culled from the herd.

BCS

All BCS was done by one individual utilizing the visual technique developed by Edmonson et al. (15). Cows were scored to the nearest quarter point. The BCS technique of the individual who scored cows in this study was validated with ultrasound and was consistent throughout the study (13).

Body condition of cows was scored weekly without scorer knowledge of prior BCS. The DBCS was obtained 1 d after dry-off. Cows were scored weekly throughout the dry period. The PBCS was determined by utilizing the BCS closest to parturition. The BCS at 30 and 15 d prior to parturition were determined by utilizing the BCS closest to 30 and 15 d prepartum. All BCS obtained during the study were not more than 3 d from any specific time or event, including parturition or specific DIM.

Typically, heifers were available for BCS 2 to 3 wk prior to expected parturition. A BCS was assigned weekly during this prepartum period, and a PBCS was determined in the same manner as described for lactating cows. After parturition, cows were assigned a BCS during weekly herd visits.

Milk Yield

Daily milk weights for all cows were stored electronically on the farm's computer. The first 120 DIM were divided into seven time periods to characterize milk yield acceleration (MYA) and total milk yield. The MYA represents the rate of milk yield for each time period and may more accurately reflect biological changes experienced by cows than total milk yield to a specific point in time. There were six 15-d time periods beginning at parturition, and the seventh time period represented 91 to 120 DIM.

For each time period, DIM was regressed on daily milk yield. The regression coefficient obtained in the analysis is referred to as the MYA and represents the rate of change in milk yield for the respective time period. The regression coefficients (MYA) were then used to estimate milk yield. Milk yield was estimated for each day in the time period with the MYA obtained for each specific time period. The estimated daily milk yields are then added together to obtain total yield for each time period. This procedure compensates for missing daily milk weights in the first 120 DIM due to missing or malfunctioning electronic transponders, or milk weights not recorded because cows were missed during milking. Daily milk weights were also missed as cows moved between production groups, particularly after parturition. Each time period's total yield was added to obtain total milk yield for 120 DIM. Cows must have had at least five daily milk weights in a time period for MYA to be calculated and have had MYA in each of the seven time periods or the cow was omitted from the analysis.

Health Disorders

All health problems were diagnosed and recorded by herd personnel or veterinarian. The data were collected during weekly visits to the farm. Each health problem was coded as occurring or not occurring (no=0; yes=1). Repeat occurrences of the same health problem in the same cow were recorded but not included for analysis. Health disorder definitions used are shown in Table 1 and are similar to those used in previous studies (10, 17, 27). The disorders recorded included dystocia, twins, retained placenta, metritis, milk fever, displaced abomasum, and lameness.

STATISTICAL ANALYSIS

BCS and Milk Yield at 120 DIM

A multiple linear regression model was developed to test the hypothesis that BCS or changes in BCS during the dry period or early lactation are associated with milk yield:

Total = intercept + DBCS + ΔDBCS + ΔPBCS + LAC + WIN + SPR + SUM + DD + $(DD)^2$ + dystocia + twins + RP + MET + DA + MF + lame + error,

where:

Total = Milk yield at 120 DIM.
DBCS = body condition score at dry-off.
ΔDBCS = change in body condition during the dry period.
ΔPBCS = change in body condition from parturition to wk 4 of lactation.
LAC = lactation number.
WIN = winter parturition (December, January, or February; yes or no).
SPR = spring parturition (March, April, or May; yes or no).
SUM = summer parturition (June, July, or August; yes or no).
DD = number of days dry.
$(DD)^2$ = number of DD squared.
Dystocia = dystocia (yes or no).
Twins = twins (yes or no).
RP = retained placenta (yes or no).
MET = metritis (yes or no).
DA = displaced abomasum (yes or no).
MF = milk fever (yes or no).
LAME = lameness (yes or no).

Lactation number was included as a continuous variable in the model because a majority of multiparous cows were second or third lactation. The mean and SD of lactation number for multiparous cows was 2.75 and 1.15, respectively; 60% of multiparous cows were second lactation. Milk yield increases linearly between lactations 2 and 3.

Because heifers prior to parturition did not have a BCS equivalent to DBCS (about 60 d prepartum), primiparous cows were analyzed separately with a similar model which did not include the DBCS, ΔDBCS, DD, $(DD)^2$, and LAC variables. PBCS was included in the model for primiparous cows.

Change in BCS during the dry period was determined by subtracting PBCS from DBCS; a negative number indicates an increase in BCS from dry-off to parturition. BCS change during the first month of lactation was calculated by subtracting the BCS at wk 4 of lactation from the PBCS; a positive number indicates a decrease in BCS from parturition to wk 4 of lactation.

Calving season was considered categorical and based on the month of parturition. December, January, and February were winter months; March, April, and May were spring; summer months were June, July, and August; and fall months included September, October, and November. By its omission from the model, fall was the basis for comparison of seasonal effects.

Sire and genetic information was unavailable for over 25% of multiparous cows completing the study. Comparison of frequency distributions of cows with or without sire information indicated significant differences in several model variables, including milk production and health disorders. Therefore, no genetic information was included in the model and the number of cows in the analysis was maximized and results less biased by cow selection.

Principal Component Analysis

When there is correlation between any set of independent variables, the true contribution of each variable to the outcome of interest may not be demonstrated. To avoid this situation, Pearson correlation coefficients and variance inflation factors were calculated between the independent variables of the regression models to determine the presence of collinearity.

Principal component analysis (**PCA**) (36, 40, 50) was used to remove collinearity between independent variables in the regression model, quantitate the association of each independent variable, and rank the variables in order of importance to milk yield. Principal component analysis has been utilized by several researchers in epidemiology and animal science (20, 39, 50).

A decision was made, prior to analysis, to utilize the principal component vectors, which accounted for at least 70% of variation of the correlation matrix of the independent variables from the regression analysis. A vector of new parameter estimates for each independent variable in the original regression model was developed utilizing the methods of O'Brien et al. (50).

The new parameter estimates were multiplied by the standard deviation of the variable to rank the estimates on a standardized scale. A standardized scale was necessary so comparison and rankings could be made regardless of the unit of measure of the independent variable. The absolute values of the standardized estimates were then ranked; the standardized parameter estimate with the largest contribution to the dependent variable was ranked first. The ranking reflected which of the independent variables had the strongest relationship to the dependent variable after reducing collinearity problems.

BCS and MYA

To test the hypothesis that BCS or changes in BCS during the dry period or early lactation were associated with MYA, regression models and principal component analysis procedures similar to previously described models were utililzed. The MYA between 1 and 15 days in milk was used to represent the rate of increase in milk yield in early lactation. The MYA was used as the dependent variable in the regression models. Principal component analysis was used to reduce collinearity, to quantify the association, and to rank each variable.

RESULTS

A total of 1,048 cows entered the study; 141 cows, or 13.5%, were culled or died prior to 120 DIM and were not included in the analysis. The BCS were collected weekly for the 907 cows that completed the study (120 DIM). An additional 70 cows were omitted from the analysis because of a separate bST study being conducted. Fifty-eight cows had missing data for production or other traits and were also omitted, leaving a total of 779 cows in the analysis.

The rolling herd average for 1993 was over 10,500 kg. Mean days open was 107, and services per conception was 1.8. Bulk tank SCC were consistently < 100,000 cell/ml. The mean age at first calving was 24.7 mo. The mean previous DD for second lactation was 61.3 (SD = 9.14; range = 16 to 112). The third and greater lactation mean for previous DD was 55.7 (SD = 15.2; range = 9 to 112).

Milk Yield

Milk yield at 120 DIM and groups of cows divided by lactation are shown in Table 2. Third and greater lactations are combined into one group. The number of cows in each lactation group was 316, 275, and 188 for first, second, and third and greater lactations, respectively. Mean yields by lactation were 3803.2, 4918.2, and 5205.7 kg; cows in third or greater lactation produced the highest amount of milk in the first 120 DIM. Range of milk yields at 120 DIM among all three groups was 2145.3 to 6805.5 kg.

Mean MYA for the first 15 DIM are reported in Table 3. The mean rate of increase for first lactation cows was .48 kg/d^2. Cows in second and third or greater lactation increased at .90 and .80 kg/d^2. The mean coefficients of determination were .32, .40, and .37 for first, second, and third or greater lactation, indicating that DIM explained between 32 and 40% of the variation in daily milk yield in the first 15 DIM. The largest MYA for all cows occurred in the first 15 DIM. Daily milk production of first lactation cows did not begin to decrease until 90 DIM, but for multiparous cows, daily milk production decreased after 45 DIM.

BCS

Mean BCS at specific times during the dry period and lactation for multiparous and primiparous cows in the study are shown in Figure 1. For multiparous cows, mean DBCS was 2.77, and cows gained condition in the early dry period before losing condition in the last 2 wk of the dry period. Mean PBCS was 2.66, which was lower than DBCS. The lowest BCS occurred between wk 4 and 8 of lactation; mean BCS increased after wk 8 for multiparous cows. Mean loss of BCS in the 1st mo of lactation was .62. Primiparous cows showed a similar pattern of BCS, but did not drop as low as multiparous cows.

Regression Analysis

All multiparous cows were combined into one group for the regression analysis because of the similarity of milk yield and MYA. A total of 463 cows were included. The model explained 20% of the variation in milk yield at 120 DIM and was signficant ($P < .0001$). The DBCS, change in BCS during the dry period, change in BCS during the 1st mo of lactation, lactation number, the linear and curvilinear term for DD, dystocia, lameness, twins, and winter parturition all had a significant association with milk yield at 120 DIM ($P < .05$).

Increased DBCS parameter estimates were associated with lower milk yield. A curvilinear relationship between DD and milk yield at 120 DIM was identified. A PBCS lower than DBCS and loss of condition in the first month of lactation was associated with increased yield. Increasing lactation number was associated with higher milk yield. Dystocia, lameness, and twins were all related to decreased milk yield. Cows calving in the winter had increased milk yield compared to cows calving in the fall.

The results of the regression analysis of milk yield at 120 DIM for first lactation are shown in Table 5. The model explained 8% of the variation in total milk yield and was significant ($P < .005$). A total of 316 primiparous cows were included in the analysis. Change in condition in the first month of lactation, winter and spring parturition tended to be associated with milk yield at 120 DIM ($P < .1$). Loss of condition in the first month was related to increased milk yield, and primiparous cows that calved in the spring and winter produced more milk than those that calved in the fall.

Regression analysis results for the model investigating MYA for multiparous cows are displayed in Table 6. The model explained 13% of the variation in MYA in the first 15 DIM ($P < .0001$). The curvilinear term for DD was not statistically associated with MYA ($P > .05$) and was not included in the analysis. Days dry, metritis, lameness, and parturient paresis and summer parturition approached significance ($P < .07$). As DD increased, MYA decreased. Cows diagnosed with metritis or milk fever had increased MYA, and lameness was associated with decreased MYA.

The results of the regression analysis of MYA for first lactation cows are shown in Table 7. The model explained 11% of the variation in MYA in the first 15 DIM and was significant ($P < .0001$). The PBCS, change in condition in the 1st mo of lactation, retained placenta, displaced abomasum, and winter and summer calvings all had significant associations with MYA ($P < .05$). Winter calvings and an increase in PBCS were related to increased MYA. A loss of condition in the 1st mo of lactation, retained placenta, displaced abomasum, and summer calvings were associated with decreased MYA.

The Pearson correlation coefficients for the independent variables in the regression models are shown in Appendix Table 1 for multiparous cows, and Appendix

Table 2 for primiparous cows. Correlations as high as .60 were acheived, and many correlations were highly significant ($P < .05$), indicating a high degree of collinearity. Variance inflation factors approached 3.0, which also suggests a high degree of collinearity. The parameter estimates and standard errors obtained in the regression analysis may be unreliable because of the high degree of collinearity. The actual, or true, associations of an independent variable might be masked or biased because of their association with other variables in the model.

Principal Component Analysis

Because of the significant associations between independent variables based on Pearson correlation coefficients and variance inflation factors, PCA was used to calculate new estimates. The linear and curvilinear terms of DD were combined into one term for PCA. This was done because DD and DD^2 were so highly correlated that a solution could not be obtained with PCA. For these reasons, DD and DD^2 were combined into a single term with Equation [1].

$$NDD = (DD - k)^2 \qquad [1]$$

For the current study, k was estimated by solving the first order conditions of the regular regression equation with respect to DD. Though the regression coefficients employed in this manner were admittedly estimated from a data set containing substantial collinearity, alternative methods were not found to be superior. The estimate obtained for k (57.78 d) is consistent with both the optimal dry period length of 60 d based on current recommendations (29), and with the mean DD in this herd.

The first eight principal components explained 70% of the variation in the independent variables for multiparous cows, and the first six principal components were needed for primiparous cows.

Table 8 contains the new parameter estimates, standard deviations of each independent variable, and rank of the independent variables for milk yield at 120 DIM of multiparous cows. Change in condition in the dry period was ranked first among the independent variables; a one point increase in PBCS over the DBCS was associated with 545 kg more milk in the first 120 DIM. Lactation number was ranked second, and each additional lactation was associated with 135 kg more milk. The DBCS was ranked third; an additional point of BCS at dry-off was related to 300 kg less milk in the first 120 DIM. From Equation [1], the highest milk yield at 120 DIM in this herd was observed for 58 DD. A loss of .339 kg of milk/d^2 above or below 58 d was observed. Cows with 48 or 68 DD produced 33.9 kg less milk in 120 DIM. This DD variable was ranked fourth among the independent variables. A one-point loss of BCS between parturition and wk 4 of lactation was associated with 242 kg more milk in the first 120 DIM of lactation and was ranked fifth among the independent variables. The sixth ranked variable was winter calving, which was associated with 288 kg more milk, as compared to fall calving. Health disorders generally ranked lowest among the independent variables.

Results of PCA of milk yield at 120 DIM for primiparous cows are shown in Table 9. The variable ranked first was change in BCS in the first month of lactation. Primiparous cows that lost one point of BCS in the 1st mo of lactation produced 162 kg more milk than did primiparous cows that did not lose any condition. The PBCS ranked second; increased PBCS was associated with 92 kg more milk. Primiparous cows calving in the summer ranked third among independent variables; they produced 191 kg less milk than cows calving in the fall. Health disorders generally ranked lowest among independent variables.

The results of PCA for multiparous cows and MYA are shown in Table 10. The DD was ranked first among the variables; each additional DD was associated with .06 kg/d^2 decrease in MYA. The DBCS ranked second and was related to a .33 kg/d^2 decrease in MYA for every one-point increase in DBCS. Change in BCS during the dry period ranked third. A one-point increase in body condition during the dry period was associated with a .32 kg/d^2 increase in MYA.

Measures of body condition for primiparous cows ranked the lowest among the independent variables used to investigate MYA. The rankings and parameter estimates are presented in Table 11. Ranking first was winter calving, which was associated with a .25 kg/d^2 increase in MYA. Retained placenta, displaced abomasum, and summer and spring calving were all related to decreased MYA.

DISCUSSION

MYA

The MYA concept was initially developed to investigate the possible role of the rapid increase in milk yield on conception to first service (14). The hypothesis in a preliminary study (14) was that MYA was associated with reduced conception. An association between MYA between 15 and 30 DIM and conception was identified, while total milk yield at 120 DIM had no association with conception (14). Based on the results of this preliminary study, MYA in early lactation could be an important indicator of cow performance.

As cited in previous studies, the association between BCS and milk yield (24, 54, 55) examined rates of milk yield by comparing daily milk yields. This approach might not reflect the rate of increase in yield experienced by a cow. The rate of increase may have a greater influence on the association between BCS and milk yield than originally thought. In the current study, the largest MYA occurred between 1 and 15 DIM for cows. The correlation between MYA in the first 15 d of lactation and milk yield at 120 DIM was .23, which was the highest correlation acheived among the seven MYA with milk yield at 120 DIM.

BCS

Mean BCS for cows in the study, graphed in Figure 1, was lower than current recommendations for BCS at various points in lactation (1, 15, 21, 66). The BCS reported in this study are generally lower than those reported in previous work (21, 54, 55, 65, 66) investigating the influence of BCS on milk yield. However, in two previous studies (30, 31), in which cows in different herds were scored by the same individual as in the current study, BCS were similar at various points of lactation.

There are several possible reasons for the lower BCS observed in this herd. In general, this herd has a higher production level than reported in some of the previous studies (54, 55, 65, 66), which may suggest an increased demand for energy reserves by high producing cows. Published information is limited regarding optimal BCS for high producing dairy cows. The BCS of this commercial herd may be more typical of high producing dairy cows milked three times a day. Possibly a herd could have lower BCS because of poor management, but the high milk yield, excellent reproductive status, and milk quality suggest high management was maintained in the herd. A comparison of BCS across high producing herds would be useful.

Recommendations for BCS are that cows maintain condition between dry-off and parturition (1, 15, 19, 21, 66). Cows in this study gained condition early in the dry period, but the PBCS was lower than the DBCS because of loss of condition late in the dry period. The loss of BCS during the late dry period corresponds to the lower feed intake 2 wk prior to parturition (45, 63) and may indicate the nutritional status of the cow at this time. Information is limited regarding BCS or changes in BCS during the dry period of high producing cows.

The mean loss of BCS in early lactation was similar to cows in other studies (6, 19, 21, 54, 55, 65). However, during this study the lowest BCS was reached between the 4th and 8th week of lactation, which was earlier than previous studies (19, 21, 65). The milk yield or MYA of cows in this study may necessitate earlier and more rapid mobilization of energy reserves after parturition. The lower BCS at nadir than previously reported may suggest that a cow may not have had condition to lose once the nadir BCS was reached.

Regression Analysis

The models used in the regression analysis were significant predictors of both milk yield and MYA. However, only 8 to 20% of the variation was explained. Milk yield is influenced by many factors that were not considered by this study. Dry matter intake and nutrient densities of rations are examples of variables that affect milk yield, but were not included in these regression models because of the difficulty in data collection. The genetic potential of the cow may also influence milk yield, but was not included in the models utilized in this study because of a lack of genetic data.

A significant curvilinear relationship existed between DD and milk yield. No other independent variables, including DBCS, had a significant curvilinear association with milk yield. Since there were no other significant curvilinear relationships identified, curvilinear terms for independent variables were not included in the models before the final regression analysis was performed.

Independent variables from the regression model were associated significantly with milk yield at 120 DIM in multiparous cows, but not primiparous cows. Only three of the variables tended to be associated with milk yield at 120 DIM in first lactation cows. First lactation cows did not produce as much milk as multiparous cows and may not have been as predisposed to changes in BCS and health problems.

The regression analysis of MYA indicated that BCS and changes in BCS were not significantly associated with MYA in multiparous cows. The MYA of multiparous cows was related to DD and disease. Summer calving was significantly related to a decreased MYA for all cows. Because of the collinearity of the independent variables, it is difficult to obtain the true influence of a single variable or draw any conclusions from traditional regression analysis.

Principal Component Analysis

The results of the PCA clarified the relationship of an independent variable to the dependent variable in the regression model. Using PCA, each independent variable can be considered independently without the correlation, or interaction, of another variable or variables. Previous research has suggested collinearity among BCS, changes in BCS, and health (24, 27, 54, 55). There was collinearity among the independent variables in this study, as indicated by correlation coefficients and variance inflation factors, thus reaffirming the need for PCA. Even though an independent variable may not have had a significant association with the dependent variable, it was not dropped from the model before PCA. This is because each variable may or may not have a contribution to milk yield after reducing collinearity, which may be important.

For multiparous cows, BCS, changes in BCS during the dry period, and DD were more important than any other variable measured in this herd. The parameter estimate for BCS change in the dry period changed from 237 in the original regression analysis to -545 after PCA, indicating that a one-point gain in BCS between dry-off and calving was associated with 545 kg more milk in 120 DIM. The collinearity between DBCS, change in BCS in the 1st mo of lactation, and other independent variables in the model was reduced with PCA and a more reliable estimate was determined. Change in BCS during the dry period is correlated highly to

DBCS, PBCS, and DD. The length of DD was also associated negatively with milk yield at 120 DIM in this study. Short or long DD was associated with lower milk yield.

These results suggest that multiparous cows in this herd should possibly be dried off at lower BCS, gain BCS in the dry period, and have a PBCS higher than DBCS. Cows in this study generally calved with a lower PBCS than DBCS. After gaining body condition in the dry period, cows have condition to lose to support milk production in early lactation. Cows that lost one point of condition in early lactation produced 242 kg more milk. The negative association of DD with milk yield suggests that cows should not have long or short dry periods, and milk yield at 120 DIM was maximal at 58 DD.

Overconditioning of cows has been suggested to be a problem in several studies (2, 22, 27, 47). The length of dry period has also been investigated (58, 60, 63), and extremely long or short dry periods have been related to milk yield and health problems. The cows in this study may have been dried off at a low enough DBCS that overconditioning (BCS > 4.0) was not a problem. In two studies (1, 2), extra energy dense diets fed to cows in the dry period did not influence yield or health. The results of this study indicate that increasing condition in a short period of time in the dry period (58 d) could be beneficial. Relatively short dry periods may not allow cows enough time to regain adequate condition before parturition.

As expected, displaced abomasum, retained placenta, dystocia, lameness, and twins were associated with less milk produced in 120 DIM. However, metritis and milk fever were associated with more milk in 120 DIM. This may be associated with a higher genetic potential for milk yield, thus possibly explaining the positive association with yield. The association of an individual health problem with milk yield was not as great as the association of BCS with milk yield for cows in this study.

Total milk yield analysis for primiparous cows was similar to multiparous cows. Change in BCS in the 1st mo of lactation had a stronger association with milk yield than PBCS. First lactation cows that lost more condition were associated with increased milk yield at 120 DIM. Cows that did not lose condition in early lactation may not have the genetic potential for higher milk yield. Increasing PBCS by one point was associated with an increase in yield. An investigation of BCS in the 60 d prior to first parturition would be useful to determine the effect of gaining condition during this period.

The PCA of MYA for multiparous cows suggested that DD, DBCS, and change in BCS in the dry period had the greatest association with MYA, which is different from the results of the regression analysis. Increasing DBCS by one point was associated with decreased MYA of .33 kg/d^2, and increased condition in the dry period of one point was related to a .30 kg/d^2 increase in MYA. Cows were dried off at lower BCS than recommended, gained condition in the dry period without detrimental effects on MYA, and, in fact, increased the rate of milk yield in the first 15 DIM. We could not find studies relating BCS in the dry period to MYA, or a rate of increase in milk yield.

The MYA was associated positively with retained placenta, metritis, lameness, milk fever, and twins and was negatively related to dystocia and displaced abomasum. Most of the diseases ranked near the bottom of the list of independent variables, indicating that other variables, including BCS, were more important. The low incidence of disease in this herd may have contributed to this positive association.

Principal component analysis of MYA for primiparous cows indicated that PBCS and the change in BCS in the 1st mo of lactation were the least associated of model variables. The changes in BCS during the 1st mo of lactation and PBCS had a significant association with MYA through regression analysis. All variables except winter calving, dystocia, and twins had a negative association on the MYA of first lactation cows. Because the MYA of first lactation cows is not as high as for multiparous cows, the association may not be as strong for BCS and changes in BCS.

Results of this study should be interpreted with caution. This study was conducted in one herd. Future work should be done across herds to see whether the relationships established in this herd exist for other herds under different management conditions. Body condition scores and milk yield reflect the cows' energy status, which is also related to many factors that were not measured in this study. Total milk yield in the first 120 DIM was used, which may not consider any long term associations that BCS or health problems may or may not have on milk yield for an entire lactation. Additional work is needed to explain the possible biological mechanisms relating BCS and milk yield. Controlled experiments could determine and identify possible reasons for the results obtained in this observational study.

Based on the results of this study, the hypothesis that BCS or changes in BCS during the dry period or early lactation are associated with milk production is accepted. BCS are an important dairy management tool which can be used to monitor the productivity of dairy cows.

SUMMARY

The BCS and changes in BCS observed in this high producing commercial dairy herd were typically lower than BCS recommended and reported in other studies. Regression and principal component analyses indicated that, in this herd, changes in BCS in the dry period, condition score at dry-off, the length of the dry period, and changes in BCS in the first month of lactation were more strongly associated with milk yield than with health problems. An increase in BCS in the dry period was related to an increase in milk yield and MYA, while an increase in DBCS was associated with a decrease in milk yield and MYA. Since these findings are contrary to current recommendations, further studies are needed where a broader range of BCS can be tested. A dry period length shorter or longer than 58 d was negatively associated with milk yield and MYA. The parameter estimates generated with standard multiple regression were unreliable due to the collinearity among independent variables. Principal component analysis was used to determine more reliable estimates by reducing the effects of collinearity. Dairy consultants and advisors can use analytical techniques, such as principal component analysis, to determine which management factors have the largest influence on milk yield to help make better management decisions.

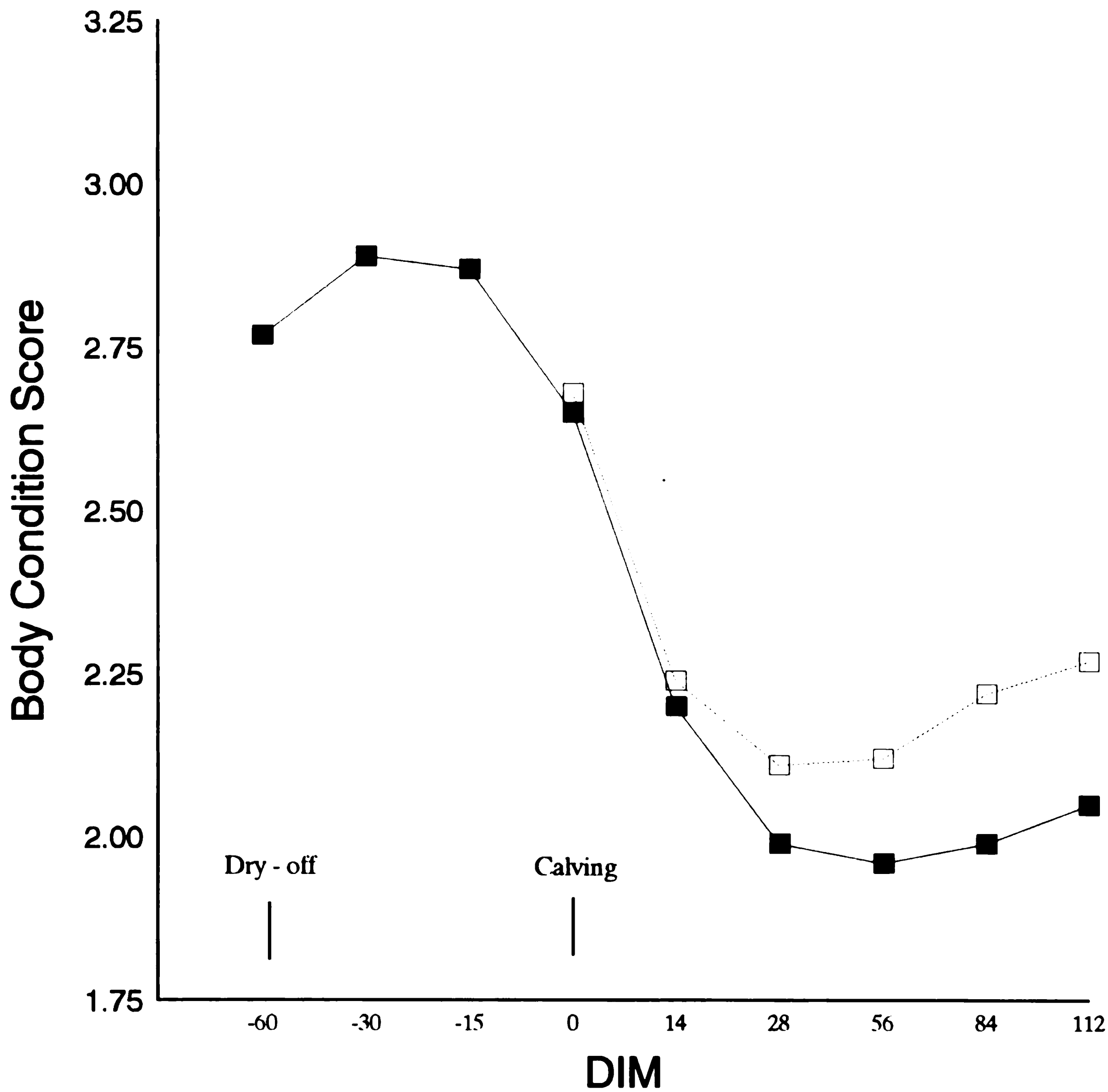

Figure 1. Mean BCS at specific points of time during the dry period and lactation for multiparous (■) and primiparous (□) cows.

Table 1. Definitions of health disorders.

Disorder	Definition
Dystocia	Any assisted delivery
Retained placenta	Retention of fetal membranes > 12 hr
Metritis	Enlarged uterus during rectal exam and/or cloudy discharge.
Lameness	Any abnormality in locomotion
Displaced abomasum	"Pinging" sound upon abdominal auscultation and surgical correction.
Milk fever	Weakness, cold skin, and favorable response to calcium therapy.

Table 2. Number of cows, means, standard deviations, and ranges of total milk yield at 120 DIM by lactation.

Lactation	Cows	$\bar{x}$	SD	Minimum	Maximum
	(no.)		(kg)		
1	316	3803.2	1151.8	2145.3	5295.1
2	275	4918.2	1498.8	2272.9	6289.9
≥ 3	188	5205.7	1540.4	3095.2	6805.5

Table 3. Mean and SD of regression coefficients (MYA) obtained by regressing DIM on daily milk yields for the first 15 DIM by lactation number.[1]

Lactation	$\bar{x}$	SD
1	.48	.63
2	.90	.65
≥ 3	.80	.95

[1] Mean coefficients of determination for the regression analysis were .32, .40, and .37 for first, second, and third or greater lactation, respectively.

Table 4. Parameter estimates, standard errors, and probabilities of independent variables in regression analysis for multiparous cows on total milk yield at 120 DIM.[1]

Variable[2]	Parameter estimate	SE	P
DBCS	-318.72	91.14	.0005
ΔDBCS	237.19	113.01	.0364
ΔPBCS	357.06	113.72	.0018
Lactation number	139.09	27.39	.0001
DD	42.99	11.73	.0003
$(DD)^2$	-.37	.09	.0001
Retained placenta	9.39	109.61	.9317
Metritis	59.38	79.21	.4539
Dystocia	-272.87	117.89	.0211
Displaced abomasum	-420.22	457.59	.3589
Lameness	-630.04	186.61	.0008
Milk fever	193.97	269.36	.4718
Twins	-371.68	175.32	.0346
Winter parturition	398.45	80.19	.0001
Spring parturition	123.56	97.96	.2079
Summer parturition	-102.41	85.92	.2339

[1] Regression model ($P < .0001$; $R^2 = .2063$; n = 463).

[2] DBCS = Body condition score (BCS) at dry-off, ΔDBCS = change in BCS during the dry period (DBCS - PBCS), ΔPBCS = change in BCS during 1st month of lactation (PBCS - BCS at wk 4), DD = days dry.

Table 5. Parameter estimates, standard errors, and probabilities of independent variables in regression analysis for primiparous cows on total milk yield at 120 DIM.[1]

Variable	Parameter estimate	SE	P
PBCS	65.14	102.86	.5270
ΔPBCS	172.72	104.60	.0997
Retained placenta	4.28	121.04	.9718
Metritis	94.68	75.32	.1295
Dystocia	-15.32	97.49	.8752
Displaced abomasum	172.07	180.30	.3407
Lameness	-400.01	263.12	.1295
Twins	-96.86	378.97	.7984
Winter parturition	143.04	82.02	.0822
Spring parturition	156.63	79.81	.0506
Summer parturition	-121.10	83.87	.1498

[1] Regression model ($P < .0053$; $R^2 = .0826$; n = 316).

[2] PBCS = Body condition score (BCS) at parturition, ΔPBCS = change in BCS during 1st month of lactation (PBCS - BCS at wk 4).

Table 6. Parameter estimates, standard errors, and probabilities of independent variables in regression analysis for multiparous cows on milk-yield-acceleration in the first 15 d of lactation.[1]

Variable[2]	Parameter estimate	SE	P
DBCS	-.127	.107	.2349
ΔDBCS	-.079	.132	.5566
ΔPBCS	-.133	.133	.3204
Lactation number	-.033	.031	.2870
DD	-.005	.003	.0717
Retained placenta	.083	.128	.5187
Metritis	.185	.093	.0457
Dystocia	-.049	.138	.7234
Displaced abomasum	-.928	.536	.0844
Lameness	-.833	.218	.0002
Milk fever	.571	.315	.0712
Twins	-.198	.204	.3332
Winter parturition	.109	.093	.2405
Spring parturition	.050	.115	.6649
Summer parturition	-.306	.101	.0025

[1] Regression model ($P < .0001$; $R^2 = .1256$; n = 463).

[2] DBCS = Body condition score (**BCS**) at dry-off, ΔDBCS = change in BCS during the dry period (DBCS - PBCS), ΔPBCS = change in BCS during 1st month of lactation (PBCS - BCS at wk 4), DD = days dry.

Table 7. Parameter estimates, standard errors, and probabilities of independent variables in regression analysis for primiparous cows on milk-yield-acceleration in the first 15 d of lactation.[1]

Variable[2]	Parameter estimate	SE	*P*
PBCS	.343	.122	.0053
ΔPBCS	-.339	.124	.0069
Retained placenta	-.245	.144	.0894
Metritis	-.097	.090	.2788
Dystocia	.115	.116	.3205
Displaced abomasum	-.540	.214	.0123
Lameness	.136	.313	.6650
Twins	.158	.451	.7268
Winter parturition	.189	.099	.0534
Spring parturition	-.090	.095	.3459
Summer parturition	-.228	.100	.0232

[1] Regression model ($P < .0001$; $R^2 = .1139$; n = 316).

[2] PBCS = Body condition score (**BCS**) at parturition, ΔPBCS = change in BCS during 1st month of lactation (PBCS - BCS at wk 4).

Table 8. Parameter estimates obtained from principal component analysis, standard deviation[1], and rank of independent variables for milk yield at 120 DIM of multiparous cows.[2]

Variable[3]	Parameter estimate	SD	Rank
ΔDBCS	-545.57	.47	1
Lactation number	135.07	1.17	2
DBCS	-300.04	.51	3
$(DD - 57.78)^2$	-.339	395.73	4
ΔPBCS	242.01	.40	5
Winter parturition	288.20	.02	6
Milk fever	1074.10	.005	7
Lameness	-539.25	.008	8
Retained placenta	-269.90	.014	9
Metritis	147.17	.018	10
Summer parturition	-86.92	.018	11
Dystocia	-110.80	.012	12
Displaced abomasum	-442.19	.003	13
Twins	-103.83	.008	14
Spring parturition	29.40	.018	15

[1] SD for each variable.

[2] Rankings based on absolute value of standardized parameter estimate (Parameter estimate * SD).

[3] DBCS = Body condition score (BCS) at dry-off, ΔDBCS = change in BCS during the dry period (DBCS - PBCS), ΔPBCS = change in BCS during 1st month of lactation (PBCS - BCS at wk 4), DD = days dry.

Table 9. Parameter estimates obtained from principal component analysis, standard deviation[1], and rank of independent variables for milk yield at 120 DIM of primiparous cows.[2]

Variable[3]	Parameter estimate	SD	Rank
ΔPBCS	162.77	.36	1
PBCS	92.43	.37	2
Summer parturition	-191.59	.023	3
Spring parturition	104.40	.025	4
Winter parturition	60.15	.023	5
Metritis	54.35	.023	6
Retained placenta	68.45	.014	7
Lameness	-85.26	.006	8
Twins	-122.44	.004	9
Dystocia	17.84	.018	10
Displaced abomasum	35.50	.009	11

[1] SD for each variable.

[2] Rankings based on absolute value of standardized parameter estimate (Parameter estimate * SD).

[3] PBCS = Body condition score (BCS) at parturition, ΔPBCS = change in BCS during 1st month of lactation (PBCS - BCS at wk 4).

Table 10. Parameter estimates obtained from principal component analysis, standard deviation[1], and rank of independent variables for MYA of multiparous cows.[2]

Variable[3]	Parameter estimate	SD	Rank
DD	-.06	12.27	1
DBCS	-.33	.51	2
ΔDBCS	-.32	.47	3
Lactation number	-.07	1.17	4
ΔPBCS	-.06	.40	5
Summer parturition	-.36	.018	6
Spring parturition	.24	.018	7
Winter parturition	.19	.02	8
Metritis	.20	.018	9
Dystocia	-.09	.012	10
Retained placenta	.06	.014	11
Displaced abomasum	-.28	.003	12
Lameness	.02	.008	13
Milk fever	.02	.005	14
Twins	.01	.008	15

[1] SD for each variable.

[2] Rankings based on absolute value of standardized parameter estimate (Parameter estimate * SD).

[3] DBCS = Body condition score (BCS) at dry-off, ΔDBCS = change in BCS during the dry period (DBCS - PBCS), ΔPBCS = change in BCS during 1st month of lactation (PBCS - BCS at wk 4), DD = days dry.

Table 11. Parameter estimates obtained from principal component analysis, standard deviation[1], and rank of independent variables for MYA of primiparous cows[2].

Variable[3]	Parameter estimate	SD	Rank
Winter parturition	.25	.023	1
Retained placenta	-.28	.014	2
Displaced abomasum	-.33	.009	3
Dystocia	.16	.018	4
Summer parturition	-.11	.023	5
Metritis	-.09	.023	6
Spring parturition	-.08	.025	7
Twins	.21	.004	8
ΔPBCS	-.002	.36	9
PBCS	-.001	.37	10
Lameness	-.03	.006	11

[1] SD for each variable.

[2] Rankings based on absolute value of standardized parameter estimate (Parameter estimate * SD).

[3] PBCS = Body condition score (**BCS**) at parturition, ΔPBCS = change in BCS during 1st month of lactation (PBCS - BCS at wk 4).

APPENDIX

Table 1. Correlation coefficients between regression model independent variables for multiparous cows.

	DBCS	ΔDBCS	ΔPBCS	LAC	WIN	SPR	SUM	DD	DYST	TWINS	RP	MET	DA	MF	LAME
DBCS	1.00														
ΔDBCS	.54	1.00													
ΔPBCS	.24	-.41	1.00												
LAC	.10	.07	.04	1.00											
WIN	-.07	-.02	-.001	.05	1.00										
SPR	-.14	-.26	-.16	.05	-.28	1.00									
SUM	.24	.20	.04	.01	-.29	-.23	1.00								
DD	.10	.07	.13	-.07	.01	-.12	-.05	1.00							
DYST	-.07	-.01	-.004	.06	.07	-.02	-.05	-.005	1.00						
TWINS	-.01	.10	-.12	.04	-.001	.003	.03	-.14	.09	1.00					
RP	-.01	.06	-.12	.08	-.04	.13	-.02	-.08	.11	.30	1.00				
MET	.04	-.04	.05	.14	.15	.09	-.09	-.04	.05	.09	.19	1.00			
DA	-.02	.04	-.07	.01	.04	-.03	-.03	-.02	-.02	-.01	-.02	-.03	1.00		
MF	.09	.02	.02	.11	.07	-.05	.09	-.05	-.03	-.02	-.04	.04	.04	1.00	
LAME	.03	.10	-.02	.16	.08	.02	-.05	.01	.004	.09	.08	.08	-.01	-.02	1.00

Table 2. Correlation coefficients between regression model independent variables for primiparous cows.

	PBCS	ΔPBCS	WIN	SPR	SUM	DYST	TWINS	RP	MET	DA	LAME
PBCS	1.00										
ΔPBCS	.62	1.00									
WIN	.07	.11	1.00								
SPR	-.17	-.12	-.32	1.00							
SUM	.13	-.05	-.26	-.32	1.00						
DYST	-.08	-.03	-.03	.19	-.08	1.00					
TWINS	-.04	-.10	-.04	.04	.06	.23	1.00				
RP	-.06	-.10	-.04	.03	-.07	.19	.14	1.00			
MET	-.007	-.01	-.03	.20	-.03	.15	.16	.18	1.00		
DA	-.11	.006	-.09	.19	-.04	.0002	-.01	.03	.01	1.00	
LAME	.001	-.08	.01	.06	-.06	-.08	-.009	-.03	.01	.15	1.00

CHAPTER 4

Relationship of Body Condition Score with Conception to First Service in High Yielding Holstein Dairy Cows

ABSTRACT

This study investigated the relationship between changes in body condition during the dry period and early lactation and conception to first postpartum AI. Holstein cows (n=720) on a commercial dairy farm were scored weekly for body condition beginning at dry-off and continuing until first service. Occurrence of postpartum diseases was recorded. A multiple logistic regression model was a significant predictor of conception success or failure for multiparous cows, but not primiparous cows. Principal component analysis reduced collinearity among independent variables and allowed the variables to be ranked based upon their contribution to conception to first insemination. The top three ranking variables were lactation number, milk yield at 120 d of lactation, and the change in body condition score between parturition and wk 4 of lactation. Increased milk yield at 120 d of lactation was associated with an increased likelihood of conception, while decreasing body condition in the 1st mo of lactation was associated with a decreased likelihood of conception. Health problems were less associated with conception than body condition or milk yield in this herd. Body condition scores during the dry period and during

the first 30 d of lactation are an important tool which can be used to identify cows at risk for conception failure at first service.

INTRODUCTION

After parturition, dairy cows experience a slow increase in DMI, a rapid increase in milk yield, and an increased mobilization of body condition (6, 24, 27, 48, 63). An estimated 80% of cows experience a state of negative energy balance in early lactation, where the energy demands for milk yield are not being met by the diet (6, 24, 27, 48, 63). Individual cows respond to negative energy balance through different combinations of feed intake, mobilization of body condition, and lower milk yields (6, 24, 48). The reproductive performance of cows, particularly the probability of conception, may be associated negatively with the magnitude and severity of negative energy balance in early lactation (6, 48).

Body condition scores (**BCS**) are a management tool to monitor the amount and mobilization of subcutaneous fat and thus indicate negative energy balance of cows in early lactation (6, 15, 24, 27, 48). If conception is related to BCS, magnitude and changes in BCS in early lactation could be used to determine whether nutritional goals are achieved and to identify potential problems (6, 24, 48).

The BCS of a cow at parturition appears to have no relationship with conception or inseminations per conception (6, 48, 52, 56, 57). Garnsworthy (24) suggested that the BCS at parturition or BCS at insemination was not related to conception. However, the loss in BCS between parturition and insemination may influence conception negatively. Butler and Smith (6), Ferguson (11), and Ferguson and Otto (12) reported similar results of conception to first service (CFS) for cows grouped by losses of BCS. Cows that lost 0.5 to 1.0 points had a 53% rate of CFS compared with 17% for cows that lost >1.0 point of BCS between parturition and insemination. Ruegg and Milton (57) identified a marginal association (P=.09) between BCS loss and number of services in a multiherd trial. In another study, Ruegg et al. (56) indicated that loss of BCS was not related to services per conception.

Several of the previously mentioned studies utilized services per conception to investigate the relationship between BCS and fertility of cows. The number of services per conception may not be the best indicator of the role of BCS in the success or failure of conception, because the magnitude and duration of negative energy balance, as monitored by BCS, changes during lactation. A more direct method to evaluate the relationship between BCS and conception was utilized by Butler and Smith (6), Ferguson (11), and Ferguson and Otto (12); only CFS was considered in those studies.

Typically, as cows move through lactation, the magnitude and duration of negative energy balance decreases. If negative energy balance, as monitored by changes in BCS, is associated with CFS, the association would probably be in early lactation when energy balance is most negative. Use of BCS to monitor changes in negative energy balance in the dry period and during the first 30 d of lactation (peripartum) may be important to CFS.

The association between BCS, or changes in BCS, with CFS has not been investigated in high yielding (> 11,000 kg/yr) cows that may have greater risk of negative energy balance and decreased BCS (48). Some of the previous studies did not control for biological and management factors, such as season, milk yield, and health disorders, which may also influence conception and bias results.

The goal of this research was to investigate the relationship between BCS and CFS in a herd of high yielding Holstein dairy cows. The **research hypothesis** tested was that BCS or changes in BCS in the dry period or early lactation were associated with reduced probability of CFS. The specific objective was to determine whether BCS or changes in BCS during the dry period or early lactation were associated with reduced likelihood of CFS, controlling for management risk factors and postpartum health disorders.

MATERIALS AND METHODS

Cow Selection

A commercial dairy farm (1,000 cows) located in south central Michigan was utilized. Facilities and herd management have been described previously (13). Multiparous cows entered the study at dry-off. All cows that were dried off during 1993 were included in the study. All heifers that calved for the first time between February 15, 1993, and February 15, 1994, entered the study prior to first parturition. Data collection terminated on all cows at 120 d of lactation or at first insemination if cows were at >120 d of lactation. Culled cows or cows that died before 120 d of lactation were not included in the analysis.

Body Condition Scores

All BCS were assigned by one individual utilizing the visual technique developed by Edmonson et al. (15). Cows were scored to the nearest quarter point. The BCS in this study were validated with ultrasound measurements of subcutaneous fat (12). Cows were scored weekly without the knowledge of previous BCS. Once a cow entered the study, a BCS was assigned every week. All cows were dried off on Thursdays, and the BCS at dry-off (**DBCS**) was obtained the next day. Body condition scores were assigned weekly throughout the dry period. The BCS at parturition was determined by utilizing the BCS obtained closest to parturition. The BCS at first postpartum AI was determined by utilizing the weekly BCS obtained closest to the AI date.

Nulliparous cows entered the study when available for prepartum body condition scoring, generally 2 to 3 wks prior to expected parturition. A BCS was assigned weekly during this prepartum period, and the BCS at parturition was determined in the same manner as described for lactating cows. After parturition, primiparous cows were assigned a BCS during weekly herd visits.

Milk Production

The daily milk yield for each cow was recorded electronically and stored via computer on the farm. The first 120 d of lactation were divided into seven periods to characterize rates of milk yield and to calculate milk yield acceleration (**MYA**) and total milk yield. The MYA represents the rate of milk yield for each time period and may more accurately reflect biological changes experienced by the cow in early lactation. Associations between MYA and CFS have been identified (14). There were six 15-d periods beginning at parturition, and the seventh period represented 91 to 120 d of lactation.

For each period, days of lactation were regressed on daily milk yield. The regression coefficient obtained in the analysis was referred to as the MYA and represented the rate of change in milk yield for the respective time period. The regression coefficients (MYA) were then used to estimate milk yield for each day in the period. The estimated daily milk yields were then combined to obtain total yield for each period. This procedure compensated for missing daily milk yields due to missing or malfunctioning electronic transponders, computer failures, or cows not milked or missed on a given day. Total yield for each period was added to obtain total milk yield at 120 d of lactation. A cow must have had at least five daily milk weights in a period for MYA to be calculated and must have had MYA in each of the seven periods or she was omitted from the analysis.

Conception to First Service

If a cow was confirmed pregnant 35 to 40 d after first service, CFS was achieved. If a cow received a second service, CFS did not occur. A successful CFS was coded 1, and an unsuccessful CFS was coded 0. Cows identified by herd personnel as not being eligible for breeding and, therefore not inseminated, were omitted from the analysis. The number of days to first service also was recorded.

Health Disorders

All health disorders were diagnosed and recorded by herd personnel or the herd veterinarian. The data were collected during weekly visits to the farm. Each health disorder was coded as occurring or not occurring (no = 0; yes = 1). Additional occurrences or recordings of the same health problem were not included. The disorders of interest were dystocia, twins, retained placenta, metritis, milk fever, displaced abomasum, and lameness. Definitions of health disorders are shown in Table 1 and are similar to those used in previous studies (9, 10, 16, 27, 28).

Statistical Analysis

A multiple logistic regression model was developed to test the hypothesis that BCS or changes in BCS during the dry period or early lactation were associated with reduced probability of CFS. Logistic regression was used because the dependent variable, CFS, is a discrete variable with only two outcomes. To demonstrate accurately the influence of BCS and changes in BCS on CFS, specific management and health disorders known to influence CFS were controlled in the analysis. The statistical model that was used is shown in Equation [1]:

$$Y=\frac{1}{1+e^{-f(BCS)}} \qquad [1]$$

where:

Y = Probability of conception to first service,
e = Base of natural log, and
f(BCS) = Intercept + DBCS + ΔDBCS + ΔPBCS + LAC + TOTAL + MYA + WIN + SPR + SUM + DD + DYST + TWINS + RP + MET + DA + MF + LAME + error.

where:

DBCS = Body condition score at dry-off,
ΔDBCS = Change in condition during the dry period,
ΔPBCS = Change in condition from parturition to wk 4 of lactation,
LAC = Lactation number,
TOTAL = Total milk production at 120 DIM,
MYA = Milk yield acceleration between 1 and 15 DIM,
WIN = First service occurring in December, January, or February (yes/no),
SPR = First service occurring in March, April, or May (yes/no),
SUM = First service occurring in June, July, or August (yes/no),
DD = Number of days dry,
DYST = Dystocia (yes/no),
TWINS = Twins (yes/no),
RP = Retained Placenta (yes/no),
MET = Metritis (yes/no),
DA = Displaced Abomasum (yes/no),
MF = Milk Fever (yes/no),
LAME = Lameness (yes/no).

Because heifers prior to parturition were not scored for DBCS, primiparous cows were analyzed separately with a similar model that did not include the DBCS, ΔDBCS, DD, and LAC variables. The BCS at parturition was included in the model for first lactation cows.

Change in BCS during the dry period was determined by subtracting the BCS at parturition from DBCS; a negative number indicated an increase in BCS from dry-off to parturition. Change in BCS during the 1st mo of lactation was calculated by subtracting the BCS at wk 4 of lactation from the BCS at parturition. The change in BCS between parturition and first service was determined by subtracting the BCS obtained nearest to first service from the BCS at parturition.

Season of first postpartum service was considered categorical. December, January, and February were winter months; March, April, and May were spring; summer months were June, July, and August; and fall months included September, October, and November. By its omission from the model, fall was the basis for comparison of seasonal effects.

Principal Component Analysis

When any set of independent variables are correlated, the true contribution of each variable to the outcome of interest may not be demonstrated. To avoid this situation, Pearson and Spearman correlation coefficients were calculated between the independent variables of the regression model to detect whether a problem of intercorrelation (collinearity) existed. Because of the high collinearity found between the independent variables in the regression model, principal component analysis (PCA) (36, 39, 40, 50) was used to reduce collinearity, to quantitate the association of each independent variable with the probability of CFS, and to rank the independent variables in the model in order of contribution to the variance of CFS.

Principal component analysis has been utilized by several researchers in veterinary and animal science (20, 39, 50). The PCA techniques utilized in this study have been described elsewhere (13, 36, 40). However, in this study, a logistic multiple regression model was developed because of the discrete dependent variable.

Odds ratios are a measure of the strength of association between the independent and dependent variables and are used extensively in epidemiology (17, 27, 38, 53). Odds ratios are the natural log of the parameter estimate obtained in the logistic regression analysis. An odds ratio of 1.0 suggests no association between the independent and dependent variables. Standardized odds ratios were calculated for the continuous independent variables. Standardization of odds ratios for continuous variables allows for the expression of odds ratios for one SD of change in the continuous variable.

RESULTS

A total of 720 cows were included in the analysis. The rate of CFS for 426 multiparous cows was 46%, and the rate of CFS for 294 primiparous cows was 47%. Milk yield, MYA, and BCS of this herd during the current study have been previously reported (13). Incidence of health disorders for multiparous cows completing the study are presented in Table 2. The health disorder with the highest incidence rate in this herd was metritis; 19.9% of multiparous cows in this study were diagnosed with metritis.

The results of the logistic regression analysis for multiparous cows are shown in Table 3. The logistic regression model was a highly significant predictor of CFS for multiparous cows (Chi-Square = 34.241, P = .012).

Although the model was highly significant, only one independent variable showed a significant association with CFS. In this herd, a cow that received first postpartum service during the summer was three times more likely to conceive to first service than were cows that were inseminated during the fall (P = .003). The 95% confidence interval for the odds ratios was 1.4 to 6.2. No other variables in the model had a significant statistical association with CFS ($P > .05$). The 95% confidence interval for the odds ratios also suggest no significant relationship between the dependent and independent variables, because 1.0 is included in each 95% confidence interval. There was no association between BCS or changes in BCS during the dry period or early lactation, and CFS based on the results from the logistic regression analysis.

For primiparous cows, a similar logistic regression model was not a significant predictor of CFS (Chi-Square = 13.81, P = .4340). No further analysis was performed for primiparous cows. There was no relationship between BCS or any other variable included in the model and CFS.

Pearson and Spearman correlation coefficients between the independent variables indicated a high degree of association, or collinearity. Correlations were as high as 0.54, indicating the need for PCA to reduce collinearity of the independent variables in the logistic regression model for multiparous cows.

Results of the logistic regression after PCA for multiparous cows are presented in Table 4. Ranking indicates the strength of the association of independent variables in the regression model with CFS after reducing collinearity. The association between lactation number and CFS was ranked first, followed by total milk yield at 120 d of lactation, and change in BCS during the 1st mo of lactation.

Loss of BCS in the 1st mo of lactation was ranked third among the independent variables. Cows that lost one standard deviation, or .40 points of BCS in the 1st mo of lactation were 1.17 (1 / odds ratio) times less likely to conceive than cows not losing any points of BCS in the 1st mo of lactation. Cows that lost two standard deviations, or .80 points of BCS in the 1st month of lactation were 1.36 times less likely to conceive. The DBCS was ranked seventh, and gaining BCS in the dry period was ranked eighth; lower DBCS and an increase in BCS during the dry period increased the likelihood of CFS. Health disorders ranked lower than measures of BCS, suggesting that they have less association with CFS than BCS.

DISCUSSION

Change in BCS in the 1st mo of lactation was included in the logistic regression model, because the correlation between change in BCS in the 1st mo of lactation and change in BCS between parturition and first postpartum service was .72 and was significant ($P < .05$). Negative energy balance is most severe in the first 2 wk of lactation and may influence physiological functions during this time period that are important to conception (6, 48). The likelihood of CFS may be determined by the loss of BCS in the 1st mo of lactation.

Hillers et al. (33) reported CFS rates of 54% for primiparous cows and 50% for multiparous cows. The rates of CFS for primiparous (47%) and multiparous cows (46%) in the current study were similar. Gearhart et al. (27) reported a 44% CFS rate for cows in a multiherd study. Based on the recommendations developed by Domecq et al. (11), the conception rate observed in this herd would be considered only a slight problem. Any problems related to reduced CFS in this herd are probably not due to poor reproductive management.

Body condition score and CFS in primiparous cows in this herd were not associated. Primiparous cows in this herd might not have experienced the magnitude or duration of negative energy balance in early lactation, as monitored by BCS, to reduce the probability of CFS.

The logistic regression model for multiparous cows was a signficant predictor of the probability of conception. However, only one variable was significantly associated with CFS. Cows inseminated in the summer were 3.02 times more likely to conceive to first service than were cows inseminated during the fall. However, because of the collinearity among the independent variables, the results of standard logistic regression might not be accurate. Relationships of an independent variable with CFS may be masked or inflated because of the effects of collinearity. More reliable associations can be established with PCA.

The PCA for multiparous cows indicated that the three measures of body condition were ranked higher than health disorders and had a greater association with CFS in multiparous cows. Cows that lost one point of BCS in the 1st mo of lactation were 1.5 times less likely to conceive than cows that did not lose one point of BCS. In other words, if the CFS for a group of cows that did not lose one point of BCS was 60%, cows that did lose a point of BCS would have a CFS of 45%. The loss of BCS for cows in this herd did not influence CFS as much as previously reported. Ferguson (19) and Ferguson and Otto (21) reported that a cow that lost one point of BCS between parturition and first service was 2.0 times less likely to conceive at first service. No relationship was found between the number of services per conception and the change in BCS between parturition and first service in several studies (56, 57, 65). Although services per conception are related to CFS, the relationship between

BCS and CFS was not addressed directly in previous studies. By controlling for management risk factors and health disorders and by utilizing PCA, the odds ratios obtained in the current study might estimate more accurately the importance of BCS to conception.

Lower BCS at dry-off and increasing BCS during the dry period increased the likelihood of successful CFS for cows in this study. Overconditioning in the dry period has been related to health and reproductive problems (22, 47, 63), but the cows in this herd were not overconditioned. Cows in this herd could gain condition in the dry period without becoming overconditioned.

Higher yielding cows in this herd were more likely to conceive than lower yielding cows. There may be an antagonistic relationship between milk yield and reproductive performance (6, 24, 48). However, Shanks et al. (59) suggested that high yielding cows may be more reproductively sound because they are healthier than lower yielding cows. The measures of BCS in the logistic regression model in this study might have accounted for the effects of negative energy balance that influence conception and removed the negative association of milk yield with reproductive performance.

After reducing collinearity with PCA, the association between summer inseminations and CFS became weaker, suggesting that other factors, including BCS, were more important to CFS. Conception rates in the summer were generally lower than for other seasons of the year (29). The summer season might not have been warm enough to have an influence on CFS in this herd. Any possible negative association between summer inseminations and conception might be seen through changes in BCS and other management factors and might not be as important to CFS as previously thought.

The incidence of most health disorders in this herd were similar to and within ranges of incidences reported in other studies (16, 27, 28). However, the metritis rate of 20% might have been inflated because of the aggressive diagnosis and treatment of uterine infections by herd personnel.

Health disorders were ranked last among the independent variables. The lack of association of health disorders with CFS might be due to several factors. The degree, or severity, of specific health disorders was not accounted for in this study and might have a stronger association with CFS.. Repeat occurrences of health disorders were not accounted for, which might also negatively influence CFS. Health disorders might have a greater influence on CFS in herds in which prevention and treatment are not considered as important as they were in this herd. The association of health with CFS might be observed through the influence of BCS.

Some cautions have to be considered when interpreting these results. Additional work across high yielding herds is needed to determine whether associations exist under different management situations. Other variables, such as DMI and genetic potential for milk yield might be included in the logistic regression models, because they might have an association with CFS. In herds in which the CFS rate is very low, BCS might have a stronger negative association with CFS than observed. The association between BCS and CFS might be different in herds with greater variation in BCS, or changes in BCS, or with overconditioned cows.

Therefore, results supported the hypothesis that BCS and changes in BCS during the dry period and early lactation of multiparous cows are associated with reduced probability of CFS. The hypothesis, however, was rejected for primiparous cows. Lower DBCS and a gain of BCS during the dry period were associated with a greater probability of CFS, and a loss of BCS in the 1st mo of lactation was associated with a reduced probability of CFS. The nutritional status of cows, particularly energy balance, during the dry period and during the 1st 30 d of lactation, as monitored by BCS, was more important to CFS than were health disorders or other risk factors.

Body condition scores at dry-off and parturition, and the loss of BCS in the 1st mo of lactation should be monitored. The BCS and changes in BCS can be used to identify cows at risk for CFS failure so that possible management strategies can be implemented to improve conception.

CONCLUSION

In this high yielding herd, a loss of BCS during the first 30 d of lactation contributed to the failure of CFS in multiparous cows more than any other variable measured. Higher total milk yield at 120 d of lactation was positively associated with CFS. Higher producing cows were more likely to conceive. Body condition score and CFS were not associated in primiparous cows. Energy balance during the dry period and early lactation, as monitored by BCS, was more important to CFS than health disorders or other risk factors. The BCS at dry-off, parturition, and during the 1st mo of lactation should be monitored and used to identify cows at risk for CFS failure.

Table 1. Definitions of health disorders.

Disorder	Definition
Dystocia	Any assisted delivery
Retained placenta	Retention of fetal membranes > 12 hr
Metritis	Cloudy discharge and enlarged uterus during rectal exam.
Lameness	Any abnormality in locomotion
Displaced abomasum	"Pinging" sound upon abdominal auscultation and surgical correction.
Milk fever	Weakness, cold skin, and favorable response to calcium therapy.

Table 2. Incidence of health disorders of multiparous cows.

Health Disorder	Incidence,%
Metritis	19.9
Retained Placenta	8.7
Lameness	2.8
Milk Fever	1.4
Displaced Abomasum	.5
Twins	2.8
Dystocia	6.5

Table 3. Parameter estimates, odds ratios and 95% confidence interval from logistic regression analysis of multiparous cows.

Variable[2]	Parameter estimate	Odds Ratios[1] Discrete	Odds Ratios[1] Continuous	95% CI[3]
DBCS	.03		.93	(.73, 1.4)
ΔDBCS	.06		1.01	(.71, 1.4)
ΔPBCS	-.37		.86	(.62, 1.2)
Lac number	.14		1.18	(.94, 1.4)
120 d Milk Production	.0002		1.14	(.91, 1.4)
MYA	.10		1.08	(.86, 1.3)
Days to First Service	-.006		.87	(.70, 1.1)
DD	.008		1.10	(.89, 1.3)
Retained Placenta	.12	1.13		(.50, 2.5)
Milk Fever	.21	1.24		(.20, 7.3)
Lameness	.70	2.01		(.49, 8.2)
Metritis	.38	1.46		(.85, 2.5)
Displaced Abomasum	-.11	.89		(.05, 3.7)
Twins	-1.01	.36		(.09, 1.4)
Dystocia	.21	1.23		(.53, 2.8)
Winter	.18	1.19		(.70, 2.0)
Spring	.53	1.70		(.93, 3.1)
Summer	1.1	3.02		(1.4, 6.2)

[1] Odds ratios for continuous independent variables calculated for one SD change.

[2] DBCS = Body condition score at dry-off, ΔDBCS = Change in body condition during dry period, ΔPBCS = Change in body condition in first month of lactation, DD = Days dry, MYA = Milk yield acceleration in first 15 d of lactation.

[3] 95% Confidence interval for odds ratios.

Table 4. Parameter estimates obtained after principal component analysis, standard deviations, odds ratios, and rank of independent variables for multiparous cows.

Variable[2]	Parameter Estimate	SD	Odds Ratios[1] Discrete	Odds Ratios[1] Continuous	Rank
Lactation number	.18	1.15		1.22	1
120 d Milk Production	.0002	654.4		1.13	2
ΔPBCS	-.39	.40		.86	3
DD	.01	12.37		1.13	4
Days to First Service	-.005	22.4		.89	5
MYA	.10	.80		1.08	6
DBCS	-.14	.51		.93	7
ΔDBCS	.03	.48		1.01	8
Summer	.55	.018	1.73		9
Winter	.32	.02	.72		10
Metritis	.37	.02	1.45		11
Lameness	.34	.008	1.40		12
Retained Placenta	.15	.014	1.16		13
Twins	-.19	.008	.83		14
Milk Fever	-.17	.006	.84		15
Dystocia	.08	.01	1.09		16
Spring	.03	.02	1.03		17
Displaced Abomasum	-.14	.003	.87		18

[1] Odds ratios for continuous independent variables calculated for one SD change.

[2] DBCS = Body condition score at dry-off, ΔDBCS = Change in body condition during dry period, ΔPBCS = Change in body condition in first month of lactation, DD = Days dry, MYA = Milk yield acceleration in first 15 d of lactation.

CHAPTER 5

Summary

RESEARCH GOAL AND HYPOTHESES

The goal of this research was to investigate relationships between body condition scores (**BCS**), milk production, and conception to first service in high producing Holstein dairy cows. Body condition scoring has become an important and accepted dairy herd monitoring and management tool. However, there has been a relatively small amount of research conducted in the United States investigating the validity and consistency of BCS, or the relationship of BCS to milk production and conception in high producing Holstein cows. Three specific hypotheses were developed and investigated in this study.

1. Are BCS valid and consistent measures of body fat.

2. Are BCS, or changes in BCS, during the dry period and early lactation associated with total milk yield at 120 DIM and the rate of increase in milk yield in early lactation.

3. Are BCS, or changes in BCS, during the dry period and early lactation associated with the probability of conception to first service.

FINDINGS

Ultrasound measurements of subcutaneous fat at the thurl, lumbar, and tailhead regions were significantly associated with the overall BCS assigned to a cow. The association between BCS and ultrasound measurements remained constant over time, suggesting that BCS were as consistent over time as ultrasound measurements of subcutaneous fat. These results suggest that **body condition scores are a valid and consistent measure of subcutaneous fat of Holstein dairy cows.**

Low BCS at dry-off, an increase in BCS between dry-off and parturition, and loss of BCS in the first month of lactation were associated with increased milk production in the first 120 d of lactation for multiparous cows. A one point increase in BCS during the dry period was associated with 545 kg more milk in the first 120 d of lactation. The BCS at parturition and loss of BCS in the first month of lactation were associated with 120 d milk production of primiparous cows. The rate of increase in milk production in the first 15 d of lactation was also associated with BCS of multiparous cows. Body condition scores were more important to milk production than health disorders or other management factors. **There was an association between BCS and changes in BCS during the dry period and early lactation with milk production.**

A one point loss of BCS in the first month of lactation was associated with a 1.5 decreased likelihood of conception to first service in multiparous cows compared to cows which do not lose one point of BCS. Lower BCS at dry-off and increases in BCS during the dry period were associated with an increased likelihood of conception to first service, but were not as important as the loss of BCS in the first month of lactation. The occurrence of health problems or other risk factors were less associated with the probability of conception failure or success than BCS. No association could be identified between BCS and conception in primiparous cows. **Therefore, an**

association was found between BCS and changes in BCS during the dry period and early lactation with conception to first service for multiparous cows in this herd.

GENERAL DISCUSSION

The techniques and statistical methods developed in this study can be used to determine the validity and consistency of other scorers. The BCS assigned by other scorers may not be valid or consistent because of the subjectivity of the BCS technique. If a scorer is an invalid or inconsistent evaluator of body condition, based on ultrasound measurements, retraining in proper BCS technique may be necessary.

There may be differences in subcutaneous fat deposits due to stage of lactation, parity, or milk production which may influence validity and consistency of BCS. Additional work could include an investigation of the role of stage of lactation or other factors in assigning and validating BCS. Body condition scores are normally assigned regardless of stage of lactation, or any other factor, but if differences in BCS and ultrasound measurements are identified due to stage of lactation or other factors, BCS techniques may need to be adjusted.

The BCS and ultrasound measurements were obtained in one herd in this study. The validity and consistency of BCS across herds may need further investigation. The environment where cows are scored may influence consistency. Factors such as the amount and type of light and where the scorer stands in relation to a cow when assigning a score may be negatively associated with validity and consistency. Additional research, across herds and scorers, may be needed.

The BCS in this study were lower than current recommendations. There are few BCS studies which include as many cows, scored as frequently during the dry period and early lactation, with milk production over 10,500 kg/yr, so it is difficult to compare results obtained in this study. The BCS observed in this herd may more accurately represent the BCS of high producing herds. The BCS of cows in the current study could be lower than similar cows in other herds due to specific herd management practices, particularly related to nutrition, grouping, and feed management. Further investigation of BCS across high producing herds is needed to determine proper BCS recommendations for high producing cows.

The individual assigning BCS in this study may assign lower BCS than other individuals utilizing the same BCS scoring chart. Thus, the cows in this study may have been scored higher by other individuals and may actually be meeting BCS recommendations. A comparison of BCS assigned by different individuals would further validate BCS.

There may be a relationship between BCS, milk production, and the genetic potential of the cow for milk production. Because of the lack of genetic information for over 25% of the multiparous cows in the research herd, it was difficult to include any genetic measure in statistical models without decreasing the number of cows in the study and biasing results. The BCS of cows with greater genetic potential for milk production may be different than cows with less potential for milk production. Higher producing cows may have lower BCS than lower producing cows, particularly at dry-off and parturition. Body condition is needed as an energy source for milk production in early lactation, so cows with higher genetic potential for milk production may store, mobilize, and utilize body condition more efficiently than lower producing cows. Future investigations of BCS should include measures of genetic potential, such as a sire's predicted transmitting ability for milk production.

Further research involving the relationship of feed intake and BCS, particularly during the dry period, is needed. Cows with a BCS below 2.5 at dry-off may eat more throughout the dry period, which may lead to gain of BCS during the dry period. The drop in feed intake observed 2 wks prior to parturition may not be as severe for cows with lower BCS at dry off. Controlled experiments, where feed intake and dietary nutrients can be monitored closely, could address the relationship between low BCS and feed intake during the dry period and future performance. The role of prepartum BCS in primiparous cows may also be important and needs further investigation.

A loss of BCS in the first month of lactation was associated with a reduced probability of conception to first service in this herd. The BCS during the dry period was also important. The loss of BCS, an indicator of negative energy balance, may alter important biological functions associated with conception. Delayed days to first postpartum ovulation has been suggested to be a problem with reduced conception because cows have had fewer estrous cycles before insemination. Controlled studies investigating the possible biological role of BCS and negative energy balance on conception should focus on the dry period and first 30 d of lactation. Studies should include monitoring hormones such as LH, FSH among others, and the number of days to first ovulation.

After a cow has been identified as having a reduced probability of conception to first service due to BCS loss in the first month of lactation, management practices to improve the probability of conception could be implemented. Future research should concentrate on management practices that could improve conception. For example, hormonal treatments, such as prostaglandinF2α, in cows which lose excessive amounts of BCS (> 1.0) in the first month of lactation, may be an effective method to improve conception.

Health problems had less association with milk production or conception than measures of BCS in this herd. It may be that the severity or the treatment of a health disorder influences milk production or conception. Additional work, across herds, where the diagnosis and treatment of health disorders are not a priority, as compared to the current herd, may yield different results.

PRACTICAL IMPLICATIONS

A quick and easy technique for monitoring the relationship between feed intake, milk production, and the mobilization of body fat is necessary, particularly as dairy herds become larger and monitoring feed intake of individual cows becomes difficult. Body condition scores are a valid and consistent measure of body fat which are relatively easy to assign and monitor.

Cows experience many dynamic biological changes during the dry period and early lactation. Feed intake decreases 2 wks prior to calving and then begins a slow increase after parturition. Milk production begins to increase immediately after parturition. To meet the demands of milk production, cows utilize different combinations of feed intake and body condition. The results of this study indicate that a critical period to assign and monitor BCS is the dry period and early lactation. The BCS at dry-off, the change in BCS during the dry period, and the change in BCS in the first month of lactation are associated with milk production and conception to first service.

Current recommendations are a BCS of between 3.0 and 3.5 at dry-off and at parturition, meaning cows should maintain condition during the dry period. The results of this study suggest that lower BCS at dry-off and increasing condition during the dry period were associated with increased production. Lower BCS than currently recommended at dry-off may not be critical, particularly if cows are allowed to gain condition during the dry period. Cows with lower BCS may have higher feed intakes than cows with higher BCS. Decreases in BCS during the dry period and overconditioning of cows (BCS > 3.5) should be avoided. Therefore, the feed intake and quality of the ration fed to dry cows are critical. This study indicates that BCS should be used to monitor the nutritional status of dry cows.

Cows lose BCS in the first month of lactation. The loss of BCS in early lactation was associated with increased production because cows utilize body fat to support lactation. However, this loss of BCS was also associated with a decreased probability of conception to first service. By monitoring BCS loss during the dry period and early lactation, cows which lose excessive amounts of body condition can be identified and management practices to improve the probability of conception can be implemented.

Body condition scores are an important dairy herd monitoring and management tool which should be used by dairy producers, nutritionists, and consultants to enhance the decision making process. Decisions important to the nutrition, reproduction, health, and profitablility of dairy cows can be made more effectively utilizing body condition scores.

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