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Association of body weight, loin *longissimus dorsi* and backfat with body condition score in dry and lactating Holstein dairy cows

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Abstract

The lactation cycle of the dairy cow induces large changes in body fat and protein pools, which can be monitored through loin backfat (BF) and longissimus dorsi *(LD) measurements. Data from two experiments (exp) using Holstein-Friesian dairy cows (no. = 40 and 32 respectively) were used to study the association of body weight (BW), BF and LD depth with body condition score (BCS) for the last 6 weeks of the dry period (DP) and the first 8 weeks of lactation. Loin and tail BCS were manually assessed (0 to 5 scale) and BF and LD depth were measured by ultrasound at the fifth lumbar process. The BCS data ranged from 1·3 to 3·0 units in the DP, and from about 1·1 to 3·1 units during early lactation in both experiments. Data were analysed by two models:*

BW, LD or BF = exp + period (DP or lactation) + BCS + interactions + cow + error (model 1);

and $BCS = exp + period + LD + BF + LD^2 + BF^2 + exp \times LD + exp \times BF + exp \times LD^2 + exp\ BF^2 + period \times LD + period \times BF + period \times LD^2 + period \times BF^2 + cow + error$ *(model 2).*

A first-order autoregressive (AR(1)) covariance structure was employed for the error terms to account for the correlation among repeated measures within cow. Regressions of BW and LD on BCS (model 1) found pre- to post-calving differences ($P<0·001$*) in intercept for BW and LD, and slope coefficients of 35 (DP) and 21 (lactation) kg BW, and 5·8 mm LD per BCS unit. Regression of BF on BCS (model 1) showed an exp × period interaction (*$P<0·001$*), with 0·4 mm BF (exp 1;* $P<0·05$*) and 2·0 mm BF (exp 2;* $P<0·001$*) per BCS unit. Regression of BCS on LD and BF (model 2) showed intercepts not equal to 0 (*$P<0·06$*), and differences (*$P<0·001$*) between DP and lactation; BCS increased (*$P<0·001$*) by 0·027 units per mm BF and 0·05 units per mm LD, but LD had a quadratic term -0·0004 (*$P = 0·02$*). It is concluded that at BCS lower than 3, LD contributes to BCS following a quadratic function, whereas BF causes BCS to increase linearly. Each unit of BCS equated to about 35 and 20 kg BW for DP and lactation periods respectively, to 5·8 mm LD, and to between 0·4 and 2·0 mm BF.*

Keywords: *body composition, body fat, body protein.*

Introduction

Body condition score (BCS) is a semi-objective, repeatable and simple technique to rank animals according to their body reserves independently of their body frame (Edmonson *et al.,* 1989). It is a practical and economical measurement to assess dairy cows nutritional status. Its non-invasive and time saving nature as well as its association with productive and reproductive variables have led to its recognition as a valuable tool in present dairy herd management. From a practical point of view, equivalence between BCS and body weight (BW) is necessary to estimate animal requirements. The idea that BCS in dairy cows is an indicator of energy reserves is pervasive and supported by reports that demonstrate the association of BCS with subcutaneous fat (Garnsworthy and Jones, 1987; Domecq *et al.,* 1995; Schwager-Suter *et al.,* 2000) and total body fat (Wright and Russel, 1984a; Gregory *et al.,* 1998; de Campeneere *et al.,* 1999) in lactating dairy cows.

There is evidence that BCS measured at the loin is influenced not only by subcutaneous backfat (BF) but also by muscle *longissimus dorsi* (LD) depth. Until recently, a proportional relationship was commonly accepted between BCS and energy reserves throughout the scoring scale, but some studies have shown a quadratic association (Wright and Russel, 1984a; Otto *et al.,* 1991; Gregory *et al.,* 1998). Additionally, some reports have shown the association of BCS with depths of muscles *l. dorsi* (Schwager-Suter *et al.,* 2000; Moorby *et al.,* 2002a) and *trapezius thoracalis* (Reid *et al.,* 1986). Some reports have studied the association between BCS and subcutaneous fat depots, but no similar assessment has been carried out for LD. Moreover, despite the importance of the dry period (DP) on the cow's whole lactation cycle, we are unaware of comparisons of BCS and ultrasound BF and LD measurements between the dry and lactation periods. The objective of this work was to characterize the relationship between BCS and BW, as well as to analyse the relative contributions of LD and BF depths to variation in BCS.

Material and methods

Data were collected from two indoor feeding experiments involving Holstein-Friesian dairy cows in their second or later lactations balanced for parity. In experiment 1, 40 cows were allocated to one of four DP treatments based on ryegrass silage offered at *ad libitum* rates in a factorial arrangement of energy (high/low, plus or minus rumen-protected fat) and protein (high/low, plus or minus high protein maize gluten meal). In experiment 2, 32 dairy cows were allocated to one of three experimental DP diets (red clover silage, ryegrass silage, and a total mixed ration comprising ryegrass silage and high protein maize gluten meal) also offered at *ad libitum* rates. Within each experiment, all animals received a common diet comprising *ad libitum* ryegrass silage plus a common dairy concentrate following calving, and had free access to water except while in the milking parlour or when being measured. One of the objectives of both experiments was to decouple the intake of protein and energy during the late dry period, with the aim of allowing cows to accrete body protein and energy reserves at different rates. Further details can be found in Jaurena *et al.* (2001 and 2002).

Animals were introduced to the experimental facilities one week before the start of the experiments (42 days pre-calving), and were assessed simultaneously for BW, BCS, LD and BF weekly from 42 days to 10 days pre-calving, and three times per week (Monday, Wednesday and Friday) around calving (-10 to + 10 days relative to calving). After calving, cows were weighed automatically twice each day after exiting the milking parlour until week 8 of lactation and assessed simultaneously for BCS, LD and BF on a weekly basis from day 10 of lactation up to the 8th week of lactation. Data were pooled into weekly averages for use in this study.

Cows were assessed to a quarter of a point using a 0 to 5 scale body condition scoring system (Mulvany, 1977). All cows were assessed by the same experienced person at the tail and loin areas, and these two scores were averaged to produce a mean condition score per animal at each recording. After scoring, cows were scanned in the loin zone (fifth lumbar process) by real-time ultrasound imaging equipment (Concept MCV Ultrasound scanner; Dynamic Imaging Ltd). *Longissimus dorsi* muscle and subcutaneous BF depths were measured along a vertical line perpendicular to the skin, between the surface of the skin and the attachment of the transverse process to the vertebral body. Scanning after BCS scoring avoided biased BCS assessment. Due to difficulty in distinguishing the interface between subcutaneous fat and skin in BCS below a score of 2, BF was measured together with the skin layer for all BCS scores.

A mixed model was fitted to the data to account for the repeated measures within cow, using PROC MIXED of the Statistical Analysis Systems Institute (SAS, 1999) statistics analysis package. Effects that entered into the final models were selected by first fitting a full model and then dropping all those factors with $P>0{\cdot}05$ and by Akaike's Information Criteria (Akaike, 1974). The covariance structure of the error terms (repeated measures within cow) from a first-order autoregressive (AR (1)) process (Littell *et al.,* 1998; model 1) produced the best fit. This covariance structure has two parameters : the first-order autocorrelation parameter (ρ) and the error variance. The variation explained by the model (R^2) was calculated as one minus the ratio of residual sums of squares for the full to the reduced model, as generalized for mixed models by Xu (2003).

Model 1:

$$y = \text{exp} + \text{period} + \text{BCS} + \text{exp} \times \text{BCS} + \text{period} \times \text{BCS} + \text{cow} + \text{error} \quad (1)$$

where y = BW, BF, LD. Fixed effects were : exp = experiment 1 or 2, and period = DP or lactation. Random effects are denoted by italic text. The participation of LD and BF in determining BCS was studied by using model 2.

Model 2:

$$\text{BCS} = \text{exp} + \text{period} + \text{LD} + \text{BF} + \text{LD}^2 + \text{BF}^2 + \text{interactions} + \text{cow} + \text{error} \quad (2)$$

where the following terms and interactions were tested : LD^2, BF^2, exp × LD, exp × BF, exp × LD^2, exp × BF^2, period × LD, period × BF, period × LD^2, period × BF^2.

Results

Body condition scores varied by similar amounts in both experiments from 1·1 to 3·1, with the highest scores being recorded during the DP and the lowest in lactation (Table 1). Cow BW was higher during the DP (Tables 1 and 2), and each unit increase in BCS was associated with an additional 35 kg and 21 kg BW ($P<0{\cdot}001$) for the DP and lactation periods respectively. Each unit of BCS was also associated with an additional 5·8 mm LD (s.e.0·46; $P<0{\cdot}001$) irrespective of physiological state or experiment (Table 2); regression intercepts (DP = 31·2; lactation = 27·9 mm) differed from each other ($P<0{\cdot}001$) and from zero ($P<0{\cdot}001$). Loin BF was also associated positively with BCS but an exp × period interaction was found ($P<0{\cdot}001$), as well as an increased measurement of BF thickness per unit of BCS for experiment 2 compared with experiment 1 ($P<0{\cdot}001$).

The association of BCS with LD and BF showed nearly significant ($P<0{\cdot}06$) regression intercepts (Table 3), which also were different ($P<0{\cdot}001$) between pre- and post-calving periods. BCS was positively and linearly associated with depth of BF, increasing approximately 0·25 BCS units with every 10 mm of BF. In contrast, BCS and LD were associated by a quadratic relationship ($P = 0{\cdot}02$). By this function, it was estimated that the maximum contribution of LD to BCS changes was achieved at a depth of 60 mm, which was estimated by solving the first derivative of model 2 (Swokowski, 1983).

Discussion

Although the limitations of live BW measurements have frequently been noted, the equivalence between BCS and BW changes is a necessary step to predict animal

Table 1 *Summary statistics for body condition score, body weight, and* longissimus dorsi *and backfat depths of the experimental animals*

	Experiment 1		Experiment 2	
	Pre-calving	Post calving	Pre-calving	Post calving
Body condition score				
No. of records	185	286	205	273
Minimum	1·3	1·1	1·4	1·1
Maximum	3·0	3·0	3·0	3·1
Mean	2·1	2·0	2·2	2·0
s.d.	0·46	0·36	0·36	0·35
Body weight (kg)				
No. of records	187	303	202	268
Minimum	500	440	598	536
Maximum	831	779	828	771
Mean	667	601	714	640
s.d.	68·5	63·1	53·1	52·9
Longissimus dorsi (mm)				
No. of records	185	286	203	268
Minimum	31·3	29·0	33·0	22·3
Maximum	56·3	58·0	60·7	54·8
Mean	43·7	40·2	44·4	39·2
s.d.	4·7	5·2	5·0	4·8
Back fat (mm)				
No. of records	185	286	204	269
Minimum	1·0	0·4	0·0	0·0
Maximum	5·4	6·1	7·8	7·8
Mean	2·7	2·5	2·4	2·3
s.d.	0·9	1·1	1·6	1·5

Table 2 *Model 1 parameters for the association of body weight,* longissimus dorsi *and backfat depths with body condition score (BCS) (Y = intercept + slope × BCS)*

	Intercept		Slope		R^2
	Estimate	s.e.	Estimate	s.e.	
Pre-calving					
Body weight (kg)	615***	10·2	35***	3·7	0·91
Longissimus dorsi (mm)	31·2***	1·07	5·8***	0·46	0·73
Backfat (mm)					
Experiment 1	1·86***	0·43	0·4*	0·19	0·48
Experiment 2	-2·2***	0·50	2·0***	0·21	
Post calving					
Body weight (kg)	573***	9·7	21***	4·1	0·91
Longissimus dorsi (mm)	27·9***	0·98	5·8***	0·46	0·73
Backfat (mm)					
Experiment 1	1·83***	0·40	0·4*	0·19	0·48
Experiment 2	-1·6***	0·44	2·0***	0·21	

Table 3 *Contribution of* longissimus dorsi *(LD) and backfat depths to body condition score estimate (mixed model 2)*

Parameter	Estimate	s.e.	Significance
Intercept pre-calving	0·76	0·329	*
Intercept post calving	0·62	0·326	†
Backfat (mm)	0·03	0·006	***
LD (mm)	0·05	0·015	***
LD^2 (mm^2)	-0·0004	0·00018	*
Coefficient of determination (R^2)	0·73	--	--

† Approaching significance (P < 0·1).

requirements. BCS showed a linear relationship with BW, but differed between the DP and lactation phases of the lactation cycle studied. The greater BW increase per unit of BCS increase during the DP (35 kg per BCS unit) is expected because a significant part of BW change in this stage can be accounted for by conceptus growth (which can account for 0·15 of total BW), mammary gland tissue development, and increased blood volume (Agricultural and Food Research Council, 1998). Additionally, the typical intake reduction associated with late pregnancy in dry cows would reduce the gut fill effect on BW compared with that during lactation. However, no comparable results have been found in the literature.

Our estimate of BW change per unit BCS for lactation (21 kg) is apparently low, but within the range (15 to 110 kg, all converted, where necessary, to a 0 to 5 scale) observed in the literature for lactating dairy cows (Frood and Croxton, 1978; Garnsworthy and Topps, 1982; Grainger *et al.,* 1982; Wright and Russel, 1984a; Garnsworthy and Jones, 1987; Jones and Garnsworthy, 1987; Chilliard *et al.,* 1991; Otto *et al.,* 1991; Gregory *et al.,* 1998). Among the highest estimates of BW per unit BCS available in the literature are the estimates of Otto *et al.* (1991), later used to validate the current National Research Council model (Fox *et al.,* 1999), and the estimate of Wright and Russel (1984a) based on non-lactating and non-pregnant dairy cows, which showed a large amount of data variation. In relation to the study of Wright and Russel (1984a), it is worth noting that their cows at BCS 1 were found by dissection to have no subcutaneous fat, which by definition of the scale used should have been scored with BCS at least close to zero. On this basis their estimate would be reduced from 110 kg to 81 kg per unit BCS. An average of literature values, including our own data and the revised estimate of Wright and Russel (1984a) yields a figure of 36 kg BW per BCS unit (0 to 5 scale).

The association between Bf and BCS was positive (model 1), but was affected by exp × period and exp × BCS interactions, which points to a lack of consistency in the relationship over time. Although great care was taken to minimize subjectivity in BCS assessments, operator bias cannot be disregarded. Assessment of BCS has been criticized for its subjectivity, but research (Edmonson *et al.,* 1989) and field experience have shown great repeatability within and between operators. However, operator bias over time, which at least in a previous report proved to be negligible (Domecq *et al.,* 1995) has been much less investigated, and could have contributed to these interactions. Ultrasound measurements can also be biased by location of the transducer, angle, coat hair (Faulkner *et al.,* 1990; Houghton and Turlington, 1992) and operator technique (Domecq *et al.,* 1995). Moreover, it is worth noting that at BCS of less than 1·5 it was extremely difficult to maintain a good contact between the ultrasound transducer and the hide of the animal, which together with the relatively thin layer of subcutaneous fat limited the measurement accuracy. It has been noted that when body fatness is low, the non-lipid components increase their contribution to adipose tissue weight (Gregory *et al.,* 1998), and variations in tissue water are also higher (Otto *et al.,* 1991). The thin BF layer of poorly conditioned cows could have contributed to the weaker association between BCS and BF in experiment 1 and the interactions with experiment.

Commonly, the association between BCS and subcutaneous BF, and indirectly total body fat content, is stressed. However, for our data, direct analysis of the BF or LD equivalence with BCS (model 1) suggested a greater contribution of LD; change of LD (5·8 mm) greater than BF (less than 2·0 mm) with each unit change of BCS. A more comprehensive approach (model 2), not only removed the significant interactions with experiment and period of the lactation cycle, but also suggested a more reasonable relationship of BF and LD with BCS. It indicated that a 1-mm increment in BF would result in an increase of 0·03 BCS units, i.e. 33 mm BF per unit BCS while the quadratic function of the relationship between LD and BCS suggests that LD contribution to BCS would be greater than BF when LD was below 25 mm and would plateau at an LD depth of around 60 mm (approximately the maximum values observed in these animals).

These results suggest that in late pregnant and early lactation high yielding dairy cattle, BCS changes at the lower range of the scale are mainly influenced by LD changes, and that as BCS increases, the proportional contribution of BF increases. In agreement with this, on an adjusted (0 to 5) scale for Holstein dairy cows, no measurable subcutaneous BF was recorded for BCS 1 (Wright and Russel, 1984a) and BCS 2·1 (Grainger and McGowan, 1982). Furthermore, it has been reported that BCS values below 1·4 and 2 have no significant influence on body fatness (Gregory *et al.,* 1998) and dissectible seam fat (9th to 11th rib sections; Otto *et al.,* 1991) respectively. However, Wright and Russel (1984b) did not find an association between BCS and *l. dorsi* area, but they were not investigating lactating animals. Consequently, it is suggested that BCS in the loin region (within the range 0 to 3) of dry and fresh dairy cows is mainly influenced by *l. dorsi* muscle depth. Previous reports have shown positive relationships between BCS and muscle to bone ratio (Gregory *et al.,* 1998), muscles *l. dorsi* (Schwager-Suter *et al.,* 2000; Moorby *et al.,* 2002a) and *t. thoracalis*, and muscle reserves (Reid *et al.,* 1986). Furthermore, positive and significant relationships of LD depth with lean body mass in beef cattle (Porter *et al.,* 1990; de Campeneere *et al.,* 1999) and with plasma albumin in dairy cows (Moorby *et al.,* 2002a) have been reported. Changes in BCS of the lactating dairy cow therefore reflect not only alterations in body fat depots but also in body muscle mass (Reid *et al.,* 1986), thus reflecting changes in labile body protein availability (Moorby *et al.,* 2002b; Jaurena, 2003).

It is worth noting that the 0 to 5 scale used in the current study (Mulvany, 1977) aims 'to assess the fatness at the tailhead and loin' of the cow and defines score zero as 'no fatty tissue felt'. From our data analysis, it is shown that there was an apparent drift of the lower part of the scale because the model 2 intercepts were 0·76 and 0·62 respectively for pre- and post-calving periods, meaning that the BCS assessor tended to over-score at the lower end of the scale. However, it must be noted that because of operative difficulties BF measurement involved subcutaneous fat and skin, leading to the estimated intercepts being different from zero. Agreeing with this apparent assessor bias an over-prediction of poor BCS by evaluators used to dealing with thin cows has been noted (Roche *et al.,* 2004), and it is also suggested by the lack of dissectible fat at BCS of 1 reported by Wright and Russel (1984a), using the similar 0 to 5 scale of Lowman *et al.* (1976) This operator bias would also contribute to explain the apparent over-prediction of the BW per BCS unit (Wright and Russel, 1984a) discussed above. Subcutaneous fat depots seem to be mobilized with priority over other stores (Butler-Hogg *et al.,* 1985; Gregory *et al.,* 1998), and therefore their depletion does not mean total body fat depletion. However, it is stressed that the inaccuracies discussed above are in scores out of the desired BCS range for healthy productive animals.

Conclusions

It is concluded that each unit of BCS equates to 35 and 21 kg BW for dry and fresh cows respectively. For BCS below 3, LD contributes to BCS up to an LD depth of about 60 mm, while BF thickness increases linearly with BCS. Moreover, ultrasound measurements showed that the relative contribution of LD and BF to BCS is not uniform but varies along the BCS scale.

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