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**Ultrasonic Body Condition Measurements for
Computerized Dairy Management Systems**

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Final Report**

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Abstract

The body condition (BC) score is recognized in the dairy industry as an essential tool for managing the energy reserves of the dairy cow, which is essential for sustaining optimal and efficient production over several lactations. The current use of BC scoring depends on the accuracy of subjective visual estimates, and this limits its usefulness as a management aid in the dairy industry. A measuring tool that would frequently provide objective data on the cow's body reserves would be a major contribution to efficient dairy herd management. Ultrasonic sensors have the potential to be developed into an efficient BC measuring device, and the experimental use of such sensors for subcutaneous fat thickness (SDFT) estimates, as an indication for BC in beef cattle, supports this assumption.

The purposes of this project were:

1. To compare visual BC scoring and ultrasonic fat thickness with on-line automated body weight (BW) measurements as monitors of nutritional adequacy of dairy cows at various stages of lactation.
2. To determine the effects of variation in digestive fill in early and late lactation on the accuracy of body weight measurements in lactating cows.
3. To modify an existing ultrasonic system and develop a specialized, low-cost sensor for repeatable determination of body condition scores by users with minimal training and skill.
4. To develop a standard for the assignment of body condition scores based on ultrasonic measurements of subdermal fat thickness.

The procedure to execute these objectives involved:

1. Frequent measurement of BW, milk yield (MY), BC (visually scored) and subdermal fat thickness ultrasonically measured of dairy cows, and data analysis on average and individual basis.
2. Testing and selection of an appropriate special-purpose sensor, finding an optimum body location for working an ultrasonic measurement, processing the signals obtained, and correlating the resulting measurements with performance responses in lactating cows.

Linking the ultrasonic signals to BC scores, and developing a BC scoring data acquisition system are the first steps towards fulfilling the necessary requirements for incorporating this device into an existing dairy herd management system, in order to provide the industry with a powerful management tool.

From the results obtained we could conclude that:

1. BC does not correlate with BW changes during all stages of lactation, although in general terms it does. These results were confirmed by individual cow BW and BC data obtained during the course of lactation, that were supported by individual objective ultrasonic measurement of SDFT.
2. BW changes reflect energy metabolism reliably only after peak milk yield; early in lactation, a decrease in BW expresses mobilization of body reserves only qualitatively, and not quantitatively.

3. Gastrointestinal content increases throughout the whole period during which dry matter intake (DMI) increases. The drastic increase very early in lactation prevents the use of BW changes as a basis for quantitative estimation of energy metabolism; at this stage of lactation, only a BC score or any other direct measurements will provide a quantitative estimate of energy metabolism.
4. Ultrasonic measurements of subdermal fat thickness can be used to quantify changes that correlate with the actual condition of the cow, as assessed by performance and the traditional way of scoring.
5. To find the best site on the cow's body at which to obtain responses to BC and its changes in the course of lactation, additional sites have to be examined. From the present study, it seems that the sites between ribs 12 and 13 have the potential for this purpose.
6. The use of templates made it easier to repeat measurements at a desired site and spot. However, the convenient easy-to-handle way to standardize the measurement, described in this study, offers scope for improvement.
7. The RF peak values of the A-mode are better indicators of the location of fat layer borders than image analysis, from the point of view of future commercial development.
8. The distances between the RF peaks of the A-mode can be automatically measured by suitable software, for future commercial development.
9. Proper analysis of daily body weight and milk yield data can provide the necessary information on body condition changes during lactation, until a direct BC measurement device is developed.
10. In any case, at least one visual BC assessment has to be done, preferably immediately after calving, for calibration purposes.

Original Objectives

1. To compare visual body condition (BC) scoring and ultrasonic fat thickness with on-line automated body weights (BW) as monitors of nutritional adequacy of dairy cows at various stages of lactation.
2. To determine the effect of variation in digestive fill in early and late lactation on accuracy of BW in lactating cows.
3. To modify an existing ultrasonic system and develop a specialized, low-cost sensor for determination of repeatable BC scores by users with minimal training and skill.
4. To develop a standard for the assignment of BC scores based on ultrasonic measurements of subdermal fat thickness (SDFT).

Description and explanation of objectives fulfilling

Objective 1. Comparison between BC scoring, fat thickness and on-line automated BW measurement

General

Objective number 1 was achieved by collecting and analyzing BW, milk yield (MY) and BC data along lactation on herd (in USA) and individual cow (in Israel and US) basis.

Introduction

Energy reserves management of the dairy cow is recognized in the dairy industry as necessary information for sustaining optimal and efficient production through the various stages of lactation. The body condition (BC) score is the current tool to evaluate it (Edmondson *et al.*, 1989; Ferguson and Otto, 1989; Chilliard *et al.*, 1991). Standardized BC scoring can be incorporated into a management expert system, together with other animal-status monitoring indicators, such as body weight (BW), milk yield (MY), etc. (Maltz *et al.*, 1992; Grinspan *et al.*, 1994). These indicators have become practical tools for optimizing lactation performance (Maltz *et al.* 1992a,b, Spahr *et al.*, 1993). The BC score at any given time during lactation is an important indicator for management decisions regarding relations between milk production and the energy reserves of the cow. The state of energy reserves of a certain cow may support to accept or reject a decision regarding milking frequency, change in feeding group assignment when feeding total mixed ration (TMR), or concentrates allocation when using computerized individual self

feeders (Maltz *et al.* 1992a,b, Spahr *et al.*, 1993, Maltz and Metz 1994, Maltz *et al.* 1997, Maltz 1997). For these kind of decisions, physiological turning points such as ceasing energy mobilization or start of deposition are not less important than the actual BC of the cow and the rate of its change (Maltz and Metz 1994, Maltz *et al.* 1997, Maltz 1997). The physiological turning points regarding energy output via milk are reflected in the lactation curve. Those of energy reserves mobilization and deposition are reflected in BC curves. However, despite the fact that these two curves are in general terms mirror images of one another, there are differences in the timing along lactation under various management strategies. (Chilliard *et al.* 1991, Maltz and Metz 1994, Bar Peled *et al.* 1995, Maltz *et al.* 1997, Moallem *et al.* 1997,). Daily BW measurements did not solve the problem of precise timing of energy balance physiological turning points, because body reserves mobilization and deposition on one hand and changes in gastrointestinal tract size and fill on the other, have an opposite effect over BW changes (Bahaa *et al.* 1997). In several works BC and BW curves contradicted one another along substantial period of lactation (Chilliard *et al.* 1991, Maltz and Metz 1994, Bar Peled *et al.* 1995, Maltz *et al.* 1997, Moallem *et al.* 1997,). It was suggested that from a certain stage in lactation BW increase indicates fat deposition (Maltz and Metz 1994, Maltz *et al.* 1997). However, the precise time when this stage starts or the time when body energy mobilization stops, can be identified only by BC scoring. The BC score is based on the subdermal fat thickness at key body locations, and is determined by visual scoring on a 1.0 to 5.0 scale with 0.25-unit steps (Edmondson *et al.*, 1989). Low BC scores usually represent thin cows and higher scores represent those with more subdermal fat. Fat thickness at any of the key sites is correlated with that at other key sites (Edmondson *et al.*, 1989). So, by definition the BC scores represent a subjective classification of visual evaluation of the subdermal fat content. The subjectivity of the traditional way of BC scoring is not in favor of precise timing of physiological energy balance turning point. Regarding individual cows, BC often fluctuates within the range of a single measurement rank (0.25), contradicting MY and BW changes (Maltz and Metz 1994, Maltz *et al.* 1997) which leaves question marks about the validity of the estimation that might be related to subjective estimation error.

Energy balance in the dairy cow can be effected by hormonal treatment and the traditional way of ration density.

Bovine somatotropin, also called Bovine Growth Hormone, is a hormone produced in the anterior hypophysis. Growth hormone was discovered many years ago, when Lee and Schaffer (1934) showed that an alkaline crude pituitary extract injected into pair-fed growing rats resulted in increased growth rate. The "factor" involved from the extract was called "somatotropin" a Greek word derived for "tissue growth". At about the same time scientists proved that when crude pituitary extracts were administered to lactating rats, lactation was affected (Stricker and Greuter, 1928). In 1937, Asimov and Krouze conducted the first large scale study with somatotropin, in which more than 500 dairy cows received a crude pituitary injection, resulting in milk yield being increased. The first study on the effects of long term administration was conducted by Brumby and Hancock (1955), who showed that milk production was

increased by 40 % in twin cows receiving daily injections of bST for 12 weeks.

Prior to the 1980's, bST research was restricted, primarily because availability of bST was limited by the amount that could be recovered and purified from the hypophysis of slaughtered animals; thus studies only involved a few animals treated for a short period of time or a few days.

With the availability of a high purity recombinant DNA derived bST, substantial amounts of bST are now available for long term studies involving many animals, as well as for commercial applications.

Adipose tissue plays a key role in the responses observed to bST treated cows during lactation because changes in lipid metabolism are essential for redirecting nutrients. Deposition of lipids in adipose tissue is a function of the rates of lipogenesis (lipid synthesis) and lipolysis (lipid mobilization). The effects of growth hormone on lipid metabolism are as a chronic modulator, and the extent to which they involve lipogenesis versus lipolysis will be determined by the energy balance of the individual. Bovine somatotropin affects lipid synthesis by decreasing glucose uptake and utilization for triglyceride synthesis in adipocytes (Vernon, 1982; Etherton *et al.*, 1987), and by decreasing insulin sensitivity for glucose uptake in whole body metabolism (McCutcheon and Bauman, 1986; Gopinath and Etherton, 1989). Thus, the decrease in glucose utilization by adipose tissue for lipid synthesis enables triglycerides and glucose to be redirected to the mammary gland for support of the increased milk production (Miller *et al.*, 1991a). The fact that in vitro studies have shown that bST decreases acetyl CoA carboxylase and fatty-acid synthase in adipose tissue suggests that in vivo it could act by altering transcription of these key metabolic enzymes (Lanna *et al.*, 1992).

Subdermal fat thickness (SDFT) measured by ultrasonic sensors was found to correlate with BC scored visually in different cows (Brethour, 1992; Domecq *et al.*, 1995). In addition, it was found that along lactation in the same cow, significant correlation occurs between subdermal fat thickness in certain locations to both, BC and BW (Mizrach *et al.* 1996, Mizrach *et al* 1997).

The purpose of this study was to analyze BW and MY changes in relation to BC traditionally scored, using SDFT for validation in order to evaluate body energy balance along lactation. This was done in view of using BW and MY data (which are commercially available) for more accurate body energy balance estimates until direct BC measurements are available.

Technical considerations

The technical problems are associated with adapting available equipment for a defined purpose: measurement standardization, and automatic data analysis. The available ultrasonic equipment has to be adapted to suit it to the task in hand. The output of the measurement has to produce, on the one hand, an image that can be deciphered visually in terms of clear identification of the layers of interest and, on the other hand, data that can be automatically analyzed in order to determine the thickness of these. Successive and frequent repetition of ultrasonic measurements over a long period of time (months), to determine changes in the thickness of a certain layer requires a high level of measurement standardization,

which must apply both to the location of measurement and to the measurement procedure and routine. In addition, an objective tool has to be developed in order to standardize and automate the data analysis of each measurement.

Physiological considerations

The measurement site preferences and interpretations of ultrasonic measurement are related to the interpretation of cows' response to energy balance. There is no clear evidence that subdermal fat changes are sensitive enough to indicate the stages reached by ongoing changes in energy balance. There is also no certainty that subdermal fat is affected equally all over the body. In addition, there is no information to indicate whether measurements at a single point are sufficient or whether it is necessary to extend them over the whole area, if the basic validity conditions are satisfied. All this has to be taken into consideration when planning a trial which is intended to lead to an objective method for monitoring BC changes during lactation.

Data analysis considerations

After overcoming the technical and physiological difficulties, we face the problem of data analysis. Ultrasonic measurements are objective, the traditional BC scoring is not. Despite the fact that the traditional, subjective BC scoring represents, in general, the energy balance status of the dairy cow (Spahr *et al.*, 1993; Bar-Peled *et al.*, 1995), its reliability in providing reference point for an objective measurement is bound to be doubtful, especially when we wish to define the precise time when a change in energy balance occurs. The only objective measurement to which the ultrasonic data can be related is that of BW. However, BW and BC do not correlate for up to several weeks, in the critical period during which the dairy cow switches from energy mobilization to fat deposition (Spahr *et al.*, 1993, Bar-Peled *et al.*, 1995), because of the nature of the BW changes during this period (Maltz and Metz, 1994; Maltz *et al.*, 1997; Maltz, 1997). However, starting from a certain point during lactation, BW may be an adequate reference basis for ultrasonic measurements of BC (Maltz, 1997).

Analysis by herd - USA

Materials and methods

Assignment of animals to treatments

Cows were alternately assigned to one of the two treatments according to calving date within breed and parity group (primiparous or multiparous) to assure that all of the sub-classes would be represented. At the end of the first period, half of the cows in each treatment group were switched to the other group.

Cows were grouped into four seasons (SSN) according to the calendar date of initiation of bST

injections in order to account for some of the variation due to the different environmental conditions during the trial, primarily heat stress. SSN "A" took place from the 05/13/94 through 06/24/94; SSN "B" from 06/30/94 to 08/26/94; SSN "C" from 09/09/94 to 10/21/94 and SSN "D" from 10/28/94 through 12/10/94.

At the beginning of week 9 of lactation, cows were injected with recombinant bST (Posilac™) provided by Monsanto, Saint Louis, MO. Injections were administered subcutaneously in the pocket lateral to the tailhead, according to the manufacturer's label, and repeated at fourteen day intervals alternating the site of injection each time until the conclusion of the trial.

Measurements and sample collection

Milk weights were recorded at each milking with electronic milk meters. Milk samples were collected from two consecutive milking on a weekly basis and a composite milk sample was sent to Dairy Lab Services, Dubuque, IA., where they were analyzed for fat percent, protein percent, and somatic cell count (SCC). Results were transferred electronically through Dairy Lab Services' Bulletin Board.

Milk production was measured as milk yield per day(kg), protein per day(kg), fat per day(kg), 4% FCM per day(kg) and 4% FCM per day, BW^{0.75} (Body weight to the 0.75 power). The averages of these measurements during weeks 7 and 8 of lactation were used as a covariant.

Cows were weighed every week during the trial and scored for body condition by two evaluators (the author and Dr. Sid Spahr) using a 1 to 5 scale with .25 unit intervals (1 = thin; 5 = obese) according to Edmonson *et al.* (1989).

Statistical analysis

Data were analyzed using the GLM Procedures of SAS®, (SAS®, 1990) using the model:

$$Y_{ijklmn} = \mu + \chi 1\beta_{1\varphi\kappa\lambda} + \text{Pty}_i + \text{Trt}_j + \text{Ssn}_k + \text{Id}_{(ijk)l} + \text{Rnd}_m + \text{Trt}*\text{Rnd}_{jm} + \varepsilon_{ijklmn}$$

where:

Y_{ijklmn} = is any of the dependent variables to be analyzed: milk yield, FCM, protein, fat, FCM/BW^{0.75}, BW or BCS.

μ = overall mean

$\chi 1\beta_{1\varphi\kappa\lambda}$ = is the regression of the covariable for the dependent variable

Pty_i = effect of the *i*th parity

Trt_j = effect of the *j*th treatment

Ssn_k = effect of the *k*th season

$\text{Id}_{(ijk)l}$ = effect of the *l*th animal of the *i*th parity on the *j*th treatment in the *k*th season

Rnd_m = effect of the *m*th round of injection

$\text{Trt}*\text{Rnd}_{jm}$ = effect of the interaction of the *j*th treatment with the *m*th round of injection

$$e_{ijklmn} = \text{residual}$$

The model is a split-plot, where the effects of treatment, parity, and season are main effects and tested with $Id(ijk)l$ as the error term; the effects of round, and treatment by round were tested with ϵ_{ijklmn} as the error term.

Results and discussion

Responses affecting BW, BCS and FCM/BW^{0.75}

Results for BW, BCS and FCM/BW^{0.75} for periods I and II are presented in Tables 1 and 2. Initial values represent the arithmetic means for weeks 7 and 8 of lactation and were used as the covariates in the statistical model.

Effect of diet

During periods I and II, significant differences ($P < 0.05$) were observed only for FCM/BW^{0.75} due to the different dietary treatments. Since Ayrshire, Brown Swiss, Holstein and Jersey cows were used in the experiment, and due to the large variability in BW, milk yield and fat content between animals, and because we were forced to exclude breed effects from the analysis due to the loss of some animals, we evaluated the amount of FCM/BW^{0.75} as a mean of estimating production over the requirements of maintenance. Cows fed the “High” diet produced more FCM/BW^{0.75}, than cows fed the “Low” diet. Since FCM was significantly greater in the “High” level diet and no differences were found for BW, the increased FCM/BW^{0.75} was due mainly to the increase in FCM. No differences were observed for BCS during period I due to the different diets. During period II, no significant differences ($P < 0.05$) were observed for FCM/BW^{0.75}, BW nor BCS due to the different dietary treatments.

Effect due to parity

No significant differences were found for FCM/BW^{0.75}, BW nor BCS during period I for the different parity groups. During period II, no significant differences ($P < 0.05$) were observed for FCM/BW^{0.75} nor BW due to the different parities, however, there was a significant differences for BCS. Primiparous cows had lower BCS than the multiparous cows. During their first lactation, primiparous cows continue growing (Tucker, 1987). Since BW was not significantly different, a possible reason for primiparous cows having lower BCS than multiparous cows could be, to some extent, due to skeletal growth.

Effect of calendar date of initiation of bST injections

As in the analysis for production parameters, cows receiving their first round of injections during SSN “A” consistently had the lowest values for FCM/BW^{0.75}, BW and BC score during the first period.

Cows receiving their first round of injections during this season were most likely heat stressed and probably reduced their dry matter intake, which affected these parameters as well as FCM, fat and protein per day yields.

During period II, the effects of the date of initiation of bST injections were significantly different for FCM/BW^{0.75} and BW. SSN "A" continued having the lowest values for FCM/BW^{0.75} and BW, and even if BC scores were not significantly different ($P < 0.05$), it was also lower for the cows in SSN "A".

An interesting observation was that for FCM/BW^{0.75}, BW, and BCS the numerical ordering within each parameter was unchanged throughout both periods. Moreover, cows starting on bST injections during SSN "A", always had the lowest values for all the parameters evaluated.

Effect of round of injection

A steady but significant decline was observed for FCM/BW^{0.75} during both periods due to the effects of rounds of injections. This was due to the decline in FCM, as well as the increase in body weight due to the progression of lactation. A significant ($P < 0.05$) increase in BW was observed during period I for the effect of round of injection, however, no significant differences ($P < 0.05$) were observed for BC score during the same period. This could suggest that there was an increase in internal organ mass, especially GI tract, as lactation progressed.

During the second period cows were still increasing BW, but by contrast with period I, there were also significant differences for BC score due to the progression of lactation.

Table 1 - Least squares means and standard errors for FCM/BW^{0.75}, body weight, and body condition score during period I.

	FCM/BW ^{0.75} (kg/kg)		BW (kg)		BCS (kg)	
Initial Value	0.220		514.6		2.45	
	LSM	SE	LSM	SE	LSM	SE
Parity						
First	0.201	0.007	515.2	3.70	2.44	0.048
Second	0.206	0.007	514.3	4.09	2.46	0.053
Treatment						
High	0.208a	0.007	515.0	3.90	2.44	0.050
Low	0.199b	0.007	514.5	3.86	2.46	0.050
Season						
A	0.192c	0.010	504.9 ^c	5.46	2.35 ^b	0.070
B	0.211a	0.010	516.3 ^b	5.24	2.49 ^a	0.067
C	0.211a	0.010	521.7 ^a	5.46	2.47 ^a	0.070
D	0.199b	0.011	516.2 ^b	5.86	2.49 ^a	0.075
Round						
1	0.208a	0.002	509.9 ^b	1.34	2.48	0.017
2	0.204ab	0.002	512.7 ^b	1.34	2.46	0.017
3	0.204ab	0.002	512.1 ^b	1.34	2.42	0.017
4	0.199b	0.002	518.7 ^a	1.34	2.44	0.017
5	0.195b	0.002	520.6 ^a	1.34	2.46	0.017
TRT*Round						
High 1	0.214	0.003	510.3	1.92	2.49	0.025
High 2	0.221	0.003	513.1	1.92	2.45	0.025
High 3	0.208	0.003	511.7	1.92	2.40	0.025
High 4	0.203	0.003	519.1	1.92	2.42	0.025
High 5	0.196	0.003	520.9	1.92	2.43	0.025
Low 1	0.202	0.003	509.4	1.86	2.47	0.024
Low 2	0.204	0.003	512.3	1.86	2.47	0.024
Low 3	0.200	0.003	512.5	1.86	2.44	0.024
Low 4	0.194	0.003	518.3	1.86	2.45	0.024
Low 5	0.193	0.003	520.3	1.86	2.49	0.024

abc : superscripts with different letters within columns differ (P<0.05)

Table 2 - Least squares means and standard errors for FCM/BW^{0.75}, body weight, and body condition score during period II.

	FCM/BW ^{0.75} (kg/kg)		BW (kg)		BCS (kg)	
Initial Value	0.220		514.6		2.45	
	<u>LSM</u>	<u>SE</u>	<u>LSM</u>	<u>SE</u>	<u>LSM</u>	<u>SE</u>
Parity						
First	0.209	0.007	531.1	5.54	2.47 ^a	0.007
Second	0.208	0.008	523.9	6.12	2.61 ^b	0.008
Treatment						
High	0.211	0.007	524.8	5.56	2.55	0.007
Low	0.207	0.008	530.2	5.97	2.53	0.008
Season						
A	0.199 ^{ac}	0.011	510.8 ^c	8.17	2.44	0.11
B	0.225 ^a	0.010	528.3 ^b	7.84	2.61	0.10
C	0.211 ^b	0.011	533.7 ^{ab}	8.17	2.51	0.11
D	0.200 ^c	0.012	537.2 ^a	8.76	2.60	0.12
Round						
6	0.215 ^a	0.001	522.5 ^c	1.22	2.51	0.022
7	0.210 ^{ab}	0.001	526.1 ^b	1.22	2.56	0.022
8	0.208 ^b	0.001	527.8 ^b	1.22	2.53	0.022
9	0.202 ^c	0.001	533.7 ^a	1.22	2.56	0.022
TRT*Round						
High 6	0.216	0.003	521.3	1.69	2.56	0.030
High 7	0.215	0.003	523.9	1.69	2.57	0.030
High 8	0.208	0.003	525.2	1.69	2.52	0.030
High 9	0.204	0.003	528.7	1.69	2.55	0.030
Low 6	0.214	0.003	523.6	1.77	2.46	0.032
Low 7	0.206	0.003	528.3	1.77	2.55	0.032
Low 8	0.207	0.003	530.3	1.77	2.55	0.032
Low 9	0.201	0.003	538.6	1.77	2.57	0.032

^{abc} : superscripts with different letters within columns differ (P<0.05).

Analysis by individual cow - Israel

Materials and methods

Instrumentation

A commercial ultrasonic system (B-3000 B-Scan, Sonomed Inc. 3000 Marcus Ave. Lake Success, 11042) was selected and adapted to the acquisition and presentation of A-mode and B-mode ultrasonic images; it was modified from its original ophthalmic diagnostic purpose. Its probe contained a mechanical single 7.5-MHz ultrasonic transducer with bow-shaped scanning sector capability. Video images of both the A-mode and the B-mode are simultaneously displayed on the screen, with a gray-level scale of 0-255, and the axis of the A-mode vector is selectable for achieving precise measurements. The A-mode signal represents a rectified RF signal. The bow-shaped B-mode scanning sector comprises 126 arrays of A-mode rays, of which the central ray (ray no. 63) was chosen for processing. An analog-to-digital converter card, that was added to the ultrasonic system by our request, was able to convert each of the A-mode RF beam signals into digitized 512-hex-byte data points and to process it into a rectified signal. The video display was recorded on videotape and the digitized data were collected by a PC for analysis. Diagnosis of the A-scan enables detection and examination of skin, fat, and muscle layers without the necessity for any auxiliary measurements. The B-scan allows a full-screen image to be observed and distances and areas within the picture to be confirmed or measured.

Site Selection and Standardization

Preliminary trials for equipment testing and A and B-mode comparison were conducted. When the ultrasonic probe was applied directly to the cows' skin, the measurements could not be satisfactorily repeated, because of variations of probe angle and pressure applied, and sliding of the probe during measurements, even when they were repeated on the same spot. It was clear that a device had to be manufactured to overcome these difficulties (see below). One trial involved measurements in the slaughterhouse. In the selected cow, ultrasound measurement of subdermal fat thickness were carried out at six sites (between ribs 12 and 13, at the hips, at two sites on the rump - fore and back - at the pin bone area and below the vulva). Several measurements were taken at each site, within about a 20-mm range, in order to examine the possibility of "area measurements" in addition to a single spot measurement in each site. Measurements were repeated at the same sites after slaughter, according to the same protocol. Skin and subdermal fat thickness were visually assessed, but accurate measurement of the subdermal fat layer was impossible because of its instability under the tension between tissues, following of incision. The visual assessments were analyzed and compared with the A-mode and B-mode measurements.

Of the six sites tested, four were rejected: the site at the pin bone, because of difficulties in establishing successive standard area measurements; the sites at the hip and below the vulva, because of

very thin layers of subdermal fat; and the site at the fore rump, because of uneven subdermal fat distribution in the area tested. The selected locations as the most appropriate ones for ultrasonic measurements of subdermal fat thickness were: 1) the flat area on the rump between the pin bone and the hip, and 2) the area between the 12th and 13th ribs, from the spine downwards. The first site was chosen because: it contains a significant amount of subdermal fat; it provides ease of standardizing the location of single points in a site of a reasonable size that does not change morphologically during lactation; and it provides ease of access and identification for future sensor development. The second site was chosen because, in addition to the above reasons, it had already been tried and found suitable for similar ultrasonic measurements of subdermal fat thickness in beef and dairy cattle (Edmonson *et al.*, 1989; Faulkner *et al.*, 1990; Domecq *et al.*, 1995).

For repeatable, standard, successive measurements to be made during lactation, each measurement had to be performed at exactly the same spot and angle; and to ensure this, each site was marked by clipping, and special probe holders were designed (see below).

Ultrasonic Probe Holders

Two ultrasonic probe holders incorporating position templates made of 66 Polyamide material were manufactured, to enable for multiple measurements to be made in each of the sites mentioned above (Figure 1).

Figure 1 - Ultrasonic probe holders for subdermal fat thickness measurements in the rump site (a) and the between-ribs site (b). Cross section of holder hole (c) shows a 0.5-mm step toward the skin side, which ensures equal probe pressure for all measurements.

The first probe, for the flat area on the rump, had a circular template, 100 mm in diameter, which contained seven holes, one in the center of an 80-mm-diameter circle and six with their centers evenly spaced around this circle, forming a hexagon. The holes were numbered from 1 (center point) through 7, clockwise (Figure 1a). The second template, for the site between the 12th and 13th ribs, was a straight strip, 120 mm in length, containing a row of five holes, 20 mm apart, numbered from 8 (at the top end) through 12 (Figure 1b). The 16-mm-diameter holes for the probe had a narrower 14-mm-diameter section, 0.5 mm long, at the skin side, to prevent the probe from contacting the skin (Figure 1c). When the hole

was filled with ultrasonic gel and the probe inserted into it for measurement, the pressure on the skin was the same in all measurements. The templates were matched to their locations according to marks on the template that corresponded with shaved marks on the cows' skin. The round holder was oriented with hole no. 2 at the top (closest to the spine) and no. 5 at the bottom (furthest from the spine). The linear template was located below the back rump with hole no. 8 upwards. The shaved marks were renewed every second week. Satisfactory repeatability was achieved when measurements were repeated with the aid of the probe holders (in any spot).

Animals, management and experimental procedures

Six multiparous Israeli Holstein cows that had calved during two successive days and which had different visual post-calving BC scores were selected to be monitored throughout lactation. Cows were fed a total mixed ration (TMR) according to NRC recommendations (1989) once daily between 0900-1000 h throughout lactation. The cows were milked three times daily (at 0400, 1200 and 2000 h) and weighed automatically at the outlet path from the milking parlor after each milking (Peiper *et al.*, 1993; Ren *et al.*, 1992). Once a week the cows were segregated for ultrasonic and traditional BC measurements. Body condition was estimated on a 1.0 to 5.0 scale with 0.25-unit steps, and determined by visual scoring and palpation by the same trained evaluator. Milk yield was measured by electronic milk meters (S.A.E. Afimilk, Afikim, Israel). One cow (696) was dried out after 40 wks, but BW, BC and SDFT continued to be measured weekly until wk 51.

The combined thickness of the skin and subdermal fat layers was found to be less than 20 mm in the preliminary tests, therefore, the ultrasonic scanning range was adjusted to a depth of 30 mm. The measurements were carried out weekly for every point on the two sites on the cow's body. The bow-shaped scanning sector of the probe was oriented parallel to a line passing vertically downwards from the cow's spine. The video images produced by both the A-mode and the B-mode were displayed simultaneously on the monitor screen, and the signal was examined during the measurements on the video screen, in order to obtain clear recognition of the peaks corresponding to the animal's skin, subdermal fat and muscle. Stable A- and B-mode images were recorded on videotape. In addition, the digitized A-mode RF beam signals were collected by the PC for further analysis.

Computer Algorithm.

Skin, fat, and muscle layers were visually defined from the B-scan image (Fig. 2). Two artifact echoes always appeared in the signal (Fig. 2). On the basis of these two echoes, three peaks were selected in the linked A-scan; they represent the ultrasonic echoes from the skin surface, the skin-attached fat layer, and the bottom of the muscle-attached fat layer (Fig 2), were used in a computer algorithm to determine the changes in subdermal fat thickness during lactation.

I

II

III

IV

Figure 2 - Typical A-mode and B-mode video images of cow no. 696, showing well defined layers and peaks from the rib site (I), unclear definition in another point in the same site (II), well defined layers and peaks from the rump site (III), and unclear definition in another point on in the same site (IV). Peaks a and b - artifacts; c - skin surface; c1 and c2 - skin membranes; d - bottom of skin-attached fat layer; e - bottom of subdermal fat and beginning of muscle. Bottom line scale represents 2 mm intervals.

The collected data were analyzed on a weekly basis. Each digitized RF A-mode signal from each measured point was analyzed and peaks were determined. A program was implemented in Matlab software (1995) which included data processing with the stored rectified RF signal as input. Each signal consisted of 512 data points and contained considerable peaks in significant positions which represented interfaces between layers, from the skin surface to 30 mm in depth.

Performing a logical procedure on the stored signal, all data points were scanned in sequence and the amplitude was measured. After scanning, a trash-hold (50% of the highest peak) was set and peaks were counted. The trash-hold level was elevated until three peaks remained. Logical location analysis was applied to each peak, in order to ensure that it represents one of the three desired peaks. After this validation process, the program presents the values of the significant peaks. Sequentially, the procedure comprised the following routines: 1) locating the two artifact echoes; 2) locating of the three desired echoes which represent the skin surface, the skin-attached fat layer, and the bottom of muscle-attached fat layer; 4) computing and locating of the exact centers of the peaks; 5) calculating the thickness of skin plus the skin-attached fat layer, and the total thickness between the surface of the skin and the beginning of muscle, for each individual point and for the mean values of all points in each site. Whenever the program failed to detect the three desired peaks, a null value was inserted. This occurred mainly when determining the beginning of the muscle layer, especially in the rib site (point e, Fig 2).

The program output the calculated values for each peak, and these values were then stored and arranged in computer files for further analysis. Statistical analysis were carried out to correlate the stored values of distances between peaks with BC and BW data, by means of the general linear model of SAS (1989).

The ultrasonic data set that was selected for comparison with the BC scoring and the direct measurements was that of a single point between the 12th and 13th ribs. The point along the measuring line differed between the cows due to different morphology and anatomy. The main consideration for selecting the measuring point for each cow was the significance of the correlation between the SDFT and BC (Mizrach et al. 1997). For more detailed considerations for this selection see Mizrach et al. 1997.

Results and discussion

For this study only the SDFT data measured in a single point of the between 12-13 rib that correlated best with the BC scoring were used. The results are presented and discussed as averaged values of all cows first, to characterize trends, and then individually in order to validate the possibility to use MY and BW data as a tool for energy balance along lactation for the individual cow.

All cows

Mean values of all available data for each week are presented in Fig 3. There was a similarity between the general pattern of BC and skin attached SDFT. A decrease after calving, followed by an

increase until end of lactation, with various periods of fluctuations along the line. This is the visual expression of the correlation described by Mizrach *et al.* (1997) for complete lactations. In general, from wk 9 pp the SDFT fluctuations correlated qualitatively with those of BC but not quantitatively. BC increased 51 wks pp by 50 percent of initial values (Fig 3), and about 70 percent above lowest values recorded (Fig 3, wk 13 pp), the SDFT increased by 13 percent above initial value and 30 percent above the lowest value of week 3 pp (Fig 3). This may suggest two physiological phenomena. The first, is that subdermal fat is mobilized and accumulated unevenly over the body despite the correlation between different sites (Edmondson *et al.*, 1989), and the second, that BC as well as SDFT may have local fluctuations along a line of general decrease or increase. The traditional BC scoring integrates the condition of all sites, while the SDFT of the site presented in this study, contributes relatively less than other sites, and in different times along lactation. Regarding BC, temporary fluctuations were observed in individual cows scored twice a week by Maltz *et al.* (1997), which supported individual weekly BC data presented as averages by Spahr *et al.* (1993). The BC and SDFT measured in this study, confirms that this is a genuine physiological phenomena and not an artifact deriving from the subjective nature of BC scoring. In addition, qualitatively the weekly fluctuations of BC correlated with those of SDFT from week 9 pp with the exception of weeks 35-43 pp (Fig 3). The inconsistency between BC and SDFT changes between weeks 35-43 can be explained by the incomplete data sets during this period (Fig 4). This however, can not be the explanation for the inconsistencies during weeks 4-9 pp. Early lactation was described in several works as a problematic period in characterizing changes and rates of changes of energy balance parameters; i.e. BC, DMI, MY and BW in individual cows. This was related to differences in the cows' physiological adjustment capacity to milk production driving force that dictates the MY increasing rates (production potential) on one hand and ability to support it by adequate increase of DMI, and body energy reserves mobilization on the other (Maltz and Metz 1994, Maltz *et al.* 1997, Maltz 1997). When there is a distance between production potential and adjustability, we witness in individual cows, phenomena such as lactating curve collapse and what seems to be unexplained contradicting fluctuations in BW and BC within relatively short periods (Maltz and Metz 1994, Maltz *et al.* 1997, Maltz 1997) as can be seen during wks 6-9 of the averaged values (Fig 3). The relevant way to discuss these fluctuations is by analyzing the data individually for each cow (see below). Nevertheless, some general relations between BW changes and energy metabolism during lactation can be withdrawn from the average values of MY, BW and BC. During the period 1-13 wks pp BC score is significantly decreasing ($P<.01$) demonstrating body reserves support for MY (Fig 3). Despite of a farther decrease in BC until wk 13 (Fig 3) maximal milk production (of wk 8) was not maintained, suggesting that body reserves are not sufficient to maintain the maximal production achieved in wk 8 pp (Fig 3). Body weight decreased parallel to that of BC until wk 5 pp (Fig 3), indicating that losing body reserves is overpowering the weight gain related to increase of gastrodigestive tract and its' content (Bahaa *et al.* 1997). This was diverted between wks 4-8 pp when BW increased during a period of constant MY (Fig 3). It seems that

the increase in DMI that is normal at the beginning of lactation and is expressed by the increase in BW during wks 5-8 pp (Maltz and Metz 1994, Maltz *et al.* 1997), may have had contributed to the BC in which a similar increase was recorded during this period. However, one can not ignore the possibility that visual BC scoring was somewhat biased by the fact of pure BW changes of the cow during this period. Especially when the SDFT changes during wks 4-8 pp (Fig 3) seemed to contradict the changes in BC. Yet, this contradiction is mainly the outcome of the SDFT results of a single cow (591, Fig 4, see below), and perhaps also because of some SDFT missing data during this period in other cows (Fig 4). Therefore, it is preferable to analyze this period on an individual cow basis (see below). For early lactation, these results are in accordance with conclusions achieved in previous studies, that BW changes, as such, can not sign the exact time that energy balance turns from being negative to balanced and positive. To deduct about energy balance turning points expressed by BW changes, it was suggested to analyze these changes in relation to those of MY. This way, together with direct DMI measurement and its effect on BW, the BW changes could explain those of BC (Maltz and Metz 1994, Maltz *et al.* 1997). However, the shadow of possible error because the subjectivity of BC estimates, lies over the conclusions. Analysis on individual basis when BC scoring is validated by SDFT may remove this shadow (see below).

From mid lactation (wk 24 pp) onwards, there is a continuous steady increase in BW that is accompanied by a similar increase (though with some fluctuation) in BC as well as (with even greater fluctuation) in SDFT (Fig 3). The correlation between these three variables during this period (Table 1), that is supported by the steady decline in milk production (Fig 3), indicates that from a certain stage during lactation the BW increase reflects the increase in BC. This stage however, may differ between cows as explained below.

Figure 3 - Average values of all available data of 6 cows. Upper panel: • - body weight (BW) as % of body weight measured after calving (IBW); □ - milk yield (MY). Lower panel: + - body condition (BC) scored on 1-5 scale in ranks of 0.25; ■ - subdermal fat thickness (SDFT) measured by ultrasonic.

Individual cows

In one cow (No. 591, Fig. 4) out of the six participating in the trial, The SDFT contradicted the BC changes along lactation. In addition, this cow was exceptional in SDFT values compared to all other cows. In all other 5 cows, the SDFT reached the value of 8 mm or close to it only at the last quarter of lactation (Fig. 4), while cow 591 had values of 9-10 mm at early lactation (Fig 4). This high values also contradict the BC score of this cow. Because using in this study only the values of skin attached fat layer, we didn't expect a correlation between BC and SDFT. This was found when both skin and muscle attached SDFT are considered (Mizrach *et al.* 1997). Nevertheless, the exceptional high values of SDFT together with low BC (2.00 and decreasing, Fig. 4), indicates that something might have gone wrong with the SDFT measurement. It is possible that in this cow some of the SDFT measurements include both, skin and muscle attached SDFT. The depth of these two fat layers together is likely to be within the range of 10 mm (Mizrach *et al.* 1996, 1997). A point that supports this assumption is the SDFT measured in this cow from wk 35 pp. From wk 35 pp a marked increase in BW that correlated with a parallel increase in BC was recorded. These increases corresponded with the decline in MY. Yet The SDFT dropped during this period in comparison to the previous measurements (Fig. 4). In this cow there was also an exceptional number of missing data (Fig. 4), demonstrating the difficulties of the software to pick up significant peaks of the ultrasonic A-mode recordings (see M&M, Mizrach *et al.* 1996, 1997) which may be the reason for the inconsistency in recording only the skin attached SDFT.

In all the six cows measured, BW decline during the first 5-6 wks of lactation corresponded with a decline in BC (Fig 4). In 5 cows, this was confirmed by the SDFT (Fig 4). The fact that the BW decline during the first wks after calving reflects loss of BC was described in several works where cows were weighed and scored weekly under different management conditions (Chilliard *et al.* 1991, Bar peled *et al.* 1995, Spahr *et al.* 1993, Moallem *et al.* 1997). This was also shown when cows were weighed very frequently (7-20 times a day in the concentrates feeding stall, Maltz and Metz 1994, Maltz *et al.* 1997) and scored twice a week. In this work similar results are supported by an objective measurement of SDFT when cows were scored once a week and weighed automatically on the outlet path of the milking parlor (Peiper *et al.* 1993). Four out of the six cows demonstrated a MY drop of 9.2-16.8 kg milk a day within a short period of 1-4 wks (Fig 4). All the 4 cows in which this lactation curve collapse was observed, reached peak MY of more than 45 kg/d that was over 8 percent of BW and BC after calving was 2.25 or more. The two cows that did not have a lactation curve collapse had lower peaks, milk production did not reach 8 percent of BW and BC after calving was 2.00 (Fig 4). In addition to this, the period during which lactation curve deteriorated, BW increased following a trough that marked the start of the MY collapse (Fig 4). This increase in BW was not followed neither by an increase in BC nor in SDFT (Fig 4). In several works it was observed, in early lactation, that BW increased without a parallel increase in BC. In fact, quite often an increase in BW was accompanied by a decline in BC (Maltz and Metz 1994, Maltz *et al.* 1997).

Figure 4 - Data of 6 individual cows. Upper panel: • - body weight (BW) as % of body weight measured after calving (IBW); □ - milk yield (MY). Lower panel: + - body condition (BC) scored on 1-5 scale in ranks of 0.25; ■ - subdermal fat thickness (SDFT) measured by ultrasonic.

It was suggested that BW increase recorded at early lactation (Fig 4; for example: cow 612 wks 5-9 and cow 599 wks 5-8 and 9-13 pp) reflects only the weight gain of gastrointestinal tract because of increased fill as a result of increase in DMI (Maltz *et al.* 1992, Maltz and Metz 1994, Maltz *et al.* 1997). Indeed, direct measurements (Bahaa *et al.* 1997) supports this assumption, but the BC and SDFT recorded in this study, show that, unexpectedly, also fat deposition may have had some contribution to this weight gain when it occurred during a period that MY was either constant or increased (Fig 4; the same examples as above). On the other hand, when BW increased, at early lactation, accompanied by a MY drop it could be only as a result of an increase in gastrointestinal fill. This was concluded from the fact that both, BC and SDFT either clearly declined or tend to decline (Fig 4; for example: cow 696 wks 9-13, cow 612 wks 13-17, cow 530 wks 8-12 and cow 599 wks 10-13 pp). So, despite the BW decline because of body reserves mobilization, the BW gain as a result of gastrointestinal fill increase screened the decline as BC loss. From this we may conclude that at early lactation (until peak production) BW loss during MY increase reflects body energy mobilization despite the increase of gastrointestinal fill. BW increase that occurs during MY stability or increase, reflects weight gain as a result of increasing gastrointestinal fill and may indicate about fat deposition. At early lactation, BW gain during a period of MY decline reflects only the increasing gastrointestinal fill while BC declines. The last conclusion contains a contradiction that needs an explanation. If MY declines and BW increases as a result of increasing DMI and consequently gastrointestinal fill, then there is no physiological reason for losing BC. This can be explained by the fact that the BC decline during the period of BW gain is a part of a BC deterioration period longer than the period of BW gain in the cows that lactation curve collapse was observed. In some cows it continues quite far beyond the MY collapse period (Fig 4). This suggests that each of these cows reaches a physiological turning point during which the genetically inherited lactation potential is challenged by a limited adaptation capacity to fulfill it under particular management and environmental conditions. The early stages of lactation for the high yielding dairy cow is characterized by the balance of these two factors; lactation potential and adaptation capacity to express it. When the gap between these two is too big, then not only MY drops, but the cow is pushed into a phase that deteriorates condition and consequently performance and may even impair her health. The period of adjustment as well as the final outcome of it is a result of the following variables: 1) milk production driving force 2) ability to mobilize body reserves 3) capacity to increase energy intake by food. The results of this study are in accordance with previous works that suggest that these three variables can be identified by MY and BW changes that are continuously measured (Maltz *et al.* 1992, Maltz and Metz 1994, Maltz *et al.* 1997, Maltz 1997). In this work this was also confirmed by an objective measurement of SDFT that is a part of the body energy reserves.

The lactation curve collapses are a result of negative energy balance for a period of several weeks (usually in high potential cows) that is not backed up by sufficient body reserves or disability to mobilize them. In the absence of continuous BC measurements, the alarm for approaching this stage is a steep

increasing rate in the MY to BW ratio (Maltz 1997) on one hand, and a decline in BW during a period of MY stability or slight decline on the other. BW increasing or constant during a period of MY increase, reflects a sufficient increase in gastrointestinal fill enlargement resulting from satisfactory DMI increase. From all the above it can be summarized as follows:

A prolonged decline in BW represents always mobilization of body reserves. At initiation of lactation, sharp decline in BW accompanied by a sharp increase in MY intensifies the probability for dangerous negative energy balance and consequently a lactation curve collapse. The curve of the ratio MY to BW was suggested to be the better indicator for that (Maltz 1997). Continuing decline in BW during a phase of MY stability or decline is the first sign of reaching the dangerous level of negative energy balance and lactation curve collapse is expected. A moderate decline or no change in BW during MY increasing phase after calving, indicates body reserves mobilization together with a sufficient DMI increasing rate inducing a gastrointestinal fill increase. Body weight increasing during a period of MY increase, slight decline or no change indicates increase in DMI at early lactation and increase in body reserves thereafter (Table 3).

Table 3 - Statistical parameters, significance and linear regression between SDFT - BC - BW during the period of established lactation.

Cow No.	Period, wk pp	Statistical Parameters	Linear regression between:		
			SDFT - BC	SDFT - BW	BC - BW
696	15 - 51	R P<	0.675 0.0001	0.607 0.001	0.756 0.0001
612	24 - 52	R P<	0.758 0.0001	0.753 0.0001	0.926 0.0001
693	23 - 52	R P<	0.799 0.0001	0.783 0.001	0.856 0.0001
530	19 - 52	R P<	0.755 0.0001	0.721 0.0001	0.89 0.0001
599	22 - 51	R P<	0.446 0.03	0.377 0.07	0.621 0.001
591	24 - 47	R P<	0.059 0.9	0.198 0.4	0.732 0.0001

Conclusions derived from objective 1.

We can conclude that body energy reserves mobilization and deposition fluctuates during lactation along lines of general trends of mobilization and deposition. Continuous MY and BW measurements can indicate about the changes in energy balance of the dairy cow if interpreted properly.

The herd results (USA) as well as average values of individual cows (Israel) correspond with previous studies that BC does not correlate with BW changes during **all** stages of lactation although in general terms, it does. These results were confirmed by individual cow BW and BC data along lactation that were supported by individual objective ultrasonic measurement of SDFT (Israel).

The gastrointestinal content is very likely to be the reason for the temporary contradiction between BW and BC during some periods along lactation.

Objective 2. The effect of variation in digestive fill in early and late lactation on accuracy of BW

General

After achieving objective No. 1, the suggested conclusions regarding the reasons for contradictions between BW and BC changes during certain stages of lactation were tested by including rumen fill content (in USA) in the analysis.

Introduction

Synthesis of milk in early lactation requires dairy cows to adjust their metabolism to balance high energy and protein requirements, for milk production and sometimes growth, with their feed consumption. If the requirements exceed their voluntary nutrient intake, then the cows must mobilize stored nutrients to meet those demands and this makes them susceptible to ketosis which is the most important metabolic disease lowering milk production in early lactation. The incidence of ketosis depends on many factors and often differs from one area to another. One major concern is its diagnosis. Many cows remain untreated because accurate diagnosis in the field is often difficult. Diagnosis may reflect the ability to recognize a clinical or visible signs of the disease and not its true incidence. Dry matter intake (DMI), milk yield, body weight (BW) changes, body condition score (BCS), rumen function, and metabolite concentrations in the blood are among the measurements which reflect the nutrient status and productivity of a cow in early lactation. These parameters have been used in this study to define relationships which may enable the incidence and severity of clinical ketosis to be reduced by improving its early diagnosis and evaluation of potential treatments. In this report only parameters regarding energy metabolism in relation to BC are presented.

Materials and methods

This experiment was conducted using 4 multiparous and 5 primiparous ruminant cannulated Holstein cows. The cows were fed a diet of 57 percent concentrate and 43 percent forage on a dry matter (DM) basis. Dairy milk yield and DMI were recorded from 1 week to 40 weeks postpartum. The milk composition was measured based on samples from 2 consecutive milking 1, 2, 3, 4, 6, and 10 weeks postpartum. Milk protein, milk fat, somatic cell count (SCC), and solids-not-fat (SNF) contents were determined. Rumen contents were emptied on three consecutive days during each week of sampling. Empty BW

(EBW) was estimated using BW, rumen contents, and the assumption that rumen contents represent, on average, 68.6 percent of total gastrointestinal contents during lactation.

Results and discussion

Dry matter intake and rumen DM increased through most of lactation and then decreased after 30 weeks postpartum (Figure 4). Body weight, EBW, and BSC followed similar patterns throughout lactation (Figure 5) and differed between each week postpartum. Empty body weight was a better measure of body reserves than BW itself. This was illustrated by the fact that BW reached a minimum 6 weeks postpartum, but EBW and BCS both reached a minimum at 10 weeks postpartum.

Increased DMI, high quality diets, and moderate milk yields in our experiment probably accounted for ketosis not being observed. Milk yield, milk composition, rumen contents, BW, EBW, and BCS all followed the expected patterns with week of lactation. Stepwise regression indicated that over 90 percent of the variation in EBW could be explained by BW, milk yield, and BCS. The final equation was: $EBW(\text{pounds}) = 1.0606 + .8695 BW(\text{pounds}) - .8395 \text{ Milk}(\text{pounds}) + 8.725 \text{ BCS}$ (1 to 5; 1 = thin, 5 = obese). A subsequent study will address the use of these relationships in the diagnosis and treatment of cows following attempted induction of ketosis in early lactation.

The fact that BW increases, reflects the increase in BC only from certain stage in lactation (Week 10- Figure 6) is confirmed in this work. In addition, rumen fill and gut fill corresponds with dry meter intake throughout lactation therefore BW changes in early lactation can not reflect energy mobilization because its decline is screened by the weight gain contributed by rumen and gut content increase due to that of DMI (Figure 5).

Figure 5 - Body condition score (BCS - *), Milk yield by parity (MY1 - o; MY2 - □), DMI - ◐, and RDM - □, for week 2 through 40 of lactation.

Figure 6 - Body weight (BW - □), empty body weight (EBW - □) and total gut content (●) of seven cows along lactation.

Conclusions derived from objective 2.

BW changes reflect energy metabolism reliably only after peak milk yield; early in lactation, a decrease in BW expresses mobilization of body reserves only qualitatively, and not quantitatively. Gastrointestinal content increases throughout the whole period during which dry matter intake increases. The drastic increase very early in lactation prevents the use of BW changes as a basis for quantitative estimation of energy metabolism; at this stage of lactation, only a BC score or any other direct measurements will provide a quantitative estimate of energy metabolism. Ultrasonic SDFT measurement may provide this objective tool.

Objective 3 & 4: Adaptation, modification and standardization of ultrasonic system and sensors for BC scores

General

The Israeli team was responsible to select, adopted and adjust the best suitable system and methods for subdermal fat thickness (SDFT) measurements. Until this was achieved (end of 2nd year) the US team used sensors and equipment that were previously used in SDFT of beef cattle. After conclusions withdrawn from the work in Israel, the system was adopted in the USA.

Three ultrasonic methods for measuring (SDFT) in different body sites in dairy cow.

1. Image analysis of 5 MHz ultrasonic probe (in USA).
2. Software analysis of RF peaks signal of A-mode (in Israel and USA).
3. Image analysis of 7.5 MHz ultrasonic probe (in Israel and USA).

Background

The body condition (BC) score

The body condition (BC) score is recognized in the dairy industry as a necessary tool for managing the energy reserves of the dairy cow, which is essential for sustaining optimal and efficient production through the various stages of lactation (Edmondson *et al.*, 1989; Ferguson and Otto, 1989; Chilliard *et al.*, 1991). The BC score is based on the subdermal fat thickness at key body locations, and is determined by visual scoring on a 1.0 to 5.0 scale with 0.25-unit steps (Edmondson *et al.*, 1989). Low BC scores usually represent thin cows and higher scores represent those with more subdermal fat. Fat thickness at any of the key sites is correlated with that at other key sites (Edmondson *et al.*, 1989). However, the BC scores represent a subjective, indirect classification and visual evaluation of the subdermal fat content. Standardized BC scoring can be incorporated into a management expert system, together with other animal-status monitoring indicators, such as body weight (BW), milk yield, etc. (Maltz *et al.*, 1992; Grinspan *et al.*, 1994). These indicators have become practical tools for optimizing lactation performance (Spahr *et al.*, 1993).

Ultrasonic sensors have the potential to provide a fast, reliable, repeatable, relatively inexpensive, efficient and nondestructive measurement of subdermal fat along the back, loin, rump and pin bones, which are the main locations currently used for assigning visual BC scores.

Ultrasound pulse-echo measurements of livestock physical composition have been used since the late 1950s. Some early basic work in this area has been described by Johnson *et al.* (1964); it concerns measurement of fat depth in cattle and other animals. The sensors that are normally used to measure fat thickness and muscle area are available off-the-shelf.

Non-destructive evaluation through ultrasonic excitation is widely applied in medicine and in the metal industry. The adaptation of this technology to other areas requires thorough investigation, since special measurement techniques, sensors, modes, standardization and data processing have to be developed. This has been discussed in relation to quality evaluation of food (Mizrach *et al.*, 1989; 1991; 1994) and meat (McLaren *et al.*, 1991; Park and Whittaker, 1991). The B-mode technique was used in a program for improving meat animals; it was discussed by Thane *et al.* (1989), McLaren *et al.* (1991), Park and Whittaker (1991) and others. There is world-wide interest in the use of ultrasound for measurement of body composition in live meat animals (Robinson *et al.*, 1992). Recent publications have discussed the meat industry's interest in the use of ultrasonic technology for improving meat quality (Brethour, 1992; Gresham *et al.*, 1992; Cross and Whittaker, 1992), and principles and potential application of the technology to BC scoring (Whittaker *et al.*, 1992). Park and Whittaker (1991) determined the optimum parameter values for design of a prototype ultrasonic B-mode probe for predicting intermuscular fat on beef carcasses. In beef finishing programs, ultrasound has, at times, been used successfully before slaughter, to predict fat content (Houghton and Turlington, 1992). Measurement of back fat thickness by

means of ultrasonic imaging, for subdermal fat estimation in beef cattle has been successfully performed by Faulkner *et al.* (1990), McLaren *et al.* (1991) and Brethour (1992). BC scoring has been utilized in studies of dairy cattle, to indicate body tissue depletion-repletion during lactation (Garnsworthy and Topps, 1982; Boisclair *et al.*, 1986, Spahr *et al.*, 1993). However, the range of expected fat thickness at each site in dairy cows, the ease of performing ultrasonic fat-thickness measurements at the various sites, and the relations of ultrasonic measurements and BC scores or BW changes have not been extensively researched. Moreover, previous studies in both beef and dairy cattle focused on the general correlation between ultrasonic measurements and subdermal or body fat; no attempts were made to apply the ultrasonic measurement as a tool to monitor changes in subdermal fat layers during a period of time, for cattle in general and for dairy cows in particular. In order to serve as a management tool for dairy cows, the technique must be sensitive enough to follow changes that occur during lactation, in order to identify the stages of fat mobilization or deposition and relate them to production. This requires the solution three kinds of problems: technical, physiological and data analysis.

Technical, physiological and data analysis considerations

All the Technical, physiological and data analysis considerations were described and discussed in the section describing the achievements of objective 1.

The objectives of this study were: to adapt the technology used in general-purpose ultrasonic equipment to a special-purpose unit suitable for determination of BC scores; to develop a standardized method for repeatable determination of BC scores as lactation proceeds; to develop an objective data analysis system; to locate a suitable site on the dairy cow, that responds to fat mobilization and deposition, to enable them to be quantified by ultrasonic measurements.

Effects of stages of lactation and sites of measurement of subdermal fat on BC score in dairy cows, using 5-MHz ultrasonic Pie medical Scanner - USA

Materials and methods

Subdermal fat, repeatedly measured on 32 lactating dairy cows, was used to determine effects of stages of lactation, sites of measurement, and relationship with body condition score (BCS) during weeks 1, 7-8, 14-16, 22-24, and 30-32 postpartum. Subdermal fat was measured at loin (5 cm from mid line), over hip, and pin bone with ultrasound (Scanner 480, Pie medical equipped with a 5-MHz transducer). Data were analyzed as split-plot with location as main effect and week as subplot. Regression analysis was used to predict BCS from subdermal fat at different body sites at each stage of lactation and combined across stages.

Results and discussions

Differences in subdermal fat occurred due to stage of lactation at all body sites. Least squares means (LSM) for fat thickness at the body sites were 191, 205, 204, and 196 cm for hip thurl, loin, and pin bone. Hip was less than thurl or loin ($P < .01$). Combined regression analysis within each stage of lactation to predict BCS from ultrasonic fat thickness at the four body sites resulted in $R^2 = .18$ with fat thickness at loin being the only significant variable. Separate regressions at each stage of lactation failed to yield a consistent pattern for most important variables among the various sites of measurement for prediction of BCS. Partial correlation's were; loin-thurl .59; loin-hip. 22; loin-pin bone .42; hip-thurl .28; hip-pin bone .23; and thurl-pin bone .50. Correlation's between BCS and subdermal fat measurements were: loin .32; hip .04; thurl .33; and pin bone .17. The limited relationship between these measurements and BCS resulted in high errors for prediction of body condition score. Loin was the best single location for predicting BCS from subdermal fat thickness, It was concluded that subdermal fat in dairy cows was so sparse that predictions of accurate BCS from the ultrasonic values obtained with this method were not feasible.

Ultrasonic assessment of body condition changes of the dairy cow during lactation using B-scan 7.5-MHz ultrasonic scanner - Israel

Materials and methods

The materials and methods were described and discussed in the achievements of objective 1 section.

Results and discussion

Video images and analysis

Typical A-mode and B-mode video images taken from the rear back and rib sites are presented in Figure 2. The bow-shaped B-mode scanning sector is shown in the upper part of the video screen while the selected central A-mode ray appears in the lower part. The first two echoes (designated as artifacts, see above) appeared clearly in all records regardless of the image quality. From the measurement procedure and the appearance sequence of these echoes it was concluded that these are built-in artifacts and that the distance between the 2nd echo (point b, Fig. 2) and the 3rd significant peak (point c, Fig. 2) was the width of the gel layer formed by the probe holder (Fig. 1). These two artifact echoes (Fig. 2, peaks a and b) were used as indicators of the 3rd echo (Fig. 2, peak c), which represented the skin surface. The skin surface echo was the best defined, and usually had the highest peak amplitude (peak c, Fig. 2). The subdermal fat (between skin and muscle) was not a homogeneous layer but comprises into sub-layers bounded by connective tissues. In the preliminary tests, it could be seen that some of these layers were skin-attached and some were muscle-attached. Peak d (Fig. 2) represents the membranes between skin and muscle-attached fat layers, while peak e (Fig. 2) represents the membranes of muscle-attached fat and

muscle. All echoes between peaks c and e (Fig. 2) represented the skin membranes (peaks c1 and c2) and fat layers, of which the best defined echo (peak d, Fig. 2) was from the border between skin-attached and muscle-attached fat. In the preliminary study mentioned above, the skin thickness was measured directly in several sites and was found to be uniform. This was confirmed by the ultrasonic scanning. For example, the measurements presented in this study, from all seven points in the back site in two of the cows, during 47 weeks, showed skin thicknesses of 4.1 mm with SD=0.3 and of 4.5 mm with SD=0.3, respectively (distance between peaks c and c2, Fig. 2). Hence, all our analyses are based on the combined thickness of subdermal fat and skin. The data were analyzed separately for skin plus skin-attached fat (between peaks c and d, Fig. 2) designated as “layer I” and skin plus skin-attached and muscle-attached fat (between peaks c and e, Fig. 2) designated as “layer II”.

Suitability of sites and points for ultrasonic measurements.

The range of variation of subdermal fat thickness between the two measurement sites and between points in each of them amounted to 20-30%. This holds for either of the fat layers considered: skin-attached or skin-and muscle-attached fat layers. Nevertheless, a considerable correlation ($R^2 = 0.7540$ when one exceptional cow was excluded) was found between subdermal fat thickness and BC, of a discrete measurement point in the first week after calving as is shown in Fig 7.

Figure 7 - Regression between body condition (independent variable) and skin plus skin-attached fat thickness measured by ultrasound (dependent variable), of a single point on the rump of six cows, immediately after calving. Cow 591 is exceptional, and was not included in the regression.

Because of the small number of cows (limited by the nature of this study) the exceptional cow (Fig. 7) distorts the correlation results. Exceptional cows can be seen in other studies that indicate a correlation

between ultrasonic subdermal fat measurements and BC (Brethour, 1992; Domezq *et al.*, 1995). It is reasonable to assume that if we had used a larger number of cows, we would have achieved similar results to those of Brethour (1992) and Domezq *et al.* (1995). Since the purpose of the present study was to record BC and ultrasonic measurements throughout lactation for the same cow, the correlation among cows is of minor significance.

Area averages of each site in the first week after calving, showed in a much lower correlation than that presented in Figure 7. This emphasizes the variations in the subdermal fat thickness within each site, despite the small distances between the points, as described above. This fact may be of major significance in trying to monitor changes in a single cow during lactation if the whole area of the subdermal fat layers in the site does not respond simultaneously to fat mobilization and deposition (see below).

Changes in subdermal fat thickness during lactation

The visual BC assessments of the cows ranged from 1.75 to 3.5 immediately after calving (Fig. 7) and from 2.75 to 3.75 when drying off. The lowest BC observed was 1.50 in two cows at peak lactation.

Layer I was usually well defined and was picked up easily by the algorithm throughout lactation (n value in Table 4). Layer II was far less defined because of the difficulty in locating it (peak e, Fig 2; n value in Table 4), especially in the between-ribs site (Table 4), which reduced the amount of data available for analysis of this layer. Table 4 summarizes the R^2 and correlation significance, P, of all available data of each point in each site, and of site averages, when BC is the independent variable and the thickness of layers I and II are the dependent ones (each separately). It can be seen that the between-ribs site was far more responsive than the back site to changes in BC during lactation. In one cow (693) the back site was useless in detecting BC changes by this method (Table 4). In the back site, the majority of the points did not respond to BC changes and those that did, usually demonstrated a low significance of response. In the points of the back site which gave responses, layer I was more responsive to BC changes than layer II. Layer II could not always be defined, especially in the rib site; in fact, in one cow (591), no layer II data could be obtained in the rib site. However, whenever it could be defined, layer II in the rib site was more responsive to BC changes than layer I, despite less data being available (Table 4). Site averages did not improve the correlation significance in comparison with the "best point" in either site (Table 4). For five of six cows, one of the points (point 8) in the rib site yielded a significant correlation between the ultrasonic layer measurements and the visual BC during lactation (Table 4); in the sixth cow (612), it was the neighboring point (point 9, Table 4). All this shows that the site of measurement is a crucial factor in assessing BC changes by this method, and this may be the result of uneven response of subdermal fat to energy balance. In addition, it seems that successive measurements at a single point, when performed as described above, are sufficient to monitor BC changes during lactation. This is especially true for the points closest to the spine in the between-ribs site (points 8 and 9). It is reasonable to assume that there may be even better sites for assessing BC changes by ultrasound, but these have yet

to be defined. We must bear in mind that the correlations described above were affected by the subjectivity and limited sensitivity which characterize the traditional BC assessment method used in this study, and it is very likely that the ultrasonic method demonstrated in this study is actually more accurate than the above analysis indicates. If we had had a more objective and sensitive technique against which to compare the ultrasonic method, we might have obtained better correlations. Measurements of BW changes are the only objective measurements available with which BC can be compared, but, despite the fact that, in general, BW changes correlate with those of BC throughout lactation, it was found that it is only in late lactation that this correlation is not screened by other physiological factors, such as changes in the gastrointestinal tract and its contents (Maltz *et al.*, 1997). It is, therefore, best to compare the ultrasonic results with those of BW measurements in late lactation. Figure 4 shows that the results of ultrasonic subdermal fat thickness measurements follow a similar pattern to those of the physiological changes, through lactation: a decline during early lactation with a trough corresponding to peak production, followed by an increase till dry off. It can also be seen from Figure 4 that from week 20 after calving, the ultrasonic measurements correlate with those with BW. Table 5 summarizes the regression results of BW as the independent variable and ultrasonic measurements as the dependent ones, for the selected points from Table 4 and site averages. The results confirm the findings described above. The between-ribs site is more responsive to fat mobilization than the back site. In the former site, layer I gave significant responses and one point in this site is sufficient to detect BC changes. In all the cows except one, this point was the nearest to the spine.

Figure 8 - Changes in body weight (●), visual body condition score (Δ), ultrasonically measured skin plus skin-attached fat layer of the point nearest to the spine in the rib site (point 8, □), and ultrasonically measured thickness of skin plus skin-attached and muscle-attached fat layers (point 11, ×), of cow 696.

The results obtained in Israel showed that this technology is superior to the traditional way of measuring ultrasonic SDFT used for beef cattle and applied in dairy cows. Therefore, the equipment and know-how were transferred to the US to be applied.

Table 4 - Regression coefficient, significance and number of data points for all points and for point averages, of rib and rump sites for all cows. Visual body condition score was the independent variable, ultrasonically measured skin plus subdermal fat thickness were dependent variables. Skin plus skin-attached fat was designated as layer I, Skin plus skin-attached and muscle-attached fat was designated as layer II.

Cow No.	Layer	Statistical Parameters	Rump Site - Point No.							Ribs Site - Point No.							Avg. 8-12
			1	2	3	4	5	6	7	Avg 1-7	8	9	10	11	12		
696	I	R ²	0.0081	0.0804	0.1533	0.0487	0.0118	0.0488	0.1294	0.0695	0.5276	0.3889	0.3481	0.3151	0.3476	0.5532	
		P	ns	ns	*	ns	ns	ns	*	ns	***	***	***	***	***	***	
	II	R ²	0.0397	0.0254	0.0003	0.0024	0.0181	0.0004	0.0099	0.0138	0.5081	0.5786	0.6848	0.7241	0.6779	0.6392	
		P	ns	ns	ns	ns	ns	ns	ns	ns	*	*	**	***	***	***	
530	I	R ²	0.0123	0.1487	0.204	0.1721	0.033	0.0549	0.0466	0.0716	0.5055	0.1528	0.3928	0.321	0.2959	0.4534	
		P	ns	ns	**	*	ns	ns	ns	ns	**	ns	*	*	*	**	
	I	R ²	5E-06	0.0243	0.2816	0.0926	0.09	0.0108	0.1344	0.1244	0.0561	0.1757	0.13	0.0525	0.1772	0.1235	
		P	ns	ns	**	*	*	ns	*	*	ns	ns	ns	ns	*	ns	
591	I	R ²	0.2844	0.1391	0.1088	0.0531	0.0828	0.5542	0.033	0.2105	0.3822	0.089	0.2133	0.2976	0.1921	0.3349	
		P	*	ns	ns	ns	ns	***	ns	*	**	ns	ns	*	*	**	
	II	R ²	0.0485	0.0689	0.2477	0.0078	0.1298	0.1495	0.0694	0.1544	-	-	-	-	-	-	
		P	*	ns	ns	ns	ns	*	ns	ns	-	-	-	-	-	-	
693	I	R ²	0.2227	0.0011	8E-06	0.0018	0.0372	0.0454	0.017	0.008	0.1797	0.1061	0.1451	0.077	0.1277	0.0731	
		P	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	*	ns	*	ns	
	II	R ²	0.2129	0.0084	0.009	0.0251	0.0325	0.0426	0.0324	0.1519	0.043	0.2012	0.245	0.1245	0.4553	0.2938	
		P	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*	*	**	*	
599	I	R ²	0.1067	0.0272	0.01	0.0002	0.0065	0.0728	0.0032	0.0158	0.4415	0.2597	0.1061	0.0411	0.0017	0.3362	
		P	ns	ns	ns	ns	ns	*	ns	ns	***	***	*	*	ns	***	
	II	R ²	0.1072	0.0877	0.0156	0.0491	0.0202	0.0007	0.0047	0.0258	0.2025	0.2188	0.7262	0.706	0.6009	0.6009	
		P	ns	ns	ns	ns	ns	ns	ns	ns	*	*	***	***	***	***	
612	I	R ²	0.0106	0.1398	0.0024	0.1326	0.1337	0.4166	0.4536	0.191	0.0565	0.2152	0.0692	0.408	0.0455	0.1985	
		P	ns	*	ns	*	*	***	***	**	ns	**	*	***	ns	**	
	II	R ²	0.0001	0.1003	0.0041	0.0302	0.0219	0.1145	0.2135	0.095	0.3973	0.6046	0.3247	0.427	0.6353	0.3453	
		P	ns	ns	ns	ns	ns	*	**	*	**	**	**	**	***	**	
		n	30	34	36	38	39	37	33	45	9	10	10	15	14	25	

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*

- P < 0.0005
- P < 0.005
- P < 0.05

Table 5 - Regression coefficient, significance and number of data points during the period following the body weight trough, of selected points, and points averages in the rib and rump sites for all cows. Body weight score was the independent variable, ultrasonically measured skin plus subdermal fat thickness were the dependent variables. Skin plus skin-attached fat was designated as layer I, Skin plus skin-attached and muscle-attached fat was designated as layer II.

Cow No. Interval (weeks) From: To:	696				530				591				693				599				612			
	I		II		I		II		I		II		I		II		I		II		I		II	
Point	Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.	
No.	1-7		8-12		1-7		1-7		1-7		1-7		1-7		1-7		1-7		1-7		1-7		1-7	
R ²	0.0248		0.0633		0.0854		0.0673		0.5271		0.2705		0.1468		0.0276		0.0809		0.0044		0.0673		0.0111	
P	ns		ns		ns		*		**		**		*		ns		ns		ns		*		ns	
n	14		14		24		24		24		26		16		18		15		17		11		13	
Point	Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.		Avg.	
No.	1-7		8-12		8		8-12		8		8-12		--		--		8		8-12		11		8-12	
R ²	0.6289		0.6881		0.527		0.4869		0.7947		0.7086		--		--		0.3950		0.2151		0.6646		0.5213	
P	***		***		***		*		***		***		***		***		**		*		**		**	
n	14		14		24		7		24		24		24		8		18		18		4		7	

*** - P < 0.0005
 ** - P < 0.005
 * - P < 0.05

Potential for developing a sensor to measure body condition score in dairy cattle - US trail applying the technique and equipment used in Israel

Procedure

We formed a team with scientists from Israel, using an approach that allowed the measured ultrasonic values to be digitized, and, as a long range goal, automatically analyzed by a computer system for rapid interpretation. The specific goals of our studies were to: 1) determine the overall feasibility of the proposed technique; and 2) to determine which body sites were the optimum locations to measure subdermal fat thickness.

Several technical problems were associated with adapting the equipment for the approach that we used. Our desire was to measure and digitize a cross section of the subdermal fat layer. We obtained a small 7.5 MHz probe, and had the instrument modified to allow the peaks of different tissue densities to be identified automatically by a special algorithm. This approach was to allow many measurements to be analyzed rapidly by a computer.

We followed body weight changes, BCS, and subdermal fat thickness at 14-day intervals between week 7 pre-calving to 120 days post-calving in five cows. Ultrasonic measurements were obtained between the 12th and 13th rib, at the loin between the 3rd and 4th transverse process and 5 cm from the vertebrae, and on the center of the rump.

Results

We were able to develop an algorithm that successfully separated skin thickness and subdermal fat thickness, Figure 2. This accomplishment was particularly useful since individual cows have their individual skin thickness that is difficult to differential from subdermal fat thickness. We found in dairy cattle, that the "body condition" is partly a function of fat that is dispersed in interstitial tissue instead of a definite layer of fat as occurs in beef cattle or swine. As a result, all body sites showed slight differences, but we concluded that any of the body sites that we tested were acceptable. The ultrasonic system was able to measure changes in subdermal fat thickness that corresponded to body weight changes and body condition scores along lactation. Patterns of subdermal ultrasonic measurements in fat and thin cows were able to differentiate between the classes of BCS, Table 6.

Conclusions

We concluded that the use of digitized cross sections of ultrasonic scans, followed by identification and measurement of subdermal via an algorithm for analysis of peak values, was a promising method for development of a sensor for scoring body condition in dairy cattle. The method removes most of the subjectivity of BCS scoring, but substantial development still is to occur to reduce the time required for

data collection (for example, a robotics sensor that could scan the cows in the milking parlor) before expecting a commercial ultrasonic sensor for scoring cows for BCS automatically.

Table 6 - Body condition score and subdermal fat thickness at 3 body sites for fat and thin cows, 3 weeks before calving.

Variable	Subdermal Fat Thickness, mm	
	Thin cow	Fat Cow
BCS	2.0	3.5
Subdermal Fat, mm		
Rib	4.4 $\pm$ 0.2	6.4 $\pm$ 0.7
Loin	3.5 $\pm$ 0.2	5.2 $\pm$ 0.2
Rump	4.8 $\pm$ 0.1	7.4 $\pm$ 0.1
All Sites	4.0 $\pm$ 0.1	5.7 $\pm$ 0.1

Conclusions derived from objective 3 & 4.

Ultrasonic measurements of subdermal fat thickness can be used to quantify changes that correlate with the actual condition of the cow as assessed by performance and the traditional way of scoring. The use of templates made it easier to repeat measurements at a desired site and spot. The data-processing algorithm applied to the stored A-mode signals easily identified the skin and subdermal fat layers but should be improved to resolve the complicated composition of fat attached to skin and to muscle. Standardization of measurements in terms of site and exact location of the point for successive measurements, seems to be a major problem; before we proceed to sensor development, substantial work has to be done in locating a site that, on the one hand, can be easily and precisely located, and on the other hand, has a measurable response.

The use of digitized cross sections of ultrasonic scans, followed by identification and measurement of subdermal via an algorithm for analysis of peak values, was applied in a series of studies in the USA and were found as a promising method for development of a sensor for scoring body condition in dairy cattle. The method removes most of the subjectivity of BCS scoring, but substantial development still is to occur to reduce the time required for data collection (for example, a robotics sensor that could scan the cows in the milking parlor) before expecting a commercial ultrasonic sensor for scoring cows for BCS automatically.

General Project Conclusions:

1. Ultrasonic measurements of subdermal fat thickness can be used to quantify changes that correlate with the actual condition of the cow, as assessed by performance and the traditional way of scoring.
2. To find the best site on the cow's body at which to obtain responses to BC and its changes along lactation, additional sites have to be examined. From the present study, it seems that the sites between ribs 12 and 13 has the potential for this purpose.
3. The use of templates made it easier to repeat measurements at a desired site and spot. However, the convenient easy-to-handle way to standardize the measurement, described in this study, offers scope for improvement.
4. The RF peak values of the A-mode are better indicators of the location of fat layer borders than image analysis, from the point of view of future commercial development.
5. The distances between the RF peaks of the A-mode can be automatically measured by suitable software, for future commercial development.
6. Proper analysis of daily body weight and milk yield data can provide the necessary information on body condition changes during lactation, until a direct BC measurement device is developed.
7. In any case, at least one visual BC assessment has to be done, preferably immediately after calving, for calibration purposes.

List of Publication Resulting from the Research

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Ultrasonic Body Condition Measurements For Computerized Dairy Management Systems
Bard project No. IS-2181-92R

Description of Cooperation

This BARD project was proposed as a joint effort between the University of Illinois, USA and the ARO at Volcani Center, Israel. This joint effort follows two previous BARD projects between the two institutes in which Prof. Spahr and Dr. Maltz (two of the present BARD project cooperators) took part in the initial study development of the automated nutrition decision aid.

The Israeli team was responsible to select, adopted and adjust the best suitable system and methods for subdermal fat thickness (SDFT) measurements. Until this was achieved (end of 2nd year) the US team used sensors and equipment that were previously used in SDFT of beef cattle. After conclusions withdrawn from the work in Israel, the system was adopted in the USA.

Both teams worked on the energy balance aspects (each team on different aspects) of the dairy cow that result in the BC changes that were measured ultrasonically. This yielded the use of available on-line performance data for on-line energy balance assessment until an automatic, easy-to-use device is developed for BC measurements.

Prof. Spahr visited the ARO in the 1st stages of the project to coordinate day to day aspects of the on coming work. Dr. Mizrach had spent a sabbatical at the University of Illinois with the US cooperators and took part in experimental work and data processing. During his staying, Dr. Mizrach studied progressive methods in ultrasonic measurements and diagnosis of meat quality together with Profs. Spahr and Novakofski. Drs. Maltz and Flitsanov had visited at the University of Illinois during 2nd year of the research. They had brought with them the ultrasonic equipment, hardware and software which was developed in Israel and had taken part in an intensive experimental work together with the US team. The jointed team, used an approach that allowed the measured ultrasonic values to be digitized, and, as a long range goal, automatically analyzed by a computer system for rapid interpretation. The equipment from Israel was left for another year, in the University of Illinois, allowing the US team to use it afterward.