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Swedish University of Agricultural Sciences
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Automatic Body Condition Scoring on Dairy Cows of the Swedish Red breed

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Automatisk hullbedömning av mjölkkor av rasen svensk röd och vit boskap

Gabriella Foschi

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PREFACE

This MSc thesis was requested by DeLaval and conducted in the summer and autumn of 2009 at the Kungsängens Research Centre in Uppsala at the Department of Animal Nutrition and Management. The MSc thesis was conducted as a collaboration project between the Swedish University of Agriculture (SLU) in Uppsala and the company DeLaval in Tumba. Supervisors were provided both from SLU; Sigrid Agenäs and Christopher Harold Knight and from DeLaval; Ole Lind and Liao Bohao. The MSc examiner, Jan Bertilsson, was provided by SLU, the Department of Animal Nutrition and Management.

The main objective of this MSc thesis was to investigate parameters reported to be associated with body condition and change in body condition and suggest a valid reference in the development of a 3D imaging based automatic body condition scoring model.

Uppsala in Januari 2010.

Gabriella Foschi

ABSTRACT

The objective of this MSc thesis was to investigate parameters reported to be associated with dairy cows' body condition and its changes. A valid reference of a dairy cow's body condition was to be suggested and investigated for suitability in the development of a 3D imaging based automatic body condition scoring model. Furthermore, it was important to accumulate data to use in training (adjustment of the algorithm mathematics) of the 3D imaging based automatic body condition scoring model. The study included 21 dairy cows of the Swedish Red breed from the herd at the Kungsängen Research Centre in Uppsala. The cows had access to an exercise pen and were fed silage and concentrates indoors according to the Swedish feeding recommendations, based on individual milk yields. Data was collected weekly from May to August 2009 and included live weight, manual body condition score, backfat thickness, 3D images, milk yield, content of fat, protein and lactose in milk and the plasma metabolites non esterified fatty acids and β-hydroxybutyrate. Data was analysed by linear correlation and regression analysis. Of all individually investigated collected parameters, backfat thickness was found to have the highest correlation with manual body condition scores and this parameter was therefore suggested and used as an alternative true reference of body condition in the training of the 3D imaging based automatic body condition scoring model. Results were promising and it was concluded that it is possible to train and calibrate the 3D imaging based automatic body condition scoring model both with manual body condition scores and with backfat thickness as reference, to predict the dairy cow's body condition. The advantage in using backfat thickness would be that it is a more objective measure and that it gives continuous data instead of the categorical data obtained from manual body condition scoring. If sufficient sensitivity is obtained in the automatic body condition scoring model it could alert the farmer to changes in the cow's body condition, instead of only recording the body condition after a change. Future studies should focus on developing this function in the automatic body condition scoring models since it would add significant value to dairy management systems.

Key Words: dairy cow management, automatic body condition score, three dimensional imaging, ultrasonography

SAMMANFATTNING

Syftet med detta examensarbete var att undersöka parametrar kopplade till mjölkors hull och förändring i hull. En referens för mjölkkors hull skulle föreslås och dess lämplighet undersökas i utvecklingen av en 3D-bild baserad automatisk hullbedömningsmodell. Därutöver var det viktigt att samla data för att använda i träningen (justering av algoritmens matematik) av den 3D-bild baserade automatiska hullbedömningsmodellen. Studien inkluderade 21 kor av Svensk röd och vit boskap och utfördes vid Kungsängens Forskningscentrum i Uppsala. Under studien hade korna tillgång till en rastfålla och de utfodrades inomhus med ensilage och kraftfoder. Data samlades in en gång per vecka från Maj till Augusti 2009 och innefattade mätningar av levande vikt, manuell hullbedömning, underhudsfetts tjocklek, 3D bilder, mjölkavkastning, mjölkens sammansättning (protein, fett och laktos) och plasmametaboliterna fria fettsyror och β-hydroxybutyrat. Insamlade data analyserades genom linjär korrelation och regressionsanalys. Av alla parametrar visade sig underhudsfettets tjocklek vara starkast korrelerad med manuell hullbedömning och föreslogs därför som referens för mjölkkors hull. Underhudsfettets tjocklek användes som referens i träningen av den 3D-bild baserade automatiska hullbedömningsmodellen. Resultaten var lovande och slutsatsen drogs att det är möjlig att träna och kalibrera den 3D-bild baserade automatiska hullbedömningsmodellen för att uppskatta mjölkkors hull med underhudsfettstjocklek som referens. Fördelen med att använda underhudsfettets tjocklek som referens för mjölkkors hull, istället för manuell hullbedömning, är att den erbjuder en mer objektiv och kontinuerlig typ av data. Automatiseringen av hullbedömningen avlägsnar subjektivitet och minskar arbetsbördan samt möjligen ger tillfället att tidigare upptäcka när förändringar i mjölkkors hull inträffar, tack vare högre känslighet. Detta skulle underlätta beslutsfattandet kring djurens skötsel för bonden.

Nyckelord: mjölkkors skötsel, automatisk hullbedömning, tredimensionell avbildning, ultrasonografi

CONTENTS

LIST OF ABBREVIATIONS

2D - Two Dimensional

3D - Three Dimensional

ACS - Automatic Body Condition Score

BCS - Body Condition Score

BFT - Subcutaneous Back Fat Thickness

BHBA - β-Hydroxibutyrate

CP - Collected Parameters

CPΔ - Collected Parameters' Change

CPT - Collected Parameters Delayed in Time

DM - Dry Matter

EB - Energy Balance

ES - Experienced Scorer

F:L - Fat to Lactose Ratio

F:P - Fat to Protein Ratio

IS - Inexperienced Scorer

ME - Metabolizable Energy

NEFA - Non Esterified Fatty Acids

NEB - Negative Energy Balance

RFT - Rib Subcutaneous Fat Thickness

TOF - Time-of-Flight

SFT - Sacral Subcutaneous Fat Thickness

SRB – Swedish Red Breed

VMS - Voluntary Milking System

INTRODUCTION

The most practical and accepted method for assessing body reserves in several animal species, dairy cows included, is manual body condition scoring. Body condition scoring is a numerical system where numbers, body condition scores (BCS), are given to describe the shape of the body. In bovines it is usually the rear area that is used to estimate body reserves, primarily fat and to lesser degree muscle reserves. Body condition scoring effectiveness, validity and accuracy, for assessing body reserves in dairy cows, have been repeatedly recognized (Edmonson et al., 1989; Fergusson et al., 1994; Kristensen et al., 2006).

In general a decrease in BCS can be observed in early lactation as the cow uses body reserves to support milk production. In the remainder of the lactation BCS usually increases again until body reserves are restored (Bewley and Schutz, 2008). For most mammals, the fluctuation in body condition is an inborn drive and will occur independently of environmental conditions (Friggens, 2003). This strategy to support milk production by using body reserves has its ground in evolution and is a mean to provide milk for the newborn, independently of food availability (Pond, 1984; Wade and Jones, 2004). The degree of reliance on tissue mobilization to support early lactation varies between mammalian species from being total, e.g. fur seals which lactate on fasting conditions (Oftedal, 2000), to being partial, e.g. dairy cows which combine energy from both body reserves and available foods (Stockdale, 2001).

Extremes in body condition i.e. fatness and emaciation, are to be avoided (Roche, 2006). Both absolute BCS, especially at calving, and BCS changes in early lactation have implications on production, reproduction, health and overall farm profitability (Bewley and Schutz, 2008). Therefore, one of the many tasks of dairy managers is to monitor cow body condition carefully in order to reduce the occurrence of problems. Nevertheless, as body condition scoring is time consuming and subjective, the application of this method as a recurring practice has not been ordinarily adopted on farm level (Bewley and Schutz, 2008). Research focusing on body condition scoring has involved its connection to several subject fields, including nutrition (Ryan et al., 2002; Beever et al., 2006), reproduction (Markusfeld et al., 1997; Hoedemaker et al., 2009) and genetics (Berry et al., 2002; Berry et al., 2003). Continued emphasis on the effects of body condition on reproduction and health, especially at transition from pregnancy to lactation, has renewed the interest in the topic (Kristensen et al., 2006). Today, new methods and technologies to better use information of BCS and its changes are needed and being developed. Ongoing research is aiming at automating dairy cows' body condition scoring systems. Reported attempts include the utilisation of thermal imaging (Keren and Olsson, 2007; Halachchmi et al., 2008; Halachmi et al., 2009) and digital imaging, which includes both 2 dimensional (2D) and 3 dimensional (3D) imaging (Pompe et al; 2005; Leroy et al., 2005; Fergusson et al., 2006; Beley et al., 2007; Krukowski, 2009). Reports state that automatic body condition scoring models need to be calibrated by using valid references of body condition and its changes (Halachmi et al., 2009). Therefore, the aim of this MSc thesis was to investigate parameters reported to be associated with body condition and change in body condition and suggest a valid reference in the development of a 3D imaging based automatic body condition scoring model. Furthermore, it was important to accumulate data to use in training of the 3D imaging based automatic body condition scoring model.

BIOLOGICAL BACKGROUND

The partitioning of nutrients during pregnancy and lactation, particularly during the transition from pregnancy to lactation i.e. the transition period (2-3 weeks prepartum to 2-3 weeks postpartum), involves great physiological challenges for the homeostatic and homeorhetic mechanisms (Table 1) of the dairy cow (Bauman and Currie, 1980). These challenges consist in that, at transition, the nutrient demands imposed on the dam are significantly increased (Bauman and Currie, 1980; Bell, 1995; Ingvartsen, 2006). In late pregnancy, the mammary gland is developed in order to prepare for lactation. At the same time, the foetus grows rapidly. At calving and in early lactation further demands are imposed by the mammary gland for production of colostrum and thereafter of normal milk (Bauman and Currie, 1980; Bell, 1995).

High producing dairy cows in early lactation are unable to meet energy and nutrient requirements for maintenance and milk production through their feed intake (Jorritsma et al., 2003). To meet imposed demands for nutrients, particularly of glucose, the dairy cow mobilises body reserves, mainly lipids but also smaller amounts of proteins and minerals (Phillips, 2001; Jorritsma et al., 2003). These metabolic adaptations are controlled by the endocrine system and mirror a resetting of important cellular functions as well as they are themselves reflected in a pattern of decreasing body condition observed in this period. Thus, there is a complete change in adipose tissue metabolism in early lactation with lipolysis, rather than lipogenesis, being dominant. The increased lipolysis is caused by decreased blood insulin, increased activity of the sympathetic nervous system within adipose tissue and increased adipose tissue sensitivity to lipolytic signals (Chilliard et al., 2000; Bewley and Schutz, 2008). Lipolysis of adipose tissue triglycerols and reesterification of fatty acids result in increased blood levels of non esterified fatty acids (NEFA) (Adewuyi et al., 2005). NEFA are very important in the adaptation of other body tissues to the decreased glucose availability, since they provide energy substrates after being converted in the liver. In the liver, NEFA can follow several metabolic pathways. They can be fully oxidized to provide energy for the liver itself, partially oxidized to produce energy fuels as ketone bodies such as acetoacetic acid, acetone and β-hydroxybutyrate (BHBA) for use by body tissues and can also be reconverted to triglycerides. These are either stored or released into the circulation as very low density lipoproteins (Vernon, 2005; Adewuyi et al., 2005; Ingvarsten, 2006).

The magnitude of the mobilization of adipose tissue in dairy cows is a function of amount of body fat reserves and the energy balance (Chilliard et al., 2000). The latter is defined as energy intake minus energy output for maintenance and milk production (Spörndly, 1995). The net deficiency in energy resulting from the discrepancy between feed energy input and energy output for milk production is termed negative energy balance (NEB). The postpartum NEB is typically reduced and reversed to a positive energy balance in mid lactation, as dry matter intake increases (Figure 1). However the speed of recovering maximum dry matter intake and positive energy balance can vary between individuals, e.g. depending on the magnitude of fat mobilised in early lactation.

Body Condition and Partitioning of Adipose Tissue

Mobilisation of body reserves may result from physiological increases in nutrient use, as in early lactation, but also due to limitations in energy supply (Chilliard et al., 1998). Limitations in energy supply might occur if husbandry standards are poor, if farm profitability is low or if fast changes occur within the industry (Agenäs et al., 2006). If energy intake instead exceeds the demands, energy is deposited as adipose tissue. Fat deposition is common in late lactation and during the dry period (Fronk et al., 1980).

Adipose tissue is partitioned across four major fat depots: subcutaneous, perinephric, omental, and intra- as well as intermuscular fat depots (Warriss, 2000). The proportion of total body fat in each fat depot varies between species and between breeds within species, including breeds of cattle. Breeds of dairy cattle tend to have proportionally less subcutaneous fat and more omental fat than breeds of beef cattle (Jones et al., 1980; Butler-Hogg and Wood, 1982; Wright and Russel, 1984). Wright and Russel, (1984) suggested that a given BCS can result in differences of total body fat amounts, depending on the cattle breed scored.

For dairy cows, a curvilinear relationship between BCS and total body fatness has been reported (Gregory et al., 1998; Gillund et al., 1999). Further, Butler-Hogg et al. (1985) investigated the lability of fat depots during lactation and found subcutaneous fat depots, including rib subcutaneous fat, to be the most sensitive to mobilisation, followed by perinephric and omental fat. This is in agreement with Gregory et al. (1998). Gregory et al. (1998) also found that intramuscular fat, subcutaneous fat and combined fat from the remaining depots accounts for 39 %, 25 % and 32 % respectively, of total mobilised body fat, in early lactation. It was suggested that BCS assesses relative, rather than absolute, amounts of mobilised body fat.

Body Condition Patterns

Broster and Broster (1998) stated that dairy cows generally experience a decrease in BCS of about 0.5 units during early lactation (first 2-4 months) after which follows a gradual recovery of energy reserves in the remainder of the lactation. However, the pattern of condition loss has been reported to differ between cows that have different body condition at calving. In early lactation, fat cows are likely to lose more body weight and condition than thin cows (Garnsworthy and Topps, 1982; Treacher et al., 1986; Pedron et al., 1993; Berry et al., 2002). Additionally, fat cows have been reported to be slower in recovering lost body condition than thin cows, which have an increase in body condition right after calving (Garnsworthy and Topps, 1982). Body condition patterns, besides being affected by management and nutrition, are also affected by age (Koenen et al., 2001), parity (Friggens et al., 2007a) and breed factors (Rastani et al., 2001; Mao et al., 2004).

Body Condition, Health and Reproduction

Over-conditioned dry cows calving at a high BCS seem to be more prone to be affected by metabolic diseases at transition and early lactation, such as ketosis (Gillund et al., 2001), fatty liver (Fronk et al., 1980), milk fever (Heuer et al., 1999) and displaced abomasum (Cameron et al., 1998). Ketosis, fatty liver, milk fever and displaced abomasum are diseases aetiologically inter-related (Roche, 2006; Mulligan et al., 2008). Because of their inter-relationship, metabolic diseases can cause a course of events leading to increased occurrence of other difficulties or diseases e.g. related to reproduction, such as retained placenta and endometritis (Roche et al., 2006). Thus, as a consequence metabolic diseases can affect cows' health over longer periods (Mulligan et al., 2008) and increase predisposition to gynaecological diseases (Roche, 2006).

Being more prone to diseases, cows calving at higher BCS may show changed reproductive performance. Reproductive performance has been found to be related to NEB (Domecq et al., 1997) low BCS at insemination, increased BCS loss in early lactation and BCS at calving (Roche et al., 2006). Markusfeld et al. (1997) reported that cows calving at higher BCS experience reduced fertility, manifested as repeated breedings per conception. Reduced fertility in association with increased loss of BCS in early lactation has been reported to manifest as delayed first estrus (Garnsworthy and Topps, 1982; Roche et al., 2006), prolonged days open (Lopez-Gatius et al., 2003; Roche et al., 2006) and increased days to first service (Ill-Hwa and Gook-Hyun, 2003).

Body Condition and Milk Yield

The relation between BCS, or changes in BCS, and milk production has been investigated in several studies (Pedro et al., 1993; Domecq et al., 1997; Busato et al., 2002), although results have been, as for associations with health and reproduction parameters, variable. Both significant (Waltner et al., 1993; Markusfeld et al., 1997) and insignificant (Pedron et al., 1993; Berry et al., 2007) effects of BCS and especially BCS at calving on the subsequent lactation have been reported. Nonetheless, although results have been inconsistent, in general increasing BCS losses at calving are associated with increased milk yields (Domecq et al., 1997; Berry et al., 2007). The response of milk production to increasing BCS has been suggested to be curvilinear (Waltner et al., 1993; Roche et al., 2006; Berry et al., 2007). Milk production appears to increase within a certain range of BCS at calving, where the highest milk production is coupled to a BCS at calving between 3.25 and 4 and thereafter decreases with increasing BCS at calving (Waltner et al., 1993; Broster and Broster, 1998).

Body Condition and Milk Components

Investigations regarding the association of BCS with milk components, especially fat and protein, have also been carried out (Holter et al., 1990; Stockdale, 2001; Berry et al., 2007). As described by Phillips (2001) "Changes in milk composition over the cow’s lactation reflect the changes in milk yield, energy balance and feeding levels”. Milk fat content is known to decline quickly in the first month of lactation and to increase thereafter throughout the remainder of the lactation (Phillips, 2001). Berry et al. (2007) reported that cows that lost comparably more body condition in early lactation produced milk with higher fat and protein concentrations than other cows. The higher fat concentration was attributed to a greater tendency of overly fat cows to lose body condition in early lactation and use the mobilised body reserves to synthesise milk fat. This phenomenon was also reflected by the composition of milk fat from cows calving at higher BCS, which comprised greater amounts of long-chain and unsaturated fatty acids (Pedron et al., 1993 and Waltner et al., 1993). The association of BCS at calving with milk fat concentration is suggested, as for milk yield, to be curvilinear (Berry et al, 2007). Milk protein content was reported to be minimally affected by BCS and BCS at calving, although a minor decrease in milk protein concentration was observed for cows calving at an overly fat condition, especially observed in cows yielding milk with higher levels of protein, as reviewed by Broster and Broster (1998), which is in agreement with results from a more recent study by Berry et al. (2007).

MEASURES OF BODY CONDITION

There are several methods available to assess energy reserves and energy balance, different methods can be more or less appropriate with regards to costs, time and accuracy if used in research or in the field. Methods include manual body condition scoring, measurements of live weight (LW), ultrasonic assessment of subcutaneous fat thickness, body water dilution, mean diameter of adipose tissue cell size, assessment of metabolic and hormonal factors and post-slaughter chemical analysis of the whole body or weighing of organs and tissues (Edmonson et al., 1989; Waltner et al., 1994; Domecq and Skidmore, 1995; Gregory et al., 1998; Reist et al., 2002; Nielsen et al., 2003). For research purposes, many of these methods provide good data but in the field many of these methods are not suitable as they either require expensive equipment or analysis, are too time consuming or require slaughter. In the field, suggested methods to be used to assess energy reserves in dairy cows are measurements of LW, plasma metabolites, milk composition and ultrasonic measurements of subcutaneous fat thickness (Schröder and Staufenbiel, 2006). Because of difficulties in performance and expenses some of the mentioned methods are less practised in dairy herd management. Nevertheless these methods can be of value in confirming the primary method used in dairy herd management, which is manual body condition scoring (Bewley and Schutz, 2008).

Manual Body Condition Score

Manual body condition scoring is a subjective, numerical system where numbers are given to describe the shape of the body, for bovines usually in the rump and pelvic area, aiming to estimate body fat and to lesser degree muscle reserves (Fergusson et al., 1994; Gregory et al., 1998). The range of the numerical scale varies between countries (Table 2) but commonly ranges between 1 and 5 with 0.25 or 0.5 units of increment (Edmondson et al., 1989; Fergusson et al., 1994; Gillund et al., 1999). Common for all body condition scoring systems are the low and high numbers attributed to emaciated and obese animals respectively (Table 3), although the emphasis on assessed anatomical locations when scoring the animal differs (Gregory et al., 1998). Furthermore, scores are assigned either by visual or palpation assessment which also differs between body condition scoring systems (Roche et al., 2004).

Body condition scoring systems may include all or a few of the main anatomical locations (Appendix 1) assessed when scoring dairy cows (Edmondson et al., 1989; Fergusson et al., 1994; Gillund et al., 1999). The anatomical features most commonly included are located in three main areas (Figure 2); the loin area including the spinous and transverse processes of the lumbar vertebrae, the pelvis area including the tuber sacrale (hook bones) and tuber ischii (pin bones) protuberances, and the tailhead area including the depression of the ischiorectal fossa (depression underneath the tail). All the anatomical locations mentioned are highly correlated with overall BCS ($r > 0.92$). However from behind, the more reliable areas to assess are the pelvic and tailhead areas (Edmondson et al., 1989).

The assignment of BCS is facilitated by the use of charts (Appendix 1 and 2) specific for each body condition scoring system, containing pictures and descriptions of the anatomical location of interest. The charts are used by industry representatives and researchers to develop skills in body condition scoring and to make the scoring less subjective (Fergusson et al., 1994). Scoring is mostly done by visual inspection (Bewley and Schutz, 2008) with the animal moving freely (Edmondson et al., 1989; Gillund et al., 1999), especially when large numbers of animals are scored (Edmondson et la., 1989). If the body condition scoring system used involves palpation the animal may need to be tied (Edmondson et al., 1989).

Several studies have examined the subjectivity, repeatability and validity of manual body condition scoring (Edmondson et al., 1989; Fergusson et al., 1994; Domecqo et al., 1995; Gillund et al., 1999; Schwager-Suter et al., 2000; Kristensen et al., 2006). Validation of manual body condition scores has involved comparison with other measurements of body condition e.g. ultrasound measurements of subcutaneous fat thickness (Domecqo et al., 1995; MacDonald et al., 1999; Schwager-Suter et al., 2000) and comparisons of BCS within and across scorers (Fergusson et al., 1994; Kristensen et al., 2006).

Using 50 Holstein dairy cows Domecqo et al. (1995) validated BCS using ultrasound measurements of subcutaneous fat thickness at the loin, pelvic and tailhead areas. Regression models indicated that BCS was significantly associated with all measurements of subcutaneous fat thickness. Correlation coefficients ranged between 0.36 and 0.86, variation depending on the ultrasound measurement used in the regression models. BCS was concluded to effectively mirror the quantity of subcutaneous fat of dairy cows, which is in agreement with similar results by Schwager-Suter et al. (2000) and Zulu et al. (2001).

Ferguson et al. (1994) validated BCS based on repeated assessments of 255 Holstein cows by 4 separate BCS scorers of which 3 were experienced (ES) and 1 inexperienced (IS). The BCS assigned by ES agreed better most of the time with the overall BCS of all observers than did BCS assigned by IS, 58 to 67 % and 27 % of the occasions respectively. Further, individual consistency for the ES, regarding variation in BCS, was more than 0.25 units on 21 to 34 % of the scoring occasions. One individual scorer may not be able to ascertain BCS changes of 0.25 increment units on successive scoring occasions but rather of 0.5 increment units. Similarly, Kristensen et al. (2006) investigated within and across-person uniformity of BCS in three herds of Danish Holstein cows. In total 57 scorers participated in the study, 51 were active veterinarians (having varying experience in BCS) and six were experienced scorers and body condition scoring instructors. The scores given by the instructors agreed, on the first and second scoring occasion, 72 to 95 % of the time with a deviation of 0.25 units of increment. On the other hand scores given by the veterinarians agreed on the first and second scoring occasion, 30 % of the time, mostly deviating by 0.5 units of increment. Across classifiers, scores on the first and second occasion agreed 83 % of the time. The validity and precision of BCS, although a discontinuous and subjective measure, can be improved by training and experience (Ferguson et al., 1994; Kristensen et al., 2006).

Live Weight

Measurements of live weight can be performed using direct or indirect methods. The most accurate direct method is individual weighing using a calibrated electronic scale (Dingwell et al., 2006), although, since not all farmers have access to expensive equipments, indirect methods have been developed. An estimation of the animal's body weight is done through assessment of body measurements e.g. wither height, heart girth, body length and hip width (Heinrichs et al., 1992; Dingwell et al., 2006; Mäntysaari and Mäntysaari, 2008). Nevertheless, changes in body weight, whether measured directly or indirectly, reflects not only changes in amounts of adipose tissue but also changes in body protein, water, gastrointestinal content, masses of organs and foetus development (Heinrichs et al., 1992; Broster and Broster, 1998; Schröder and Staufenbiel, 2006).

In dairy cows, associations between BCS and measurements of LW have been of variable nature, mainly due to the subjectivity of body condition scoring and the many factors (mentioned above) affecting LW. Furthermore, the relationship between BCS and measurements of LW might be influenced by additional factors e.g. body conformation, breed, age, parity and lactation stage (Berry et al., 2006), although not all results agree (Nielsen et al., 2003). LW is reported to be neither an independent nor a precise mean for prediction of actual energy reserves or mobilisation of energy reserves (Andrew et al., 1994; Schröder and Staufenbiel, 2006). However, Maltz et al. (1997) suggested that LW measurements and its changes, if measured recurrently, could properly characterize the physiological status of the animal.

Associations between BCS and measurements of LW ranges between 0.15 and 0.67 (Otto et al., 1991; Gillund et al., 1999; Berry et al., 2006; Mäntysaari and Mäntysaari, 2008) and estimations of LW change in kg per one unit BCS, for lactating cows, ranges between 15 and 110 kg (Garnsworthy and Topps, 1982; Otto et al., 1991; Waltner et al., 1994; Gregory et al., 1998; Nielsen et al., 2003; Jaurena et al., 2005). Variations in associations and estimates, besides the earlier mentioned reasons, might also be partially ascribed to whether calculations were carried out using total LW or by using weights only accounting for changes in adipose tissue. Additionally, regression models differed when accounting for factors such as breed, gut fill and stage of lactation, reviewed by Bewley and Schutz (2008). Nielsen et al. (2003) also attributed the variation in associations and estimates to the different BCS scales that are used across studies.

Backfat Thickness

As described by Schröder and Staufenbiel (2006) "backfat is the layer of subcutaneous fat that is terminated by the skin and the fascia trunci profounda, which in the back and rump area is located above the gluteus medius and longissimus dorsi muscles". In most cows, subcutaneous fat is divided into the subcutaneous fat layer (Figure 3), between the skin and the superficial fascia, and the inter-fascial subcutaneous fat layer, between the superficial fascia and the profound fascia (Schröder and Staufenbiel, 2006).

Subcutaneous backfat thickness (BFT) is mostly measured in beef animals since the proportion of lean to fat is important to predict carcass components (Hamlin et al., 1995; Greiner et al., 2003a). In addition measurement of BFT might be used to predict energy reserves in dairy cows as an alternative or as a tool to confirm body condition scoring systems (Domecq et al., 1995; Mizrach et al., 1999; Schwager-Suter et al., 2000; Jaurena et al 2005).

Today BFT can be measured with ultrasound devices (Schröder and Staufenbiel, 2006). The most common type of ultrasound device used for assessment of BFT in dairy cows is the B-mode ultrasound device equipped with a linear transducer, having a frequency between 5 and 7.5 MHz (Brethour, 1992; Bruckmaier et al., 1998, Schwager-Suter; 2000). Other types of ultrasound devices for measurement of BFT are available and reviewed by DeCampeneer et al. (2000). Skin contact with the transducer is done with a couplant, usually some type of vegetal oil (Brethour, 1992; Bruckmaier et al., 1998; Hassen et al., 1998) and by clipping or shaving of the haircoat at the assessment location (Bruckmaier et al., 1998; Hassen et al., 1998; Schwager-Suter, 2000). Ultrasound devices transfer electrical pulses into high frequency sound waves, often ranging between 2 and 10 MHz, through crystals having piezoelectrical properties (Houghton and Turlington, 1992). The ultrasound image is created by the sound waves, as reflected in the tranducer, from boundaries between mediums of different densities (Houghton and Turlington, 1992). When measuring BFT, fat, fascia, and muscle tissues have all different densities (Shröder and Staufenbiel, 2006). The image produced on the screen shows the assessed surface cross-sectionally in greyscale. Fat, fascia and muscle tissue, due to their different densities have all, in the image, different degree of shading with fat appearing the darkest (Whittaker et al., 1992; Houghton and Turlington, 1992).

When carrying out measurements, the animal's position should be normal and relaxed (Shröder and Staufenbiel, 2006). The transducer is put and held very lightly on the surface assessed, as fat and muscle tissues are sensitive to pressure and can be compressed, and in a perpendicular orientation to the tissue interface (Brethour et al., 1992; Robinson et al., 1992; Bruckmaier et al., 1998; Charagu et al., 1999). Nevertheless, careful and slight movements of the transducer on the assessed area can help in image interpretation (Robinson et al., 1992). To interpret images generated on the B-mode type of scanners, a planimeter coupled to a computer or a microprocessor is often used to measure depth in the image (De Campeneere et al., 2000). In modern devices however, measurements are usually done by use of incorporated software. BFT can be measured to the nearest 1 mm, although often included in the measure is the thickness of the skin (Schröder and Staufenbiel, 2006).

On each animal, the examination site is located visually or by palpation. Locations selected for ultrasound measurements of BFT in dairy cows are the sacral area in the flat area between the pins and the hooks, downwards from the first coccygeal vertebra (MacDonalds et al., 1999; Mizrach et al., 1999; Schwager-Suter et al., 2000; Schröder and Staufenbiel, 2006) and the rib area, measured at the 10th, 11th, 12th, or 13th rib (Otto et al., 1991; Domecq et al., 1995; MacDonalds et al., 1999; Mizrach et al., 1999). The rib area is the location most commonly used for measurements of BFT in beef animals (Brethour et al., 1992; Robinson et al., 1992; Greiner et al., 2003b), although the location has also been used for dairy cows as most of the reports on ultrasound measurements of BFT for cattle have evaluated that area. Nevertheless the sacral area has been reported to have the highest correlation ($r = 0.86$) with BCS and to be the area most suitable for ultrasound measurements of BFT in dairy cows, as it assesses the same area as most body condition scoring systems (Domecq et al., 1995). Further, Domecq et al. (1995) suggested that only one side and location on the animal is needed for BFT evaluation as combining ultrasound measurements of BFT from several anatomical locations did not improve regression models coefficients of determination.

The repeatability and validity of ultrasound measurements of BFT in beef cattle have been investigated by looking at operator variability (McLaren et al., 1991; Brethour et al., 1992) or machine variability (Robinson et al., 1992; Charagu et al., 1999) and relation of BFT to actual carcass backfat quantity (Brethour et al., 1992; Robinson et al., 1992; Greiner et al., 2003b) or total body fat (Klawuhn, 1992; Wappler, 1997). Validation of ultrasound measurements of BFT in dairy cows has mostly been done by associations with BCS (Domecq et al., 1995; Mizrach et al., 1999; MacDonald et al., 1999; Schwager-Suter et al., 2000; Jaurena et al., 2005). Associations of BCS with ultrasound measurements of BFT range between 0.37 and 0.84 (Domecq et al., 1995; Mizrach et al., 1999; MacDonald et al., 1999; Schwager-Suter et al., 2000; Jaurena et al., 2005). Differences in the degree of association between these two parameters could be partially attributed to variability in operators' image interpretation, type of equipment used, anatomical locations assessed, level of animal fatness, hide thickness, and type of statistical models used for data analysis.

Nevertheless, Schröder and Staufenbiel (2006) suggested that since ultrasound measurements of BFT are continuous, precise and quickly obtained these, rather than BCS, should be used to predict energy reserves in dairy cattle.

MEASURES OF CHANGES IN BODY CONDITION

It is often important to identify changes in body condition. Glucose, cholesterol, urea, insulin, growth hormone, triiodothyronine, thyroxine, NEFA, BHBA, creatinine, albumin, and globulin in blood as well as milk components such as fat, protein, lactose, fat to protein ratio (F:P), fat to lactose ratio (F:L) and acetone have been linked to energy status in the dairy cow (Grieve et al., 1986; Reist et al., 2002; Clark et al., 2005; Macrae et al., 2006; Friggens et al., 2007a; Fall et al., 2008).

When blood samples are used to monitor short-term NEB and adipose tissue catabolism, in dairy cows, serum BHBA and NEFA are serum constituents that are frequently analysed (Reist et al., 2002; Clark et al., 2005; Agenäs et al., 2006; Fall et al., 2008). Analysed serum constituents' concentrations are compared, for each specific constituent, to optimum values established for animals in positive energy balance (Whitaker, 2004; Macrae et al., 2006; Quiroz-Rocha et al., 2009). For lactating cows, optimum blood levels of BHBA are below 1.0 mmol/L and for dry cows below 0.6 mmol/L. Above 1.0 mmol/L, health and productivity is reported to be affected. Optimum blood levels of NEFA, for lactating cows, are below 0.7 mmol/L and for dry cows (in the last 3 to 4 weeks of pregnancy) below 0.4 mmol/L (McNamara et al., 2003; Whitaker, 2004; Quiroz-Rocha et al., 2009). NEFA is a better and more direct measure of adipose tissue mobilisation than BHBA (Agenäs et al., 2002; Whittaker et al., 2004), although it can return to optimum range rapidly e.g. after an increase due to NEB. It has been reported that NEFA is the serum constituent most closely reflecting

BCS losses, especially in early lactation (Stengärde et al., 2008). In early lactation, NEFA and BHBA are positively correlated to each other (Meikle et al., 2004; Cavestany et al., 2005) and negatively correlated to energy balance and BCS (Reist et al., 2002; Meikle et al., 2004).

Milk components have also been related to energy status, especially milk fat and protein content (Friggens et al., 2007a). F:P and F:L ratios have also been used (Grieve et al., 1986; Reist et al., 2002; Friggens et al., 2007b). In early lactation, contents of fat and protein as well as F:P and F:L ratios are negatively correlated to energy balance (Reist et al., 2002; Clark et al., 2005). Friggens et al. (2007b) reported the option of estimating energy balance from milk components or their ratios as cheap and practicable, as automatic sampling and inline milk analyses are available, if proved reliable.

Whether using milk components, serum constituents or a combination of them, precision of estimating energy status in individual cows seems low, since these measures of energy status often are affected by diet composition. Further, precision on a herd level seems affected by herd size, even though less in larger herds (Heuer et al., 2000; Reist et al., 2002). Nevertheless, precision of energy balance estimation, using milk composition measures, is increased when combining measures of days in milk, milk yield, milk fat, and milk protein in a common equation (Friggens et al., 2007b).

Even if serum constituents and milk components might provide a timelier and more objective measure of energy status, each has limitations, especially for serum constituents, including the need of sampling, expensive analysis and difficulties in results interpretations (Adams et al., 1978). The benefit of manual body condition scoring seems to be a more available and practical method to assess energy status (Bewley and Schutz, 2008).

AUTOMATIC MEASURES OF BODY CONDITION

Today, new methods and technologies, to better use information of body condition and its changes, are needed and being developed. Research is in progress to automate dairy cows' body condition scoring. The aim with an automatic body condition scoring method is to be quick, objective, consistent, cost efficient, and un-stressful for the animal (Leroy et al., 2005). Reported attempts, although few, to automate dairy cows' BCS include the utilization of thermal imaging (Keren and Olsson, 2007; Halachmi et al., 2008; Halachmi et al., 2009) and digital imaging, including both 2D and 3D imaging (Pompe et al; 2005; Leroy et al., 2005; Fergusson et al., 2006; Bewley et al., 2008; Krukowski, 2009) in combination to image analysis techniques. Digital imaging and image analysis techniques have been successfully applied to assess body shape, live weight, daily growth and fat reserves in other livestock species e.g. pig, chicken and buffalo (Schofield et al., 1999; DeWet et al., 2004; Negretti et al., 2008). The use of digital or thermal cameras in combination with image analysis techniques is advantageous, as measures are done without the need of direct contact with the animal, causes no stress at assessment, and provides images rich in data (Leroy et al., 2005).

Although technologies are promising, reported attempts have not yet properly addressed the prediction of automatic dairy cows' BCS (Halachmi et al., 2008). Nevertheless potential applications for improved automated body condition scoring methods in the future have been stated to be vast; including improved management of individuals and herds of dairy cows, and usefulness in programmes of genetic evaluations (Bewley and Schutz, 2009).

2D imaging

Leroy et al. (2005) and Bewley et al. (2008) extracted contours or anatomical points on digital back-view images of dairy cow with known manual BCS using 2D imaging, and produced prediction models that automatically estimates BCS. Leroy et al. (2005) used a digital camera, providing two dimensional silhouette images, to photograph the rear-end of dairy cows. To establish the overall contour of individual animals, from which to estimate BCS, the outlines of 19 anatomical points corresponding to visual features were incorporated into prediction models. The outcome of the study resulted in an automatic prediction of BCS with an accuracy having the same error margin as human estimation (0.25 units), between and within ES, reported by Ferguson et al. (1994) and Kristensen et al. (2006). Similar results were obtained in an extensive study carried out by Bewley et al. (2008), where digital images were automatically captured from a permanent weighing station on which a digital camera had been installed at a direct angle above the cow's back. From the images retained a total of 23 anatomical points, thought to be associated with BCS, were manually chosen and used in descriptions of the cow's contour. The easiest points identifiable were around the hooks rather than the pin-bones and the tailhead. Angles produced by the pin-bones, tailhead and hooks were automatically extracted from the produced contour-images and used in the prediction models. Hook angles, posterior hook angles and tailhead depressions were all important in the prediction of automated BCS, although BCS estimated from the extracted angles produced by the hooks alone gave excellent results. Of the automatically predicted BCS, 100 % were within 0.5 units and 90 % were within 0.25 units of manual BCS. Although a validation of the results with an independent dataset was not reported.

Leroy et al. (2005) and Bewley et al. (2008) attempted to automate BCS using 2D imaging but encountered problems, amongst others, related to poor lighting, poor image quality and background colour intensity, the latter making the separation of cows contour from the surroundings difficult. Nevertheless the mentioned limitations were partially overcome by the use of 3D (Krukowski, 2009) and thermal imaging (Halatchmi et al., 2009) where, in the latter study, the images were analyzable in almost all cases.

3D imaging

Krukowski (2009) attempted to automate dairy cows' BCS by combining lateral-view 2D imaging with back-view 3D imaging. Lateral-view 2D images were manually captured with an 8.0 megapixel Canon IXUS 80IS digital camera whereas back-view 3D images were manually captured with a time-of-flight (TOF) camera having a spatial resolution of 176x144 pixels, the Mesa Swissranger SR-3000. In contrast to 2D imaging, when using 3D imaging the distance to the surface of the item is measured and the volume of the item can be estimated. The TOF technique measures the distance to an item as the time it takes for an emitted pulse of energy, travelling at the speed of light, to travel from its transmitter to the item of interest, in this particular case the rear-end of the cow, and back to the receiver (Amann et al., 2000; Krukowski, 2009). Krukowski (2009) established a method for processing 3D images of dairy cows, by automatic localization of anatomical reference points. Anatomical points around the hook bones and following the spinal ridge were assessed and resulted in 30 parameters which were statistically analysed to identify those that best described cows' BCS. When the prediction model was tested, 100 % of the automatically predicted BCS were within 0.5 units and 79 % where within 0.25 units of manual BCS. A validation of the results, using an independent dataset, was carried out where 46 % of the predicted BCS were within 0.5 units and 20 % within 0.25 units of manual BCS. Krukowski (2009) attributed the poorer results from the statistical validation to problems related to setup limitations and poor image quality; partially ascribed to manual procedures, photo angle, and the animals' position as well as movements. The author strongly suggested that further studies, attempting to automate dairy cows' BCS, should use a constant calibrated above angle when capturing images.

MATERIALS AND METHODS

Animals and Management

The study included 21 dairy cows of the Swedish Red breed (SRB) from the herd at Kungsängens Research Centre in Uppsala. The 21 cows were housed in the Voluntary Milking System (VMS, DeLaval, Tumba, Sweden) free-stall barn and had access to an exercise pen. All management routines followed standard practice in the herd. Cows were in lactation numbers 1 to 7. At the beginning of the study a variety of lactation stages were represented, the majority of the cows being in post peak lactation. The cows' overall range in body condition was 2 to 5 on the 1 to 5 BCS scale described by Gillund et al. (1999).

Silage and concentrates were fed indoors according to the Swedish feeding recommendations (Spörndly, 1995) based on individual milk yields. Cows that passed peak lactation during the study were kept on peak lactation diets for an additional 8 weeks after peak lactation in order to create high BCS for the data recording. The silage had an average dry matter (DM) content of 44.3 % and a metabolizable energy (ME) content of 10.2 MJ/kg feed. The concentrate offered had an ME content of 11.6 MJ/kg of feed and consisted of oats (23.4 % DM), barley (23.2 % DM), peas (20 % DM), rapeseed cake (12.5 % DM), dried sugar beet pulp (9 % DM), rapeseed (2.5 % DM), wheat germ (7 % DM), calcium carbonate (1.3 % DM), sodium chloride (0.6 % DM) and magnesium oxide (0.36 % DM). Cows that were dried off or developed health problems during the study, were replaced with other individuals.

The experimental design and all handling of the animals were approved by the Uppsala Local Ethics Committee.

Data Collection

Data were collected weekly from May to August 2009 and included measurements of LW, BCS, BFT, 3D images of the rear-end of the cow, milk yields, major milk components (protein, fat and lactose) and plasma metabolites (NEFA and BHBA).

Data were collected each week on Wednesdays, Thursdays and Fridays, in the same order each week. Manual assessment of BCS and blood sampling was carried out on Wednesdays, weighing and 3D imaging on Thursdays and measurements of BFT on Fridays (Table 4). The order of the procedures was chosen to avoid biased data, especially biased BCS data. Further, general information such as days in milk, as well as more specific information as milk yields, feed intakes and feed analyses were obtained from the databases at Kungsängens Research Centre.

Energy balance of individual cows was calculated for each week by using information regarding energy requirement; feed intake, feed analyses and milk yield.

Body Condition Score. Body condition scoring was carried out following a visual 1 to 5 scale method for visual evaluation (Appendix 1), with 0.5 units of increment. Score 1 and 5 represented emaciated and obese animals, respectively, as described by Gillund et al. (1999). The assessment of the cows' BCS was done while the cows were loose in the VMS free-stall barn. Body condition was scored once a month by an ES, an employee at Kungsängens Research Centre and weekly by an IS, the author.

Blood and Milk Samples. Blood sampling was carried out by the author in the morning between 09.00-11.00 am. Blood was collected from the tail vein, into evacuated heparinised tubes (BD Vacutainer Systems, Plymouth, UK). The punctures were done when the cows were standing in a cubicle, while being groomed. The samples were put on ice immediately after sampling and centrifuged for 20 minutes at 300xG within 60 minutes after sampling. Plasma was stored at -20˚C until analysis for BHBA and NEFA. Plasma analyses were carried out by staff at the Kungsängen Research Centre Laboratory, Uppsala, Sweden using commercial kits according to the manufacturer's instructions. Enzymatic kits were used for determination of both plasma BHBA (Kits catalogue no. 700190; Cayman Chemical Company, MI, USA) and plasma NEFA (Kits catalogue no. FA 115; Randox Laboaratories Ltd, Ardmore, UK)

Milk yield was recorded daily and milk samples for analysis of major milk components, fat, protein and lactose were obtained once per week, during a 24 hour period (Mondays from 13.00 pm to Tuesdays 13.00 pm). Milk samples were obtained at each milking through the VMS automatic milk sampler (DeLaval, Sweden) and were stored at 4˚C until analysis (Wednesday mornings at 09.00 am). Protein, fat and lactose concentrations were determined by staff at the Kungsängen Research Centre Laboratory, Uppsala, Sweden using infrared spectroscopy (Foss Electric, Hillerød, Danmark).

Live Weight. Measurements of the cows' LW were recorded by the author in the morning, approximately between 09.00 and 11.00 am. Cows' time of fodder intake in relation to recorded LW measurements was not recorded.

Ultrasound Measurements. BFT was measured by the author with a portable ultrasound equipment, the B-mode Draminski Ultrasound Scanner (Draminski Electronics in Agriculture, Poland) provided with a 7.5 MHz linear probe (Figure 4). Measurements were carried out at two locations, at the sacral and rib area (Figure 5). BFT at the sacral area (sacral subcutaneous fat thickness, SFT) was measured in the flat area between the hooks and the pins (Schröder and Staubenfiel, 2006) and BFT at the rib area (rib subcutaneous fat thickness, RFT) was measured between the 12th and the 13th rib, 5 cm down from the spine (Robinsson et al., 1992; Brethour, 1992; Mizrach et al., 1999; Schwager et al., 2000). Three measurements were performed on each of the two locations every week and a mean value was calculated for SFT and RFT. Ultrasound measurements of SFT and RFT were carried out only on one side of the animal (Domecq et al., 1995).

The two measuring locations were shaved and a couplant was used to allow good contact between the measuring locations and the ultrasound probe. In order to ensure the exact same measurement position between weeks, the positions for ultrasound measurements were marked with permanent blue colour in the middle of the shaved squares (Figure 5). At the sacral area, the exact location was where a horizontal line, between the hooks and the pins, crossed a vertical line coming down from the beginning of the coccygeal vertebra (Figure 5). At the rib area, for the same purpose as for the sacral area, a shaved square was created five centimetres below the middle line, the spine, between the 12th and 13th rib (Figure 5). At each measurement site the probe was positioned perpendicularly to the interface (Brethour et al., 1992; Robinson et al., 1992; Bruckmaier et al., 1998; Charagu et al., 1999), on the marked blue lines. The ultrasound image was frozen on the screen of the ultrasound scanner and the BFT was measured using the Draminski Animal*profi*L software, with an accuracy of 1mm. Skin thickness was included in the BFT value and consequently BFT was less by that amount.

3D Images. Photographs were taken, by the TOF MESA Swissranger SR-4000 camera (Figure 6), from above, giving images with a top view of the rear-end of the cow (Figure 7). The camera was installed above one of the selection gates in the VMS barn at the Kungsängen Research Centre and cows were photographed when passing through the selection gate. To enable the camera to photograph the passing cow, the opening of the selection gate was delayed for 10 seconds giving a total time of 15 seconds for taking the photographs. As the cow entered the selection gate, the cow's transponder identification number was registered by the sorting sensor of the gate and a sound signal was sent to an Alcom listener. The Alcom listener was joined to a computer programmed to log the cow's ID and trigger the camera to take photographs (Figure 8). Each time the camera was triggered to take photographs a total of 20 photographs were taken. The images obtained could be shown as 3D images and as intensity images (Figure 9). From usable intensity images, staff at DeLaval, Tumba, Sweden selected range data (Figure 10) to be used for prediction of automatic body condition scores (ACS); 90 % of the usable intensity images' range data were used for training of the 3D imaging based automatic body condition scoring model. Training of the 3D imaging based automatic body condition scoring model refers to the use of input data to adjust the mathematics of the algorithm in the model. The remaining 10 % of the usable images were used as an independent dataset for validation of the trained 3D imaging based automatic body condition scoring model. Validation of the 3D imaging based automatic body condition scoring model refers to tests done to evaluate the robustness of the used model. The 3D imaging based automatic body condition scoring model was primarily constituted by the algorithm Artificial Neural Network (Krogh, 2008) and trained using manual BCS as true reference for body condition (input data). Furthermore all collected parameters (CP) were, after statistical analyses, individually investigated for suitability as true reference for body condition to be used in the training of the 3D imaging based automatic body condition scoring model.

Selection of images' range data as well as training and validation of the 3D imaging based automatic body condition scoring model were performed by staff at DeLaval, Tumba, Sweden whereas statistical analyses were performed by the author.

Estimated Energy Balance. EB was estimated by the author using information regarding feed intakes, feed analyses, estimated maintenance requirements calculated according to the Swedish feeding recommendations (Spörndly, 1995) for producing dairy cows, and milk yields. EB was estimated and defined as the difference between energy in feed and energy in milk and maintenance. When the estimate of EB is negative, the cow is referred as to be in NEB.

[EB = Energy in feed - Energy in milk + maintenance]

Statistical Analysis

Linear correlation and regression analyses were performed on the dataset, using Microsoft Office Excel 2003 (Swedish University of Agriculture, Uppsala, Sweden) and scatter plots were made using Matlab R2007a (Uppsala University, Uppsala, Sweden).

Correlations were used to investigate associations between the CP and their change; Δ values (CPΔ). Some of the CP were calculated, including EB, F:P and F:L. Furthermore one of the CP was predicted, ACS.

Additionally, correlations were done between collected parameters delayed in time (CPT). The delay of parameters in time was done through shifting one of the parameters by one or several weeks, e.g. if the association between BCS and NEFA was to be investigated, taking in consideration a delay of effects by one week, then the parameters would be shifted by a single value. For either BCS or NEFA values, the value representing week 1 would be removed and in the remaining parameter (either BCS or NEFA depending on the previous choice) the value representing week 14 would be removed. Thereby, a shift of one week would be obtained when correlating the parameters. The procedure of removing values was carried out repeatedly to investigate correlations between CPT, up to four weeks.

RESULTS

Data were successfully collected throughout the study for most of the SRB cows in the experimental group. Only 1 of the total 21 SRB cows was taken out of the experimental group and replaced, for reasons not related to the experimental procedures. Furthermore, also for reasons not related to the experimental procedures, data were incomplete for three cows, although the partial data was still included in the overall dataset used for statistical analyses. For all CP, the overall dataset included 231 observations (Table 5). However, ACS was not predictable for all 21 cows all 14 weeks, mostly due to lack of usable images and thereby linear correlation and regression analyses between CP and predicted ACS were done using a second overall dataset including 168 observations.

A total of 5880 3D images were collected of which 2800 were possible to use for model training and validation, the others were discarded due to problems associated with image quality and the cow's position in the image.

Results from the linear correlation and regression analyses between CP and CP**Δ**, in-between CP**Δ,** between CP and CPT, and in-between CPT are not presented here since the best correlation coefficients were found in-between CP. Results from the linear correlation and regression analyses, in-between CP, are shown in table 6 whereas results between CP and predicted ACS are shown in table 7. The highest and significant correlations (Figure 11), were found between manual BCS and predicted ACS ($R= 0.90$; $P< 0.001$), manual BCS and SFT ($R=0.75$; $P< 0.001$), SFT and predicted ACS ($R= 0.70$; $P< 0.001$), and SFT and RFT ($R= 0.70$; $P< 0.001$). Further, the validation of the 3D imaging based automatic body condition scoring model, trained with manual BCS as true reference of body condition, resulted in a high correlation coefficient ($R= 0.83$) between predicted ACS and manual BCS (Figure 12).

Of all individually investigated CP, measurements of SFT, as mentioned, was found to have the highest correlation with manual BCS ($R= 0.75$; $P< 0.001$) and was thereby used as an alternative true reference of body condition in the training of the 3D imaging based automatic body condition scoring model. However when SFT measurements are used as reference values, the 3D imaging based automatic body condition scoring model predicts automatic SFT (AFT) rather than ACS. The correlation coefficient between predicted AFT and manual SFT was found to be high ($R= 0.80$).

Moreover, the correlation coefficient between the experienced BCS scorer and the inexperienced BCS scorer was high and significant ($R= 0.75$; $P< 0.001$).

DISCUSSION

Of the investigated CP, plasma parameters (NEFA and BHBA), milk parameters (milk yield, milk protein, milk fat, and milk lactose) and calculated parameters (F:P, F:L and EB) did not follow general patterns and were not chosen for further discussion. Manual BCS, measurements of LW, ultrasound BFT measurements (SFT and RFT), and 3D imaging measures (predicted ACS) are discussed.

Body Condition Score

The degree of association between the ES and the IS (R=0.75) is in agreement with results obtained by Fergusson et al. (2006), who found correlation coefficients between ES and IS ranging from 0.76 to 0.79.

Live Weight

Overall, associations between measurements of LW and other CPs were low. The low association between LW measurements and manual BCS (R= 0.13) is close to, although lower than, correlations in literature (between 0.15 and 0.67) (Otto et al., 1991; Gillund et al., 1999; Berry et al., 2006; Mäntysaari and Mäntysaari, 2008). The low correlation found, besides being attributed to fluctuations of LW known to occur daily and weekly (Maltz et al., 1997), can be partially explained by the type of correlation analysis chosen. This because no other factors known to influence LW could be taken into account by the linear correlation model used and partially due to limitations in the experimental design as measurements of LW were collected only once weekly for each individual cow and time of fodder intake in relation to recorded LW measurements was not recorded.

Today, cows can be weighed manually by stationary and movable electronic scales or automatically by using stationary electronic scales incorporated in the barn management system (Maltz et al., 1997). When using manual weighing, as done in the present study, the collection of LW measurements becomes labour intensive, especially at repeated collection, and inefficient. The use of automatic weighing when possible is suggested, since recording LW at a daily basis or repeatedly within the same day could be a mean to overcome the natural daily and weekly fluctuations of LW and thereby detect an actual LW change. This more accurate detection of LW change can then be added as one of the factors considered in the management decision-making process. Further, LW has been successfully estimated by using prediction models combining body size measurements, manual BCS and relevant demographic information as age at first calving, parity, days in milk and milk yields (Maltz et al., 1997). Although LW measurements, due to the low correlation found with other CPs and especially manual BCS, were not used as true reference of body condition in the calibration of the 3D imaging based automatic body condition scoring model they should be further investigated. LW measurements are of a continuous type and thereby more objective than manual BCS measurements. However, means of collecting this parameter are to be well thought-out as well as automatic models should take into account factors affecting LW measurements' reliability.

Ultrasound Measurements

Several (Domecq et al., 1995; Mizrach et al., 1999) have examined anatomical regions, in the sacral and rib area, to determine suitable locations for BFT measurements. Conclusions were inconsistent as both the sites examined; at the rib area, between the 12^{th} and 13^{th} rib

(Mizrach et al., 1999) and at the sacral area, between the pins and hooks (Staubenbiel, 1992; Domecq et al., 1995) have been suggested to be the ones more appropriate for BFT assessment in dairy cows. Results from the current study are in agreement with Staubenbiel (1992) and Domecq et al. (1995) rather than Mizrach et al. (1999) since the association between SFT and manual BCS (R= 0.75) is higher than between RFT and manual BCS (R= 0.49). Thereby these results suggest the sacral, rather than the rib area, to be the better assessment site for BFT in dairy cows. As Domecq et al. (1995) pointed out, manual BCS is mainly assigned by examination of the animal's lumbar, thurl and tailhead regions and thus the correlation between manual BCS and measures of SFT would likely be higher, as both measures assess the same area. Further, the similar results obtained for association of predicted ACS with RFT and SFT respectively, strengthens the suggestion that the sacral area is the more appropriate site for BFT assessment in dairy cows. The correlation coefficient between SFT and predicted ACS rather than between RFT and predicted ACS is the highest, R= 0.70 and R= 0.45 respectively. These results could probably be attributed to the fact that even the 3D imaging based automatic body condition scoring model used, like measures of SFT, evaluates a similar assessment area as manual BCS. However these results could have been affected by the reference used as true value of body condition in the training of the 3D imaging based automatic body condition scoring model, which was manual BCS.

Measures of SFT were found to have a high correlation with manual BCS (R= 0.75) and when SFT, rather than manual BCS, was used as true reference in the training of the 3D imaging based automatic body condition scoring model used, the model seemed to be able to predict AFT from 3D images at a similar degree as the model seemed able to predict ACS from manual BCS (R= 0.80 and R= 0.90 respectively). Although the correlation between SFT and predicted AFT is somewhat lower, SFT is a continuous type of measure, rather than categorical as is the measure of manual BCS. Thereby, if measures of SFT were used as the true reference of body condition in the calibration of the 3D imaging based automatic body condition scoring model, the automatic BCS model could probably detect and follow changes in body condition more gradually, sensibly and objectively than if using manual BCS as true reference. At a given BCS, changes have usually already occurred at detection. The degree of correlation between manual BCS and measures of BFT were in agreement with correlation coefficients' ranges (between 0.37 and 0.84) found in the literature (Domecq et al., 1995; Mizrach et al., 1999; MacDonald et al., 1999; Schwager-Suter et al., 2000; Jaurena et al., 2005). In this study, correlation coefficients ranged from 0.50 (RFT) to 0.75 (SFT). However, on the ultrasound images obtained at scanning, BFT measures were obtained linearly with the Draminski Animal*profi*L software. Therefore, due to the unevenness of the BFT layer (Mizrach et al., 1999), the linear measurement could have over- or underestimated the actual BFT layer depending on where in the image the measurement was carried out. It is suggested that BFT measurements could correlate to manual BCS better if more representative measures were collected. This might be possible by using image analysis. Image analysis would be done on the area representing BFT in the ultrasound image and result in a mean estimate based on the whole BFT area. Although partially solving the problem related to BFT unevenness, the operator could still affect results e.g. by performing or not the measurement at the same site for each ultrasound assessment and by level of skills in image interpretation which are both factors stated to influence results (McLaren et al., 1991; Brethour et al., 1992). Thus, image interpretation may still be an issue, especially with regards to the image area to be analysed by image analysis which still needs to be defined.

3D Images

Because of setup limitations regarding the experimental equipment, not all of the collected 3D images were possible to use. It was the position of the camera rather than the camera itself that resulted in many images of poor quality. This was in contrast to technologies used in other studies (Leroy et al., 2005; Bewley et al., 2008) where, beside the cow's position in the image, it was also the quality of the images taken that was poor, contributing to discarding of images. In retrospect, the additional images could have contributed to the robustness of the system by providing more examples of each cow, from which the clearest images could have been selected.

One of the primary reasons for discarding images was the position of the cow in relation to the camera. Because of the position of the selection gate where the camera was installed, the cows often stood at an angle in front of the gate. If the cow was standing too much to the side, the shape of the body in the captured image inhibited the selection of range data to be used in the training of the 3D imaging based automatic body condition scoring model and thereby also made prediction of ACS more difficult. In addition, it was a problem that the cow could move around and in front of the gate. In some cases, images were taken of either the front or rear quarter of the cow, but not catching the anatomical parts of interest for selection of range data. 3D images were defined as useful when the thurl, lumbar and tailhead regions were clearly identifiable and the position of the cows in the image was straight.

Problems related to lighting or cows standing at an angle within the selection gate were not an issue for the 3D imaging based automatic body condition scoring model, in contrast with 2D imaging based automatic body condition scoring models (Bewley et al., 2008), since the 3D imaging based automatic body condition scoring model can easily discern the cow from the surroundings. The MESA Swissranger SR-4000 camera provides 3D images with information containing measures of the actual distance between the sender (the camera) and the item assessed (the cow's rear-end), for all pixels in the 3D images and thereby, surroundings can be discerned as having a different range of distance to the sender.

To obtain images of cows standing in a more straight position the camera could be placed on top of feeding stations or inside the milking robot in VMS systems, or at any other place in the barn where there is a narrow aisle. Feeding stations are often visited and have limited space for the cow to move around, as is also the case inside the milking robot. In the present study, the camera was placed above one of the selection gates because the other alternatives suggested (feeding stations and milking robot) were not a practicable option in the VMS barn at the Kungsängen Research Centre.

Today automation is present in most modern dairy herds, e.g. through automatic milking, automatic feeding and automatic estrus detection. A large amount of regularly registered cow data, such as milk yield and somatic cell count, is automatically integrated in support decision software. Support decision softwares are valuable tools for the farmers, as they provide gathered information on both herd and individual cow level. The 3D imaging based automatic body condition scoring model seems promising and could provide additional data to be incorporated into support decision softwares. Information about condition in support decision softwares, whether in the form of ACS or AFT, could be a good addition to all other gathered information as a mean to optimize the assessment of the cow's energy status. The farmer, having access to such a system, could be alerted to changes in condition and decide on how to proceed.

CONCLUSIONS

It is possible to train and thereby calibrate the 3D imaging based automatic body condition scoring model to predict body condition. It is interesting to continue the work with biological references of body condition, especially with the ultrasound SFT measure, since it is a good predictor of energy reserves. Additionally SFT measures give a more objective and continuous type of data. Limitations in the study's design and dataset made conclusions difficult regarding which parameters could or not be used as reference of body condition in the training of the 3D imaging based automatic body condition scoring model. Although of all the biological parameters investigated BCS and BFT seem to be the collected parameters most suitable to use as reference of body condition in the training of the 3D imaging based automatic body condition scoring model. Further it appears that the 3D imaging based automatic body condition scoring model used in this study is much more robust than the 3D model used by Krukowski (2009). Nevertheless, data on biological parameters needs to be collected on cows at the extremes of the BCS scale and on cows that change in body condition, in order to further improve the calibration of the 3D imaging based automatic body condition scoring model. Moreover, if using a continuous type of measure as 3D model calibration reference of body condition, the MESA Swissranger SR-4000 camera's sensitivity to body condition change could be determined.

In the future, monitoring body condition should focus on its changes rather than on its actual state at assessment and high-quality ACS data could be included in support decision software and improve output data with regards to cow´s energy status. The added value from an automatic body condition scoring method will be the automation itself eliminating subjectivity and labour, but also the possibly higher sensitivity to detect onset of changes in body condition making management decisions easier e.g. making the adjustment of feed rations more applicable and effective.

SUGGESTIONS FOR FUTURE WORK

A future research approach could be to create groups of cows with different body conditions at calving in order to obtain data on extremes of BCS scales and thereby also data for significant changes in body condition. Trials should collect full lactation data, including the dry period, and focus on measuring changes in body condition rather than on actual body condition. The goal should be to detect change in body condition as sensibly as possible to be able to adjust feed rations accurately. In addition to further trials, Meta-analysis is suggested as a mean to obtain clearer answers regarding importance of BCS and its effects on health, productivity and reproduction as well as to gather similar findings and strengthen conclusions.

Image analysis is suggested as an alternative to obtain more representative measures of BFT as image analysis techniques could predict the area representing BFT rather than obtaining values only based on linear measurements.

Decision support softwares i.e. a dairy herd management system could be programmed so that each farmer could log cow's preferred body condition (farmer's cow eye) into the system. By this mean the farm's own body condition scoring system subjectivity would be applied creating a calibrated ACS model suited for that farm and herd.

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TABLES

Table 1. A list of some important metabolic changes related to the transition period in ruminants (Ingvartsen, 2006)

Process or metabolism	Response	Involved tissue
Milk synthesis	↑ Number of secretory cells	Udder
	↑ Blood flow	
	↑ Nutrient consumption	
Fat metabolism	↓ *De novo* fat synthesis	Adipose tissue
	↓ Absorption of fatty acids	
	↓ Esterification of fatty acids	
	↑ Lipolysis	
	↑ Use of lipid as energy	Other body tissues
Glucose metabolism	↑ Size of the liver	Liver
	↑ Blood flow	
	↑ Rate of gluconeogenesis	
	↓ Use of glucose as energy	Other body tissues
Protein metabolism	↓ Protein synthesis	Muscular tissue
	↑ Proteolysis	
	↑ Protein synthesis	Other body tissues
Mineral metabolism	↑ Absorption	Gut
	↑ Mobilisation	Bones
Feed intake	↑ Feed intake	Central nervous system
Digestion	↑ Hypertrophy of the digestive tract	Digestive tract
	↑ Absorption rate and capacity	
	↑ Metabolical activity	
Blood flow	↑ Output of blood from the heart	Heart
	↑ Part to the udder	
	↑ Part to the gastrointestinal tract, including the liver	

Table 2. Represents body condition scoring systems in different parts of the world. Modified after Bewley and Schutz (2008)

Country	Scale	Increments	Assessment	Source of Description
Ireland	0-5	0.5	Palpation	Mulvany (1977)
United States	1-5	0.25	Visual	Fergusson et al. (1994)
New Zealand	1-10	0.5	Palpation	McDonald and Roche (2004)
Australia	1-8	0.5	Visual	Earle (1976)
Denmark	1-9	1	Visual	Landsverk (1992)
Sweden	1-5	0.5	Visual	Gillund et al. (1999)[1]
Norway	1-5	0.5	Visual	Gillund et al. (1999)

[1]Personal communication, Lotta Wahlgren (2009)

Table 3. Represents an example of what a body condition system for dairy cows based on a five point scale could look like (McNamara, 2002)

BCS	Body Fat 600 kg cow		Description
	Kg	%	
1 Emaciated	25-45	5-10	Individual bones prominent; sharp look and feel to the bones; deep depressions between vertebrae and between pelvic bones.
2 Below Average	65-80	10-15	Individual bones evident; sharpness, prominent depressions between vertebral and pelvic bones.
3 Average	105-120	18-22	Smoother ridges; individual bones not prominent; vertebral processes just evident; moderate flesh covering.
4 Above Average	140-160	25-30	Flat over vertebrae; smooth, rounded edges over bones; no depressions between bones of vertebrae or pelvis.
5 Obese	> 180	> 30	Vertebrae buried in fat; rounded over back; bulging fat deposits; rounded appearance over pelvis and tailhead.

Table 4. Represents the day of collection for each of the data collected. Manual body condition score was assigned before the collection of any other data. Energy balance is not listed in the table as calculated during the statistical analysis through information obtained from Kungsängens Research Centre’s databases.

Data	Weekdays				
	Mondays	Thursdays	Wednesdays	Thursdays	Fridays
Body Condition Score			x		
Blood Samples			x		
Milk Samples	x	x			
Live Weights				x	
Ultrasound Scans					x
3D[1] Imaging				x	

[1] 3D = Three Dimensional

Table 5. Summary over collected parameters (CP).

Parameter	n	Mean	SE	SD	Minimum	Maximum
BCS	231	3.28	0.060	0.84	1.5	5
LW[1]	231	599	4.28	65.1	479	760
SFT[2]	231	8.91	0.34	5.10	2.00	23.33
RFT[3]	231	5.37	0.14	2.11	2.67	13
NEFA	231	0.14	0.080	0.12	0.020	0.84
BHBA	231	0.76	0.010	0.23	0.29	1.91
Milk Yield	231	32.64	0.47	7.070	13.76	51.79
Milk Fat	231	3.96	0.050	0.78	1.63	6.43
Milk Protein	231	3.42	0.020	0.33	2.78	4.52
Milk Lactose	231	4.87	0.010	0.18	4.17	5.23
Fat to Protein Ratio	231	1.16	0.010	0.20	0.49	2.13
Fat to Lactose Ratio	231	0.81	0.010	0.17	0.36	1.33
EB[4]	231	27.72	1.36	20.66	-87.94	134.37

[1]LW = Live weight
[2]SFT = Sacral subcutaneous fat thickness
[3]RFT = Rib subcutaneous fat thickness
[4]EB = Energy balance

Table 6. Linear correlation coefficients for the collected and calculated parameters (Overall dataset of 231 observations).

	BCS	LW[1]	RFT[2]	SFT[3]	BHB	NEFA	Milk Yield	Milk Fat	Milk Protein	Milk Lactose	Fat to Protein Ratio	Fat to Lactose Ratio	EB[4]
BCS	1,000												
	*												
LW	0,131	1,000											
	***	***											
RFT	0,487	0,439	1,000										
	***	***	***										
SFT	0,748	0,338	0,667	1,000									
		***	**										
BHBA	-0,018	0,242	0,168	0,044	1,000								
		***		†									
NEFA	-0,021	-0,255	-0,123	-0,111	-0,048	1,000							
	***		***	***	***	†							
Milk Yield	-0,516	-0,014	-0,274	-0,524	0,234	0,127	1,000						
	***	***	**	***	†	†	***						
Milk Fat	0,290	0,269	0,176	0,319	0,039	-0,035	-0,413	1,000					
	***		**	***	***		***	***					
Milk Protein	0,495	0,071	0,185	0,454	-0,312	-0,059	-0,811	0,520	1,000				
		***	***	***		†	***	†					
Milk Lactose	0,030	-0,303	-0,364	-0,297	-0,007	0,112	0,265	-0,121	-0,064	1,000			
		***			***			***		†			
Fat to Protein Ratio	0,038	0,287	0,089	0,101	0,226	-0,019	-0,022	0,868	0,033	-0,109	1,000		
	***	***	***	***	†		***	***	***	***	***		
Fat to Lactose Ratio	0,273	0,315	0,240	0,365	0,036	-0,054	-0,447	0,982	0,511	-0,306	0,853	1,000	
		***		†	†	**	**	***		†	***	***	
EB	0,015	0,260	0,081	0,128	-0,054	-0,191	-0,195	-0,263	0,061	-0,120	-0,339	-0,229	1,000

[1]LW = Live weight
[2]RFT = Rib subcutaneous fat thickness
[3]SFT = Sacral subcutaneous fat thickness
[4]EB = Energy balance
†P < 0.1; *P <0.05; ** P < 0.01; ***P < 0.001

Table 7. Linear correlation coefficients for the collected and calculated parameters, and the predicted ACS parameter (Overall dataset of 168 observations).

	BCS	ACS[1]	LW[2]	RFT[3]	SFT[4]	BHB	NEFA	Milk Yield	Milk Fat	Milk Protein	Milk Lactose	Fat to Protein Ratio	Fat to Lactose Ratio	EB[5]
BCS	1,000 ***													
ACS	0,898 *	1,000 †												
LW	0,174 ***	0,146 ***	1,000 ***											
RFT	0,534 ***	0,477 ***	0,454 ***	1,000 ***										
SFT	0,715	0,696	0,387 **	0,695 **	1,000									
BHBA	0,072	0,100	0,222 ***	0,198 †	0,099 †	1,000								
NEFA	-0,066 ***	-0,005 ***	-0,262	-0,137 ***	-0,138 ***	0,076 *	1,000 †							
Milk Yield	-0,466 ***	-0,420 †	-0,001 ***	-0,346 **	-0,491 ***	0,200 †	0,182	1,000 ***						
Milk Fat	0,262 ***	0,196 ***	0,333 **	0,238 ***	0,330 ***	0,148 ***	-0,107 †	-0,344 ***	1,000 ***					
Milk Protein	0,421	0,351	0,146 **	0,290 ***	0,428 ***	-0,274	-0,163	-0,797 ***	0,462 *	1,000				
Milk Lactose	0,042	0,000	-0,243 ***	-0,366	-0,343 †	0,017	0,097	0,292	-0,164 ***	-0,120	1,000			
Fat to Protein Ratio	0,064 **	0,028 †	0,313 ***	0,112 ***	0,142 ***	0,304 †	-0,047	0,007 ***	0,893 ***	0,020 ***	-0,130 ***	1,000 ***		
Fat to Lactose Ratio	0,242	0,189	0,361	0,298	0,383 †	0,133 *	-0,120 *	-0,385 **	0,982 ***	0,466	-0,346	0,872 ***	1,000 **	
EB	0,039	0,003	0,233	0,105	0,160	-0,183	-0,170	-0,220	-0,260	0,128	-0,088	-0,356	-0,229	1,000

[1]ACS = Predicted automatic body condition score
[2]LW = Live weight
[3]RFT = Rib subcutaneous fat thickness
[4]SFT = Sacral subcutaneous fat thickness
[5]EB = Energy Balance
†P < 0.1; *P <0.05; ** P < 0.01; ***P < 0.001

FIGURES

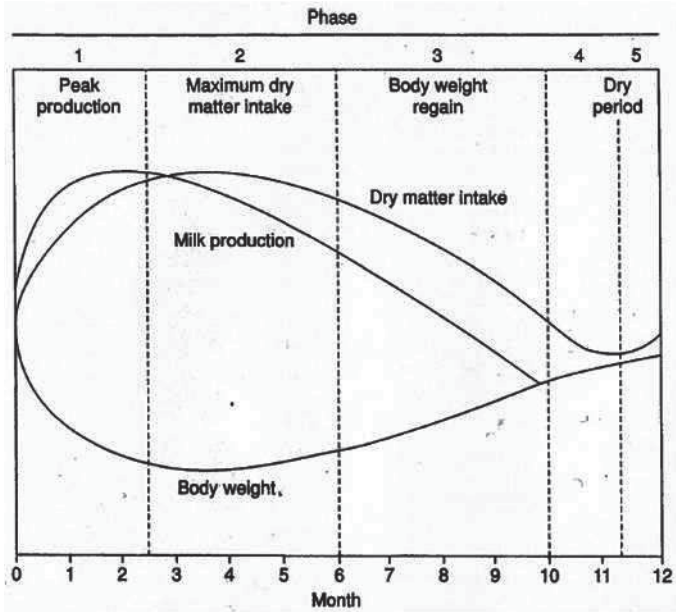


Figure 1. Changes in milk production, dry matter intake and live weight (in the picture "body weight") during the reproduction and production cycle of the average dairy cow (Phillips, 2001).

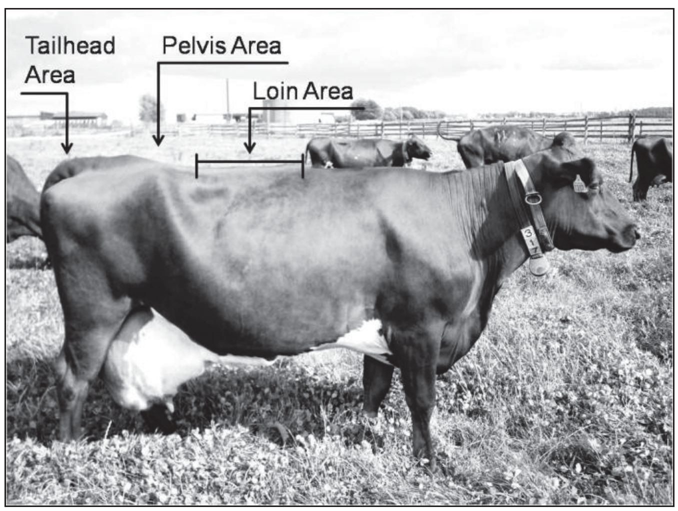


Figure 2. Represents the areas that might be considered when scoring the body condition of a dairy cow.

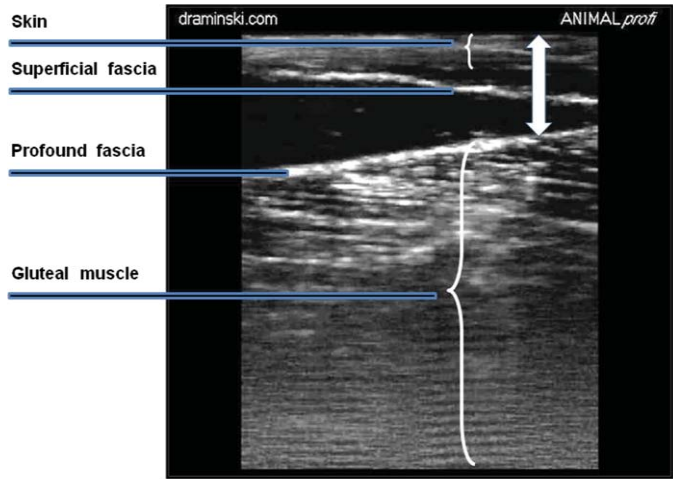


Figure 3. Ultrasound image illustrating subcutaneous fat thickness measured as the distance from the skin to the profound fascia. The subcutaneous fat thickness is indicated with the white two-end arrow. Modified after Schröder and Staufenbiel (2006).

Figure 4. The Draminski Ultrasound Scanner.

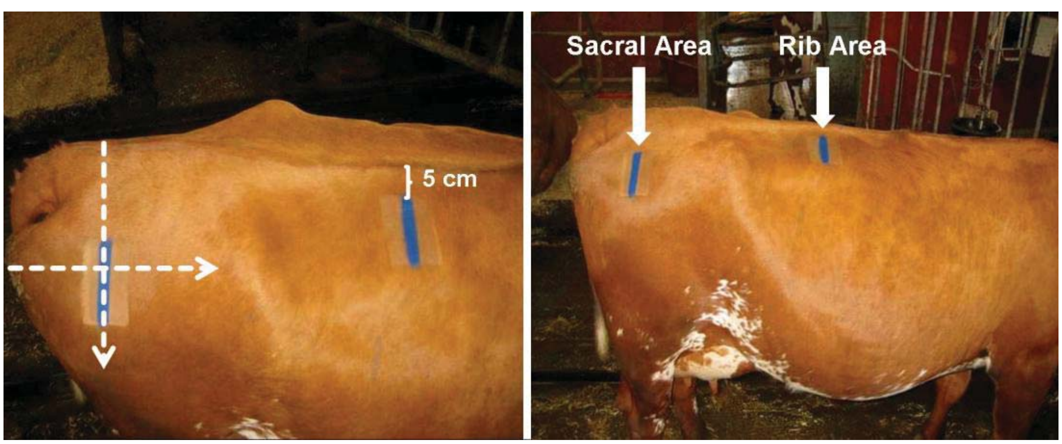
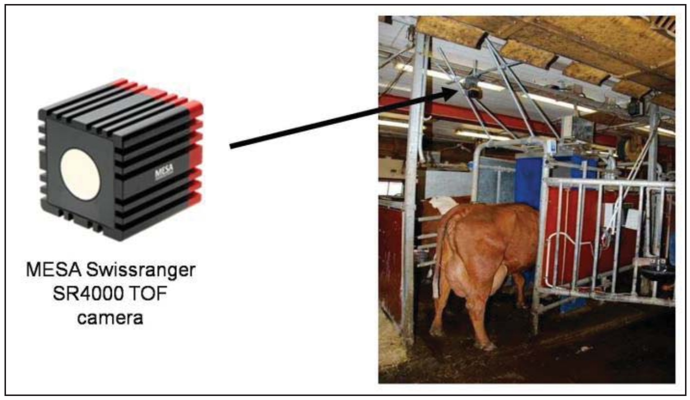


Figure 5. Represents the locations of the ultrasound examination sites seen from a lateral (left) and top (right) view. In the photo, at the right, markings for the placement of the examination sites are indicated.

Figure 6. The time-of-flight (TOF) MESA Swissranger SR-4000 camera.



F**igure 7.** Position of the time-of-flight (TOF) MESA Swissranger SR-4000 camera. The positioning of the camera at a direct angle, above a selection gate, gave top view images of the rear-end of the cow.

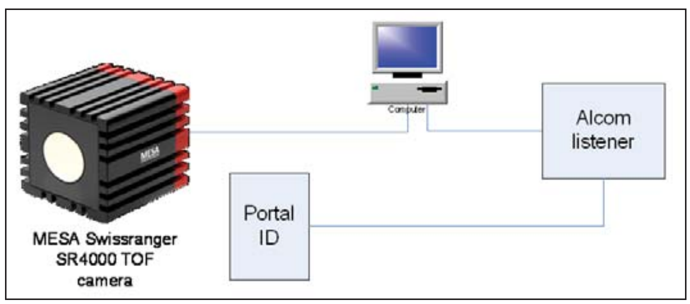


Figure 8. The time-of-flight (TOF) MESA Swissranger SR-4000 camera was coupled to obtain photos of the cows in the VMS barn. As the cow entered the selection gate (Portal ID) the cow's transponder identification number (ID) was registered and sent to an Alcom listener. The Alcom listener was coupled to a computer which triggered the camera to take photographs.

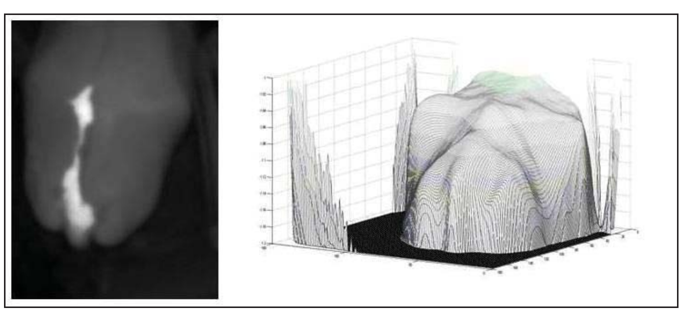


Figure 9. Images taken by the TOF MESA Swissranger SR-4000 camera. Images can be seen as intensity images (left) and 3D images (right).

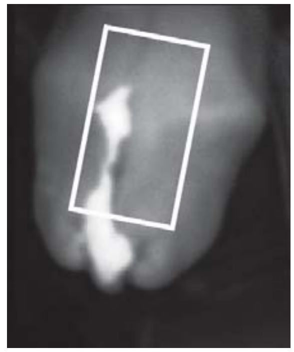


Figure 10. Range data, represented by the white rectangle, included from each usable intensity image for training and validation of the 3D imaging based automatic body condition scoring model.

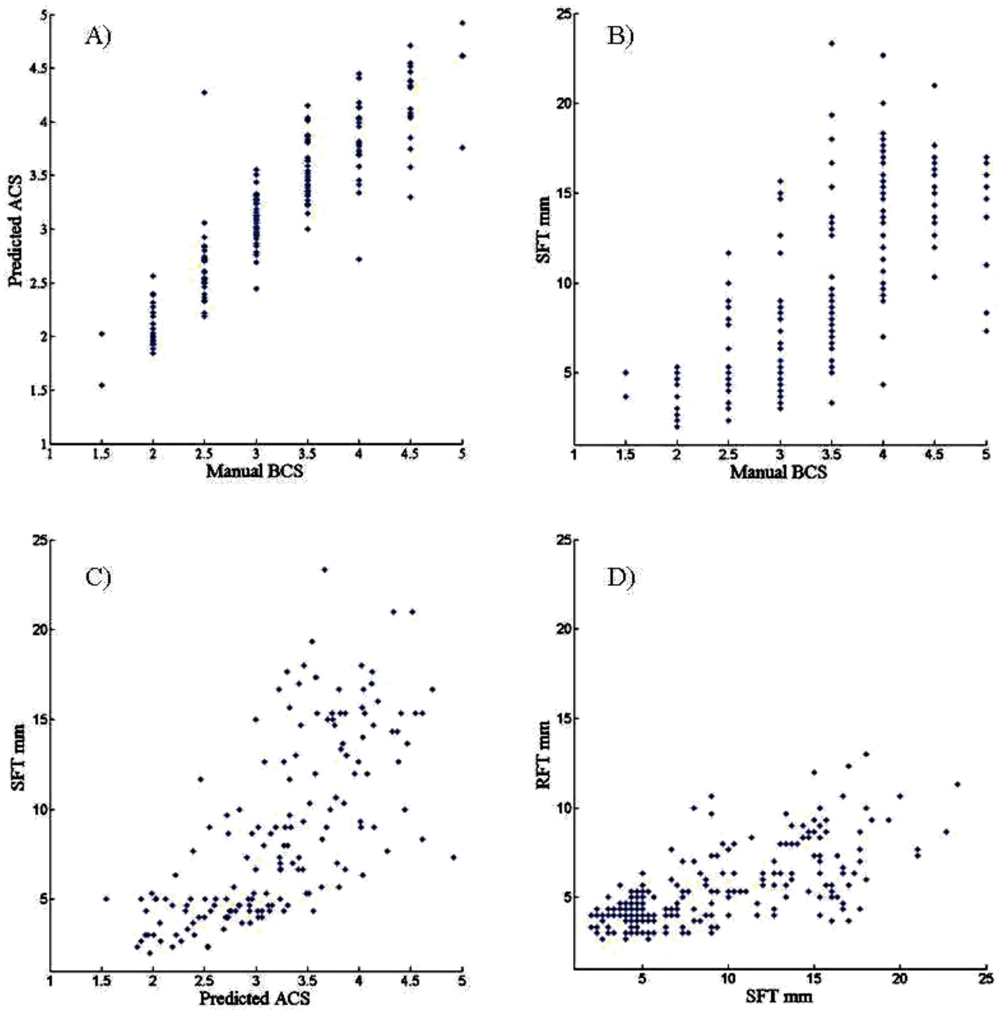


Figure 11. Scatter plots between the parameters giving the highest and significant correlation coefficients; A) Scatter plot between manual BCS and predicted automatic body condition score (ACS) (R= 0.9; P< 0.001), B) Scatter plot between manual BCS and sacral subcutaneous fat thickness (SFT) (R= 0.75; P< 0.001), C) Scatter plot between SFT and predicted ACS (R= 0.7; P< 0.001) and, D) Scatter plot between SFT and rib subcutaneous fat thickness (RFT) (R= 0.7; P< 0.001).

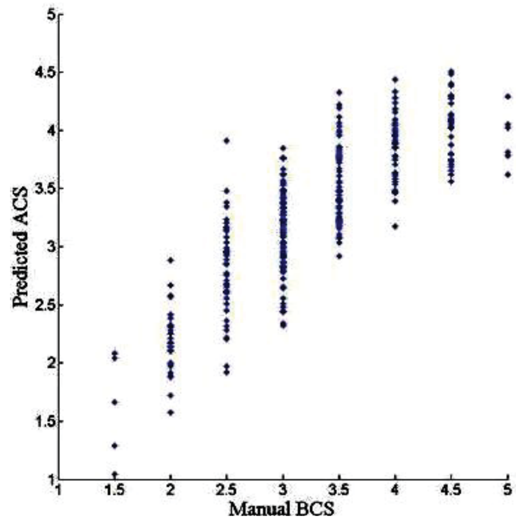
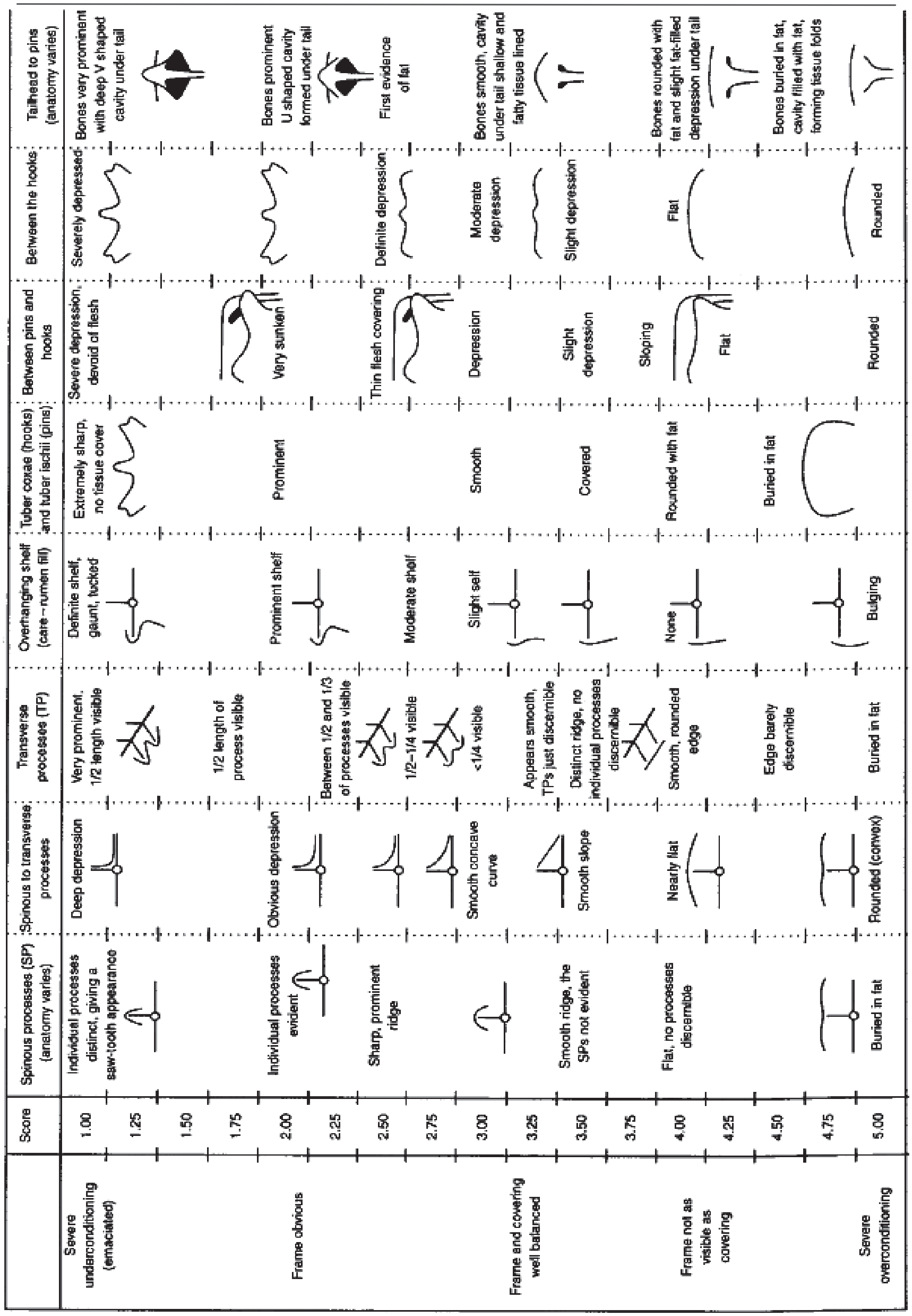


Figure 12. Scatter plot, of the 3D imaging based automatic body condition scoring model's validation, between predicted automatic body condition score (ACS) and manual BCS (R= 0.83).

APPENDIX

1. Chart for body condition scoring in dairy cows (Edmondson et al., 1989).



2. Chart for body condition scoring of Norwegian Red breed dairy cows (Gillund et al., 1999)

	Holdpoeng 2,0	**Holdpoeng 2,5**	**Holdpoeng 3,0**
			
Rygg/ryggtakker	Hver enkelt ryggtakk tydelig	Skarp, utstående rygglinje	Noe avrundet rygglinje
Området mellom ryggtakker og sidetakker	Tydelig innsunket	Tydelig konkav bue	Lett konkav bue
Hofteknoker og setebeinsknoker	Utstående og tydelig kantete	Noe utstående og litt kantete	Jevne, ikke kantete
Halegropa	Framstående knokler, U-formet rom under halerota	Uthulet, men tendens til fettavleiring	Avrundede knokler, grunn halegrop med noe fettavleiring
	Holdpoeng 3,5	**Holdpoeng 4,0**	**Holdpoeng 4,5**
			
Rygg/ryggtakker	Avrundet rygglinje, ryggtakkene er ikke tydelige	Flat, ingen ryggtakk tydelig	Flat, tydelig fettlag
Området mellom ryggtakker og sidetakker	Svak konkav bue, nesten jevn helling	Nesten flat	Svak konveks bue
Hofteknoker og setebeinsknoker	Tildekket med noe fett	Avrundet med fett	Betydelig fettfylde
Halegropa	Avrundede knokler, grunn hale-grop med tydelige fettavleiring	Avrundet, utfylt med fett. Antydning til vevsfold ved halefeste	Knokler tildekket, gjemt i fett, tydelige vevsfolder

Nr	Titel och författare	År
280	Use of market crop wastes as feed for livestock in urban/periurban areas of Kampala, Uganda 15 hp C-nivå Emma Selberg Nygren	2009
281	Capacity studies on DeLaval's sort gate DSG10 30 hp E-nivå Johanna Karlsson	2009
282	Metanproduktion hos mjölkkor utfodrade med hög andel grovfoder Methane emissions from dairy cows fed high levels of forage 30 hp E-nivå Rebecca Danielsson	2009
283	Minskade andelar kraftfoder i foderstaten under betesperioden - effekt på mjölkavkastning och betesbeteende hos mjölkkor Decreased concentrate levels in the diet during the grazing season – effects on milk yield and grazing behaviour of dairy cows 30 hp E-nivå Karin Alvåsen	2009
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285	Validation of rumination measurement equipment and the role of rumination in dairy cow time budgets 30hp E-nivå Erika Lindgren	2009
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287	The Importance of Shade for Dairy Cattle in Sweden 30 ph E-nivå Maria Andersson	2009
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