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Swedish University of Agricultural Sciences
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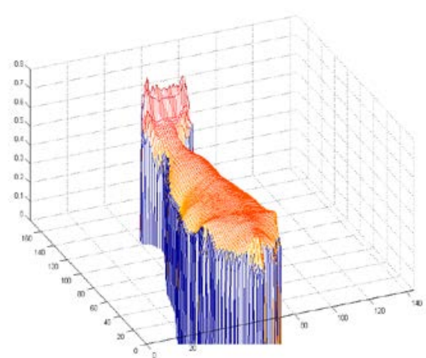

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ABSTRACT

The main aim of this MSc thesis was to investigate the possibility of using three dimensional (3D) imaging technique for automatic estimation of body weight in dairy cows of two breeds; Swedish Holstein and the Swedish Red Breed (SRB). Reference data for validation of automatic BCS in SRB has been collected in previous studies and an important part of this study was to collect reference data on one more breed; the Swedish Holstein. Data collection lasted from April to July, 2010 and was performed at Jälla agricultural school, Uppsala. The data collection included 120 dairy cows, 70 of the SRB and 40 Swedish Holstein. Body weight and 3D images were collected automatically twice daily. Manual body condition score (BCS) as reference data was performed once a week and measurements of back fat thickness were carried out at three occasions during the data collection period. The image analysis showed that the camera had difficulties to identify the shape of the body in cows with black pigment, and therefore, only cows of SRB were included in the results. Data was analyzed by linear regression and the highest correlations were found between estimated body weight by camera and measured body weight by scale ($R=0.87$; $P< 0.001$) and BSC estimated by camera and manual BCS ($R=0.84$; $P<0.001$). A day to day variation of 5.33%, 2.83 % and 7.01 % was found for body weight estimated by camera, body weight measured by scale and automatic BCS respectively. It was concluded that estimations of body weight can be performed by the 3D imaging technique and that correlation between manual BCS and automatic BCS is in agreement with previous studies. The repeatability, precision and sensitivity of the method were good but estimation of body weight would probably be improved by including BCS, milk yield and rumen fill degree in the model. Application of this product should focus on identifying changes in physical state of the animal and could then be a powerful tool monitoring heard health and fertility.

Key words: dairy cows, body weight, automatic body condition scoring, three dimensional imaging

SAMMANFATTNING

Syftet med detta examensarbete var att undersöka möjligheten att använda tredimensionell (3D) bildteknik för att automatiskt skatta vikt hos mjölkkor utav två raser; Svensk Holstein och Svensk rödbrokig boskap (SRB). Referensdata för validering av automatisk hullbedömning har utförts i tidigare studier men bara på SRB och därför var en viktig del i denna studie att samla mer referensdata från ytterligare en ras; Svensk Holstein. Datainsamlingen pågick från och med april till och med juli 2010 och genomfördes på Jälla lantbruksgymnasium, Uppsala. I datainsamlingen ingick 110 mjölkkor, 70 SRB och 40 Svenska Holstein. Kroppsvikt samt 3D bilder samlades automatiskt två gånger dagligen. Som referens till automatisk hullbedömning utfördes manuell hullbedömning en gång i veckan samt ultraljudsmätningar av underhudsfettet, vilka utfördes vid tre tillfällen. Bildanalysen visade på att kameran hade svårigheter att skatta kroppsytan hos kor med svarta pigment och därför inkluderades bara kor av SRB ras i resultaten. Data analyserades med linjär regression och den högsta korrelationen hittades mellan kroppsvikt skattad av kameran och vågens uppmätta kroppsvikt ($R=0.87$; $P< 0.001$) samt hullbedömning skattad av kameran och manuell hullbedömning ($R=0.84$; $P<0.001$). En daglig variation på 5.33%, 2.83 % och 7.01 % hittades på kroppsvikt skattad av kameran, vågens uppmätta kroppsvikt respektive kamerans hullbedömning. Slutsatsen var att kroppsvikt kan skattas med hjälp utav 3D bildteknik och att korrelationen mellan kamerans hullbedömning och manuell hullbedömning var i enighet med tidigare studier. Repeterbarheten, precisionen samt känsligheten i metoden var goda men skattningen av kroppsvikt skulle troligtvis bli ännu bättre om faktorer sådana som hullpoäng, mjölkmängd och vomfyllnadsgrad inkluderades i modellen. Applikationen i denna produkt bör främst fokusera på att identifiera fysiska förändringar hos kon, då kan den bli ett viktigt verktyg för övervakning av hälsa och fertilitet på stora gårdar.

Nyckelord: mjölk kor, kroppsvikt, automatisk hullbedömning, tredimensionell bildteknik

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INTRODUCTION

The dairy farming of today puts high demands on both animals and farmers as size of dairy farms grows and the demand to keep labor costs at low levels increases, a high milk yield for each individual cow is required. The possibility to convert body fat reserves into milk is a fundamental function for lactation and in early lactation the daily energy output in milk is larger than energy intake, in this state of negative energy balance milk production is supported by mobilized body reserves (Bewely and Schuntz, 2006; Schröder and Staufenbiel, 2008). This period, close after calving is sensitive and the cow extends a higher risk of metabolic disorders that might impair the upcoming lactation as well as disturb fertility (Schröder and Staufenbiel, 2006; Bewely and Shutz, 2008). For the farmer, impaired fertility as well as diseases contribute to the largest economical losses and cow welfare is seriously affected (von Keyserlingk *et al*., 2009). Technical development of automatic monitoring of heard performance and health is therefore of great interest and it is important to find early indicators of disease (von Keyserlingk *et al*., 2009). For instance, measuring the rate of body weight change has been suggested as a helpful indicator of dairy herd performance (Maltz *et al*., 1997; Kohirumaki *et al*., 2006) as well as estimation of energy content in the body, which can be performed by body condition scoring (BCS) (Schröder & Staufenbiel, 2006). There are potentially large benefits of measuring both body weight and BCS continuously in dairy herds, in order to detect changes of the state of the animal and enable suitable changes in management in time to avoid impaired production.

However, sufficient frequency of body weight measurements and body condition scoring are not easy to accomplish; body weight is often measured using a scale that the cows walk through which can be stressful for the animals as well as labour intensive for the farmer. Furthermore, the use of the output data from body weight measurements is often poor and not integrated into herd management software. Also body weight data does not tell anything about the composition of the body, which BCS might do. BCS also involves high labour costs and it may even be hard to score the cows as often as necessary to obtain sufficient information that can be used in herd management. There is a need to automate the process of BCS as well as make it easier to measure body weight with of a higher frequency.

Different methods for automatic body condition scoring by imaging technique have been investigated (Leroy *et al*., 2005; Bewery *et al*., 2008; Krukowski, 2009; Foschi, 2009) but neither of these methods have been completely automatic or included body weight in the estimation. By including BCS in an estimation model predicting body weight or vice versa the accuracy of predicting the cows' physical state increases (Enevoldsen and Kristensen, 1997). The technique to estimate BCS trough three dimensional (3D) imaging has been initiated but the technique needs to be refined and measurements of body weight are to be included for application on dairy farms. Furthermore, studies have only been performed on the Swedish red breed (SRB) (Krukowski, 2009; Foschi, 2009) and it is therefore important perform studies that include cows of different breeds since it is known that there are differences between breeds regarding BCS (Koenen *et al*., 2001). The main aim of this MSc thesis was to investigate the possibility of using 3D imaging for automatic estimation of body weight in dairy cows of two breeds; Swedish Holstein and SRB. Furthermore, the study aimed to collect reference data for the validation of automatic BCS by 3D imaging of dairy cows of two different breeds and to determine day-to-day variation in estimates of body weight and body condition, in order to describe the repeatability, precision and possible sensitivity of the method. Finally, it was important to discuss the applicability of the method on farm level.

LITERATURE REVIEW

Composition of the dairy cow body

The composition of the dairy cow body is in constant change because of the adaptations to lactation and pregnancy. Variation in body water content is positively correlated to lactation stage as well as milk yield, and their relationship is linear (Yan *et al*., 2009). The variation in water content in the body is greater for pre partum and early lactation cows than for late lactation cows (Andrew *et al*., 1994; Yan *et al*., 2009). Yan *et al*. (2009) suggests that more water is stored in the body of high yielding cows due to higher dry matter intake, compared with cows with a lower milk yield. For very thin cows, changes in amount of water in tissue, e.g. dehydration, could be mistaken for change of body protein or fat (Otto *et al*., 1991).

The proportion of protein content in the body is relatively constant (Andrew *et al*., 1994; Yan *et al*., 2009) and the relationship between proportion of protein and body weight is linear (Reid and Robb, 1971; Gibb and Ivings, 1993). The relationship between BCS and protein content in the body seems to be diverse depending on body condition; for lower BCS (score :: 3.0) there is a wide range in the percentage of body protein between individuals while for higher BCS (score 2 3.75) the percentage of body protein seems to be similar between individuals. The relationship between BCS and amount of total body protein is however negative (Otto *et al*., (1991).

Fat is the most variable component in the body of lactating dairy cows (Reid and Robb, 1971; Schröder and Staufenbiel, 2006; Yan *et al*., 2009) as well as the most important energy store (Schröder and Staufenbiel, 2006). The proportion of fat deposit is influenced by nutrition (Andrew *et al*., 1994; Yan *et al*., 2009), stage of lactation (Andrew *et al*., 1994) and lactation number. In early lactation, fat from adipose tissue is mobilized to support milk production (Schröder and Staufenbiel, 2006). Changes in amount of fat in the body are also related to genetics in a large extent (Koenen *et al*., 2001; Schröder and Staufenbiel, 2006). The amount of mobilized fat can range between 40 and 60 kg in high yielding dairy cows (Andrew *et al*. 1994; Schröder and Staufenbiel, 2006). The amount of fat in the body is similar in first and second lactation but higher in third and higher lactation (Yan *et al*., 2009).

Energy balance

In early lactation, the energy needed for milk production exceeds the daily energy intake, (Moe *et al*., 1971; Reid and Robb, 1971; Schröder and Staufenbiel, 2006), see Figure 1. Therefore, body fat reserves are mobilized to compensate the lack of sufficient nutritional intake needed to maintain the high milk production (Bewely and Schuntz, 2006; Schröder and Staufenbiel, 2008). Up to one third of the energy in milk derives from adipose tissue energy reserves (Bewely and Schutz, 2006). Negative energy balance, calculated as the difference between energy intake and energy output in milk, is then a fact (Bewely and Schuntz, 2006; Schröder and Staufenbiel, 2008). The negative energy balance usually lasts for about 8 weeks after parturition, but the length of this period varies depending on the dry matter intake, milk yield and the body condition before parturition (Schröder and Staufenbiel, 2006; Bewely and Schuntz, 2008). The peak in milk yield usually occurs before the animal returns to energy balance (Wood *et al*., 1980) while the ability for dry matter intake reaches its maximum when milk yield starts to decline (Maltz *et al*., 1997).

Neither depletion nor replenishment of body fat reserves should exceed certain limits. Over- and under conditioning can cause problems regarding on milk yield and composition, fertility and health as well as digestive disorders (Schröder and Staufenbiel, 2006; Bewely and

Schuntz, 2008). Genetics also influence energy balance, thus cows selected for a higher milk yield mobilize the reserves in their adipose tissue faster (Koenen *et al.*, 2001). Some breed differences regarding negative energy balance have been noted, some breeds e.g Friesian seem to recover from it at a much faster rate than for instance Jersey or Ayrshire do (Wood *et al.*, 1980).

Methods of estimating energy reserves in dairy cattle

Estimation of energy content in the cow body can be based on chemical analysis of the body composition from slaughtered animals (Andrew *et al.*, 1994; Yan *et al.*, 2009), blood- or milk sampling for metabolic and hormonal factors (Reist *et al.*, 2002) or by urea dilution technique (Agnew *et al.*, 2005). More common methods of estimating energy status of the cow is by measuring the body weight (Schröder and Staufenbiel, 2006; Bewely and Schutz, 2008), ultrasound measurements of the back fat thickness (Mizarch *et al.*, 1999; Jaurena *et al.*, 2005) or BCS (Wildman *et al.*, 1982; Edmonson *et al.*, 1989; Ferguson *et al.*, 1994; Gillund *et al.*, 1999; Roche *et al.*, 2004), which is the most common method (Schröder and Staufenbiel, 2006; Bewely and Schutz, 2008). All methods have limitations although the techniques for chemical analysis, urea dilution technique and sampling of blood or milk are the most expensive and somewhat difficult to perform on a regular basis and therefore mostly suitable for research purposes (Schröder and Staufenbiel, 2006; Bewely and Schutz, 2008). Body weight is not a good estimate of energy reserves of dairy cattle since body weight is influenced by many factors, for instance gastrointestinal content, pregnancy and milk yield (Schröder and Staufenbiel, 2006; Bewely and Schunz, 2008).

***Measurements of back fat thickness*.** Thickness of the subcutaneous back fat can be obtained through ultrasonic measurements. This method can either be used to estimate body condition itself or as a verification of the body condition scoring systems (Jaurena *et al.*, 2005; Schröder and Staufenbiel, 2006; Bewely and Schutz, 2008; Mahlkow-Nerge and Malchau, 2009). Ultrasonography is an easy measuring technique and the layer of subcutaneous back fat can be measured with a precision of 0.1. mm, although the thickness of the skin, 5-6 mm, is hard to exclude in the measurement (Schröder and Staufenbiel, 2006). The measurements can either be performed at the sacral location of the rear end between the hooks and the pins, the loin back area (Schröder and Staufenbiel, 2006) or between the 12th and the 13th rib at the loin rib area (Mizarch *et al.*, 1999). The fat deposit on the loin back area is positively correlated to BCS (Jaurena et al., 2005) and the loin rib area tends to be more sensitive to change in body condition than the loin back area (Mizarch *et al.*, 1999). However, measurements at the loin back area could sometimes be impossible to carry out (Mizarch *et al.*, 1999). This might be explained by the findings of Otto *et al.* (1999) that no dissectible fat is present at the location of section between the 9th and 11th rib for BCS 3 and below on a 5 point scale. Schröder and Staufenbiel (2006) suggest performing measurements of back fat thickness in the sacral region between the hooks and the pins; the back fat does not change much in a range of some centimeters and high correlation have been found between measurements of back fat thickness and total fat deposit on the body of the cow at this area.

BCS is positively and linearly associated with depth of back fat thickness, increasing 0.25 units 5 per 10 mm of back fat according to Jaurena *et al.* (2005). Schröder and Staufenbiel (2006) suggests that 0.5 unit corresponds to 5 mm of back fat thickness while Machlkow-Nerge and Malchau (2009) claims that at a given BCS significant lower back fat thickness is measured, Table 1.

BODY CONDITION SCORE

Body condition scoring is best described by Schröder and Staufenbiel (2006) as a "subjective estimate of the metabolizable energy reserves in the adipose tissue". The method mainly used, when scoring the body condition, is a scale, using visual or tactile evaluation of the cow's body shape to categorize the amount of adipose tissue. The body condition is divided into categories represented by numbers. For dairy cattle, the most used scales have 5, 8 or 10 points (Roche *et al*., 2004) but the unit increments may vary and therefore, number of scores is quite similar. Some scales score the body as a whole unit while others only score certain body locations, these are scored separately and then integrated to an absolute score (Wildman *et al*., 1982; Ferguson *et al*., 1994; Roche *et al*., 2004). Combinations of both methods exist as well (Edmonson *et al*., 1989; Gillund *et al*., 1999). For instance, some of the most cited scales are described by Wildman *et al*. (1982), Edmonson *et al*. (1989) and Ferguson *et al*. (1994) and have certain common characteristics; the scales are 1 to 5 point scales with 0.25 units of increment. Whit such a scoring system the cow can receive 17 different scores. Usually, low numbers represent thin animals and high numbers represent obese animals (Bewely and Schutz, 2008).

Scoring the body condition

The anatomical details examined when scoring body condition may vary between scales, but the main regions observed are normally loin, pelvis and the tail head. In more detail, regions like spine, short ribs, hook- and pin bones as well as the depression between hooks and pins (thurl) and the sacral ligament have been suggested as important locations to look at to determine body condition through BCS assignment (Wildman *et al*., 1982; Edmonson *et al*., 1989; Otto *et al*., 1991; Fergusson *et al*., 1994; Bewerly and Schutz, 2008), Appendix 1. There is some disagreement on whether it is important to score multiple body locations or not (Bewerly and Schuntz, 2008). Gillund *et al*. (1999) suggests that a score from one single area is a good predictor of body condition. Furthermore, the score given with regard to the pelvic area, the hooks and pins, is the most closely associated to the absolute score (Edmonson *et al*., 1989). Certain body locations tend to give higher scores, e.g. the spine, hooks and pins, other lower scores, tail head and the overhanging shelf; the rumen fill (Edmonson *et al*., 1989). Changes in specific body regions are associated with changes in absolute BCS (Fergusson *et al*., 1994). Otto *et al*. (1991) found that an increase in BCS was associated with an increased heart girth. There might also be a risk of over or underestimation in body condition when scoring cows near calving due to the relaxation of tail head ligaments (Bewely and Schutz, 2008). On the other hand, younger cows are often scored with higher scores with regard to body condition (Otto *et al*., 1991).

BCS and scorer. Although body condition scoring is a subjective method, the repeatability and precision of trained scorers has proven to be high (Edmonson *et al*., 1989; Ferguson *et al*., 1994; Schröder & Staufenbiel, 2006). When scoring with a chart, the accuracy is the same for all cows (Edmonson *et al*., 1989). Furthermore, scoring of certain body regions, for instance between hooks and pins, and scoring of hooks shows no or little variation between scores (Edmonson *et al*., 1989). Edmonson *et al*. (1989) found no differences between experienced and inexperienced scorers in accuracy of body condition scoring. Contrary, Ferguson *et al*. (1994) suggests that the lower correlation between scorer and BCS is due to lack of experience. According to Bewely and Schutz (2008) inexperienced scorers tend to give scores near the end points of the BCS scale.

Limitations. The scorer can usually only separate the BSC into 0.25- unit increments from a score of 2.5 to 4.0 on a 5 point scale. For scores lower than 2.5 or higher than 4.0, the unit increments can often only be separated by 0.5 (Ferguson *et al.*, 1994). This might be explained by the fact that change in absolute BCS is associated with distinct changes in specific body regions which are more difficult to see in animals with extreme body condition i.e. lower than 2,5 or higher than 4.0 (Ferguson *et al.*, 1994). Change in body condition has a greater influence on milk yield than actual body condition at parturition (Schröder and Staufenbiel, 2006) and to detect when the change begins, scoring must be carried out very often.

Body condition scoring as management tool

Scoring body condition is important when estimating the amount of body fat loss in upcoming lactation. By scoring cows for body condition and separating fat cows from thin, with regard to feeding regime, there is a good chance of improving performance of the cow in upcoming lactation (Schröder and Staufenbiel, 2006). Monitoring BCS could also be a valuable tool for monitoring fertility (Kadarmideen, 2004; Bewely and Schutz, 2008; Roche *et al.*, 2009; van Straten *et al.*, 2009) health (Bewely and Schutz, 2008; Roche *et al.*, 2009) and breeding in general (Koenen *et al.*, 2001; Berry *et al.*, 2002; Kadarmideen, 2004; Schröder and Staufenbiel, 2006).

***BCS and fertility*.** Reproduction is one of the most important traits of dairy cows and the effect of body condition on reproductive success has been investigated in several studies (Kadarmideen, 2004; Bewely and Schutz, 2008; Roche *et al.*, 2009; van Straten *et al.*, 2009). Most studies show positive correlations between BCS at calving and fertility (Kadarmideen, 2004; Roche *et al.*, 2009) and cows in positive energy balance tend to have shorter intervals to insemination after calving (Kadarmideen, 2004) while for cows in negative energy balance, the situation is the opposite (Butler and Smith, 1989; van Straten *et al.*, 2009). For reproductive success it is suggested to maintain cows condition at BCS 3.0 to (Butler, 2000) 3.5 (Roche *et al.*, 2007) on a 5 graded scale, especially in late pregnancy (Schröder and Staufenbiel, 2006) and early lactation (Butler, 2000; van Straten *et al.*, 2009).

The high energy demand in early lactation and nutrient supply might be one of the most important factors affecting reproductive performance (Butler and Smith, 1989; Butler, 2000; Roche *et al.*, 2009). This might be due to the fact that under nutrition has a negative impact on release of luteinizing hormone which is necessary for normal ovarian function (Butler and Smith, 1989; Butler, 2000). Overfeeding can also give problems with reproduction, but there are different opinions on the effects of overfeeding on fertility (Butler and Smith, 1989; Bewely and Schutz, 2008) and lowered fertility has mainly been associated with decreased BCS at first insemination (Bewely and Schunz, 2008). On the other hand, over conditioned cows have lower feed intake capacity and show higher mobilization of fat after parturition which leads to a more severe negative energy balance than in thinner cows (Butler; 2000; McNamara *et al.* 2003; Bewely and Schutz, 2008). The associated accumulation of triacylglycerols in the liver is linked to impaired fertility e.g. longer interval to first ovulation (Butler and Smith, 1989). McNamara *et al.* (2003) found no relationship between prepartum diet and fertility, despite differences in energy balance among cows fed with different energy density.

Higher milk production has also been associated with fertility problems in dairy cattle (Butler and Smith, 1989; Butler, 2000) and selection for high milk production is suggested to be associated with cows with low BCS i.e. thin animals (Kadarmideen, 2004). The loss of BCS is also higher in high yielding cows compared to cows with lower milk yield (Gallo *et al.*, 1996).

BCS and health. There have been different findings regarding the relationship between disease, BCS and BCS change (Bewely and Schutz, 2008; Roche *et al*., 2009). However, it is more likely that cows in negative energy balance develop clinical problems like ketosis, mastitis, retained placenta or suffer from displaced abomasum than cows in positive energy balance (Mulligan and Doherty, 2008). Negative energy balance can be prevented by good management and nutrition in the end of pregnancy (McNamara *et al*., 2003; Mulligan and Doherty, 2008). Different herd-level factors such as stocking rate or level of concentrate in the diets have been reported to influence BSC (Roche *et al*., 2009). Over conditioned dry cows are more likely to suffer from diseases, i.e. fatty liver or ketosis (Mulligan and Doherty, 2008; Bewely and Schutz, 2008) Berry *et al*. (2007) found a reduction in somatic cell count among first and second parity cows with a higher BCS at calving, but for third parity cows the relationship was reversed. Furthermore, the authors' claim that changes in body condition in early lactation does not influence udder health excessively. Kadarmideen (2004) found a favorable genetic correlation between BCS and somatic cell count but the relationship was rather weak. The relationship between BCS and disease is not clear and is probably a matter of several dimensions that are worth more interest.

BCS and genetics There are breed differences regarding BCS (Koenen *et al*., 2001; Bewely and Schutz, 2008). Breeds with dual purpose have in general more muscle than dairy breeds, (Bewely and Schuntz, 2008; Roche *et al*., 2009). Therefore, a change in BCS mainly reflects change in fat reserves in dairy breeds contrary to the dual-purpose breeds, where change in BCS also to a large extent reflects change in muscle tissue (Bewely and Schutz, 2008). There are also differences in BCS regarding dairy breeds for instance, higher BCS have been found in Jerseys compared to Holstein (Bewely and Schutz, 2008) and Koenen *et al*. (2001) found a decrease in BCS as the percentage of Holstein genes increased in crossbred dairy cows.

Heritability for BSC has been suggested to be around 0.27 by Kadarmideen (2004). Berry *et al*. (2002) found that the heritability for BCS ranges from 0.27 to 0.37. Similar findings were made by Koenen *et al*. (2001) suggesting that the heritability of BCS could range from 0.24 to 0.38 depending on breed and lactation period. Change in amount of fat in the body is related to genetics in a large extent (Koenen *et al*., 2001; Schröder and Staufenbiel, 2006) but for BCS change, the heritability seems to be lower, from 0.02 to 0.10 (Berry *et al*., 2002).

Techniques for automatic estimation of BCS

Due to increasing numbers of animals on modern dairy farms, scoring the body condition involves high labour costs and it may even be impossible to score the animals as often as it would be necessary to detect changes in BCS before the change has become too large. Therefore, other methods than visual body condition scoring have been investigated, for instance automatic scoring with assistance of images and image analysis (Leroy *et al*., 2005; Bewery *et al*., 2008; Negretti *et al*., 2008; Krukowski, 2009; Foschi, 2009).

The 2D technique. Leroy *et al*. (2005) investigated the possibility for automatic estimation of BCS with a 2D imaging technique on cows of the Holstein breed. Images were taken from rear view as the cow was scored simultaneous on a 1 to 5 scale. To extract the cow body from the image, a binary image was created and 19 contour points on the cow body were chosen for observation. BCS was then estimated by comparing contour of the test cow with contours of reference cows with known BCS. The deviation between estimated BCS by camera and score given by assessor was on average 0.27 units, the same error as the assessor according to the authors.

In a study by Bewely *et al*. (2008) Holstein-Friesian cows were photographed with a black and white digital camera when passing a scale after morning milking. The photographs were taken at the rear end of the cow and 23 anatomical points that had potential influence on BCS were chosen for analysis. The points were manually identified but a computer program calculated the outline of the cow from the identified anatomical points. The angles of seven different body parts, for instance angle between hooks and pins, were calculated in the same way. Two different BCS scales were used, the American scale (US) and the United Kingdom scale (UK). Result from this study showed that 100 % of the predicted BCS were within 0.5 points of the actual US score BCS and 92.97% within 0.25 points. For the UK BCS 99.87% were within 0.5 points and 89.95 within 0.25 points of the actual BCS. Adding tail head depression did not improve the model.

Negretti *et al*. (2008) developed a visual image analysis system that estimated both body weight and BCS in buffalos. The buffalos were weighed on a scale and the body was measured at several locations. Photographs of the side profile and the area of the hindquarters were taken simultaneously with body condition scoring. For estimation of the body condition, the angle between the back and the hooks as well as the area behind the hooks was used. The correlation with BCS was significant (R=0.88).

The 3D technique. Krukowski (2009) photographed cows manually with a 3D camera in order to develop an algorithm predicting BCS on SRB cows as well as cows of the Swedish low land breed (SLB). Two different viewing angles were studied; one showing the dorsal and posterior parts of the cow, the spinal process, the tail head, hooks and pins, and the other showing the area between the pins and the hooks as well as the edge of the spinal process, the dorsal and lateral parts of the cow. Two separate data sets were collected, one for method development, evaluation and model predicting BCS another for validation of the development model. Same cows were used in both sets but images of black and white SLB cows were excluded in the training set due to technical issues. Results showed that 100 % of the predicted BCS were within 0.5 points of the BCS given by the assessor and 79 % within 0.25 points. The author points out advantages with the 3D method i.e. the model reacts to changes of BCS over time.

Foschi (2009) advanced with a different 3D technique by adding measurements of back fat thickness as an additional reference to BCS. Parameters such as body weight, milk yield and content of fat, protein and lactose in milk as well as plasma metabolites were examined as possible references in the development of an automatic body condition scoring model. However, BCS and back fat thickness measurements showed the highest significant correlations with automatic estimated BCS (R=0.83 and R=0.75 respectively). Because of its continues nature, back fat thickness was suggested to be used as an additional and more objective reference of body condition.

BODY WEIGHT

Body weight of cattle is often used as a management tool for diet calculation, determining insemination date of heifers and as a measure of body size when housing systems are planned. Body weight affected by many different factors such as frame size (Schröder and Staufenbiel, 2006), dry matter intake (Wood *et al*., 1980; Andrew *el al*., 1994), growth (Swanson, 1966; Miller *et al*., 1968; Koenen *et al*., 1999), pregnancy (Prior and Laster, 1979), parity (Enevoldsen and Kristensen, 1997) and lactation (Wood *et al*., 1980; Jaurena *et al*., 2005). Development of udder tissue and mass also affects body weight (Gibb and Ivings, 1993) but is a small factor compared to the above mentioned factors. Changes in body weight do not necessarily reflect the energy status of the dairy cow (Andrew *et al.*, 1994; Schröder & Staufenbiel, 2006). The case is rather that a cow could be show a higher body weight by an increase in dry matter intake (Andrew *el al.*, 1994) that leads to a higher rumen fill (Hartnell and Satter, 1979) but in fact losing in body tissue due to mobilization of fat to support lactation (Andrew el al., 1994). Some differences in type of diet regarding body weight change during lactation have been found by Korver *et al*. (1985) while Reynolds *et al.* (2004) could not find any effect on average body weight by feeding with supplement feed in late gestation. According to Woods *et al.* (2005) the feeding regime only affects the weight of the gastrointestinal tract. Wood *et al*. (1980) suggested that body weight is affected by output e.g. changes in body weight are substantially reflected by increasing milk yield. Contrary, Korver *et al*. (1985) did not find any affect on body weight change with regard to the genetic potential for milk production capacity. Overall, the body weight at calving has a positive correlation with weight loss during lactation but there is however a large individual variation (Touchberry and Batra, 1975; Koenen *et al.*, 1999).

Methods of estimating body weight

Most commonly, body weight is measured using a scale which the cows walk trough. However, there are some other methods as well, for instance measuring various body parts of the cow (Heinrichs *et al*., 1992; Enevoldsen and Kristensen, 1997; Schröder and Staufenbiel, 2005). Measurements of heart girth and hip width have the highest correlation with body weight (Enevoldsen and Kristensen, 1997) but body parts such as heart girth, wither height, and body length could also be included when predicting body weight (Heinrichs *et al*., 1992; Schröder and Staufenbiel, 2005). By adding BCS and days in milk to the model, a more precise estimation of body weight could be achieved (Enevoldsen and Kristensen, 1997; Yan *et al*., 2009). Frame size also affects body weight (Schröder and Staufenbiel, 2006). Negretti *et al.* (2008) measured the area of the lateral profile as well as area of the hindquarters of hundred buffalos in order to estimate body weight. High correlations were found both between body weight and lateral profile area (R=0.98) as well as area of hindquarters (R=0.94) and body weight.

Body weight can also be predicted by using different equation models (Enevoldsen and Kristensen, 1997; Ellis *et al*., 2006: Yan *et al*., 2009). Furthermore, to avoid errors in body weight estimation, empty body weight could be estimated. Empty body weight could be defined as body weight excluding gastrointestinal contents, fetus, placenta and amniotic fluids (Andrew *et al*., 1994). The difference between body weight and empty body weight can range between 45 and 70 kg (Gibb and Ivings, 1993). Empty body weight is strongly correlated to body weight and when factors such as BCS and stage of lactation are added, predictions of empty body weight and empty body composition are even more reliable (Yan *et al*., 2009).

Main factors affecting body weight

Lactation. The body weight is higher during dry period than during lactation, (Jaurena *et al.*, 2005) lower after calving (Reynolds *et al*., 2004) and continues to decrease the first one or two months after calving, between early and peak lactation (Miller *et al.*, 1968; Touchberry and Batra, 1975; Koenen *et al*., 1999; Baldwin *et al.*, 2004). The body weight is lowest around lactation week five (Koenen *et al*., 1999) and starts to increase around the 17th week of lactation (Baldwin *et al*., 2004), see Figure 1. The variation in body weight is highest in lactation week 20 to 30 (Maltz *et al*., 1997),.

The body weight increases with lactation number (Touchberry and Batra, 1975; Enevoldsen and Kristensen, 1997; Koenen *et al.*, 1999; van Straten *et al*., 2008), probably due to growth

(Miller *et al*., 1968; Koenen *et al*., 1999) since the largest change in body weight occurs in the first lactation (Miller *et al*., 1968). Furthermore, Miller *et al*. (1968) found that the weight loss ceases after 8 to 9 weeks of lactation for older cows but for first calf cows, the weight begins to increase already in the fourth week of lactation. Cows in first, second and third lactation reach the mean body weight during the lactation earlier after parturition than older cows (Miller *et al*., 1968; van Straten *et al*., 2008). Older cows, in third lactation and above, lose weight during a longer period than younger cows (van Straten *et al*., 2008).

From a genetic point of view, selection for high milk yield has a negative influence on body weight change during lactation. The relationship is somewhat complicated since growth of cows with a generic merit for high milk production might be impaired or the mobilization of body tissue might be superior compared to lower yielding cows (Veerkamp, 1998).

Growth. Growth contributes the most to the changes in body weight in first lactation (Koenen *et al*., 1999). Cows in their first lactation are smaller (Enevoldsen and Kristensen, 1997) but gain more weight than in later lactations (Miller *et al*., 1968). Koenen *et al*. (1999) found growth during first, second and third lactation to be 46 kg, 52 kg and 23 kg respectively and that single body weight observations in heifers are good predictors of mean body weight during the first three parties. Each animal has a mature body size at which the development aims but growth can persist constantly or fluctuate in time (Swanson, 1966). There are differences in growth patterns between individuals, as well as between heifers of different breeds (Swanson, 1966). Composition of the diet also influence growth rate and first grazing can decrease the growth rate temporary (Le Cozler *et al*., 2009).

Fertility. The impact of growth on reproduction and lactation is a more important factor for dairy heifers than actually gaining in body weight (Swanson, 1966). It is the growth rate and not age that determines time for the first breeding, this is due to the positive correlation between growth and fertility (Swanson, 1966; Sejrsen *et al*., 1982). Signs of puberty often occur at a body weight of 250 to 300 kg for Holstein (Swanson, 1966; Le Cozler *et al*. 2009) and 180 to 200 kg for Jersey (Swanson, 1966). Therefore, well fed heifers are normally younger at puberty, since the daily average gain is higher than for heifers fed with poorer nutrition supplement, but the overall body weight at insemination of the heifers is however similar (Le Cozler *et al*. 2009). Further, an undersized heifer has a smaller body size in relation to the fetus and stands a higher risk of complications at calving (Swanson, 1966). On the other hand, overfeeding of heifers that result in overgrowing during the post pubertal stage may impair mammary tissue development (Sejrsen *et al*,. 1982) and parts of the mammary gland may develop abnormally (Swanson, 1960). Monitoring heifer growth rates is therefore an important management tool.

Pregnancy. When using body weight as a management tool or for research purposes, it is important to be able to correct body weight for stage of pregnancy (Silvery and Haydock, 1978). Pregnancy affects body weight in different ways; the weight of uterine fluids increases linearly throughout the entire gestation while the growth rate of the fetus declines. At its highest rate, the fetus grows 130 g per day (Prior and Laster, 1979).

As for the body weight of the dam, differences in body weight between dry period and stage of lactation may reflect growth of the fetus (Jaurena *et al*., 2005). The estimated effect on body weight due to pregnancy is between 30 (Koenen *et al*., 1999) and 60 kg (Andrew *et al*., 1994; Koenen *et al*., 1999). No significant effect of pregnancy was found on body weight for first lactation cows; however the effect was significant but small for cows in their second and third lactation (Koenen *et al*., 1999). Furthermore, it was found that pregnant heifers had less carcass mass than non- pregnant heifers, probably due to mobilization of energy to fetal development and to development of the mammary gland that occurs in late gestation (Scheaffer *et al*., 2001).

There have been some attempts to find techniques to correct body weight for pregnancy using different equation models (Silvey and Haydock, 1978) or by using fetus growth curves for determination of the uterus weight during gestation (Bereskin and Touchberry, 1967). However, as long as the exact length of the gestation period and the birth weight of the fetus are unknown the accuracy is rather low e.g. effect of pregnancy can be estimated with a high accuracy after parturition (Bereskin and Touchberry, 1967). Measurements of paunch girth as predictor on effect of pregnancy have also been investigated. In young cows and heifers, up to 48 months of age, it is not only stage of pregnancy, but growth as well that affects paunch girth. Therefore it is important to separate true growth from pregnancy when assessing measurements of paunch girth (Bereskin and Touchberry, 1967). Rumen fill and fluid volume is also affected by pregnancy; it is greater in early pregnancy but decreases in late pregnancy (Scheaffer *et al*., 2001).

Rumen fill. Rumen fill has an obvious effect on body weight (Berry *et al*., 2006) and the weight of rumen content can range from 68 kg in late lactation up to 98 kg in early lactation (Hartnell and Satter, 1979; Andrew *et al*., 1994). Bath *et al*. (1966) reported lower weights of rumen content, 40 to 60 kg and suggested that the weight of rumen content by itself constituted 11 % of total body weight. Size and weight of the rumen itself is not affected by lactation according to Doreau *et al*. (1984) while Baldwin *et al*. (2004) found that the weight of rumen and intestine increased in mid lactation. There are differences among individuals regarding the size of the rumen and it is clear that rumen size is linked to the size of the cow (Doreau *et al*., 1984) but not to the body condition (Reid and Robb, 1971). The level of fill in the gastro internal tract is highest in early lactation and declines in late lactation remaining on a low level pre-partum (Hartnell and Satter, 1979; Andrew *et al*., 1994). Dry matter intake, and consequently dry matter content in the rumen, decreases during the dry period and is suggested do to so because of space limitations caused by the increasing fetus size (Reid and Robb, 1971; Hartnell and Satter, 1979; Scheaffer *et al*., 2001). According to findings by Reynolds *et al*. (2004) the total digesta and liquid volume does not differ between gestation and lactation but tend to be lower at 10 days post partum.

Since rumen fill is closely related to dry matter intake (Hartell and Satter, 1979; Reynolds *et al*., 2004) it will reflect the feeding behavior of the cow (Andrew *et al*., 1994; Maltz *et al*., 1997). Rumen fill can also reflect drinking behavior. Bath *et al*. (1966) found the gain in rumen content weight, in heifers fed restricted rations, to be due to a higher liquid content in the rumen compared to heifers fed *ad libitum*. The individual saliva production or liquid turnover can also affect total liquid content of the rumen. This was suggested by Hartnell and Satter (1979) as they found a different liquid rumen content among cows with similar water intake. If changes in rumen fill could be estimated, body weight changes could more easily be related to changes in energy content, tissue development and overestimation of energy mobilization due to weight change could be avoided (Moe *et al*., 1971).

Body weight as management tool

Maltz *et al*. (1997) suggested that body weight change could be used as a tool for both diagnostic and management decisions on farm level in a larger extent than it is used today. Since fat is the most variable body tissue component in lactating dairy cows (Yan *et al*., 2009) and increase in body fatness is associated with increase in weight (Reid and Robb, 1971) long term changes of body weight reflect mobilization of body fat. However, body tissue gain or loss could range from 100% of water to 90 % of fat (Reid and Robb, 1971) the cow is probably already in negative energy balance when the weight change is detected. Therefore, Maltz *et al*. (1997) studied changes in body weight by measurements with a high daily frequency. In their findings, the body weight varied 10 to 11 kg weekly and between 1 and 3 kg on daily bases. The authors suggest that the individual daily weight pattern for each cow reflects the cows eating behavior and thereby, cows that stop eating could be detected. The change in feed intake can also be a good indicator of disease (von Keyserlingk *et al*., 2009) van Straten *et al*. (2008) found that body weight change is not linear. In their studies a pattern of 7 and 21 day cycles in body weight were found. Authors claim that the 7-day pattern was associated with feeding strategies and Moe *et al*. (1971) concluded that it is unrealistic to relate tissue energy change to changes in body weight, unless the effects of rumen fill is included. Neither could the effect of pregnancy on body weight and body weight change be excluded (Silvery and Haydock, 1978).

Since change in body weight is associated with disease (Maltz *et al*., 1997; Kohiruimaki *et al*., 2006) or oestrus (Maltz *et al*., 1997; Kohiruimaki *et al*., 2006; van Straten *et al*., 2008; van Straten *et al*., 2009). There have also been attempts to create a dynamic model to predict dry matter intake from body weight (Ellis *et al*., 2006) which could be a valuable tool in herds with cows fed total mixed ration.

Body weight and fertility. Body weight post partum is associated with the reproductive cycling (Butler and Smith, 1989) and specific body weight change patterns have been observed in connection with oestrus (Maltz *et al*., 1997; van Straten *et al*., 2008; van Straten *et al*., 2009). Maltz *et al*. (1997) found a one to three days long lasting drop in body weight, which may start one or two days before standing heat. The fast response in body weight is probably due to the decrease in dry matter intake. This might be compared to milk yield, which responds slower to drops in dry matter intake. It could therefore be concluded that milk yield is in some cases bad as heat indicator whereas body weight responds more clearly (Maltz *et al*., 1997). Cows lacking the 21 day cycle in connection to ovarian activity found by van Straten *et al*. (2008) were more likely to be diagnosed with inactive ovaries. Monitoring these cycles is suggested to be an important management tool for improving fertility (van Straten *et al*., 2008; van Straten *et al*., 2009). In later studies, van Straten *et al*. (2009) suggested that relative body weight loss (%) is a better predictor of impaired reproductive performance than absolute body weight loss (kg).

Body weight and health. Changes in feeding behavior can be sensitive indicators of disease (von Keyserlingk *et al.*, 2009). Kohiruimaki *et al*. (2006) suggest that cows with a small body weight change a month before parturition stand a higher risk of disease post partum. Maltz (1997) found that diseases were associated with a drop in body weight. The decrease in body weight occurred before a decline in milk yield could be detected and 50 percent of the health problems could be detected three days before milk yield dropped by noticing body weight change. The body weight decrease could be detected prior to the day the cow got ill. Sometimes the drop in body weight could be very big, ten times of kg. The deviation from the daily variation in body weight seems to be a better predictor for health issues than notifying changes form the average body weight (Maltz, 1997; Maltz *et al*., 1997). There is also a link between body weight and udder health; body weight is positively correlated with somatic cell count. Clinical mastitis is more likely to occur among cows with increasing body weight pre calving (Berry *et al*., 2007).

Body weight and genetics. Estimates of heritability for body weight are normally high (0.24-0.88), especially when based on several measurements. However, the heritability for body weight changes is lower (0.10-0.27). Correlations between body weight or body weight change and different parameters such as milk yield or dry matter intake are variable. The correlation between milk yield and body weight is actually more dependent on when the body weight is measured (Veerkamp, 1998). The heritability for body weight change is low (Berry *et al*., 2002).

RELATIONSHIP BETWEEN BODY CONDITION SCORE AND BODY WEIGHT

The relationship between BCS and body weight has been widely investigated (Otto *et al*., 1991; Veerkamp, 1998; Gillund *et al*., 1999; Enevoldsen and Kristensen, 1997; Maltz *et al*., 1997; Jaurena *et al*., 2005; Berry *et al*., 2006). There are different suggestions regarding the relationship between BCS and body weight. Some authors suggest no correlations (Wildman *et al*., 1982; Maltz *et al*, 1997) or low correlations (Foschi, 2009) while others suggest moderate correlations (Berry *et al*., 2006) and or high correlations (Veerkamp, 1998). Otto *et al*. (1991) found that body weight increased with increased score group. According to Veerkamp (1998) a large part of the variation in body weight could be described by BCS. Despite the lack of overall correlations, Maltz *et al*. (1997) found a week correlation between maximal body weight and maximal body condition. Further, Maltz *et al*. (1997) suggested that the turning points of body weight- and BCS change do not correlate in a constant manner, and they sometimes contradict each other. During the first weeks of lactation, body weight increases while body condition decreases (Maltz *et al*., 1997). Contrary, Jaurena *et al*. (2005) found the relationship between body weight and BCS to be linear and Otto *et al*. (1991) found body weight to increase with increased score group.

It has been suggested that 1.0 unit increase in BCS corresponds to about 31 to 34 kg increase in body weight (Enevoldsen and Kristensen, 1997; Berry *et al*., 2006) but the pattern is different during the dry- and lactating period; 35 kg and 21 kg respectively corresponding to an increase of one BCS unit (Jaurena *et al*., 2005). Berry *et al*. (2006) found variation of 20 to 35 kg corresponding to one BSC unit with regard to parity. Higher numbers for the relationship between BCS and body weight have also been suggested; one BCS unit corresponding to a change of 74 kg (Gillund *et al*., 1999) or 56 kg (Otto *et al*., 1991) in body weight. However, there might be some errors for these estimations. For instance, before Jaurena *et al*. (2005) corrected body weight for age and frame size, the weight change corresponding to one BCS unit was estimated to 79 kg.

MATHERIAL AND METHODS

Ethical approval

The ethical application for this trial was approved by the Uppsala Local Ethics Committee and the trial was performed in accordance with the Swedish animal welfare regulations. The cows were handled according to normal procedures at the farm during the entire data collecting period.

Data collection period

The data collection was running during 13 weeks, from April to July, 2010.

Animal material. The trial was performed at Jälla agricultural school in Uppsala, a dairy herd owned by the Swedish University of Agriculture. The herd consists of 110 dairy cows of two breeds; 70 cows of the SRB and 40 cows of the Swedish Holstein breed. The cows were kept in a loose housing system, divided into groups according to milk yield and udder health; high yielding cows, average yielding cows and a small group of cows with health issues, e.g. mastitis (groups 1, 2 and 3 respectively). The cows were let out on pasture on the 8^{th} of May and consequently, all cows were housed in one large group from that day. The cows were kept indoors at night, except for group 3 that was kept indoors as a small group during entire data collection period.

At the initial phase of the data collection period the distribution of cows in different lactation stages was 25 % in early lactation (14-100 days in milk), 50 % in mid lactation (100-200 days in milk) and 25 % in late lactation (200-305 days in milk). With regard to lactation number, the distribution was 49 % of the cows in first lactation, 29 % in second, 15 % in third and the remaining, 6 % were in forth lactation or higher. For overview, see Table 2.

Feed. The cows were fed a total mixed ration (TMR) *ad libitum*. The TMR included silage, straw, barley seed, maize, rapeseed meal, soybean meal and concentrate Mingla 30. For further details, see Table 3. The ration was recalculated weekly to fit the milk yield of each group according to the Swedish LFU system (Svenska Lantmännen, 2003). The energy content and composition of the TMR was adjusted according to average milk yield of each group. The feeding ration for group 1 was based on a daily milk yield of 39 kg energy corrected milk (ECM) and for group 2 and 3 the daily milk yield of 32-35 kg ECM. From 8^{th} of May cows of group 1 and 2 were kept in one large group and fed according to a daily milk yield of 32 kg ECM.

Manual data collection

BCS, Rumen fill score and measurements of back fat thickness were collected manually once a week. BCS and rumen fill score was performed on Thursdays between 7 am and 9 am. Measurements of the back fat thickness was carried out at three occasions, in week 2, 5 and 8 of the data collection, on Wednesdays in group 2 and 3 and Thursdays in group 1. Scoring was performed by the same person during the whole period. For overview, see Table 4. Signs of heat or standing heat were registered on daily bases, several times daily by the staff at Jälla.

Body condition scoring. The scale used for BCS was a combination of the scales suggested by Wildman *et al*. (1982) and Ferguson *et al*. (1994). These scales are non breed specific, 1 to 5 point scales with 0. 25 increments where low numbers represent thin cows and high number obese cows. The method mainly visual but palpation of pin bones is recommended .The scales have been combined into a BCS card provided by the Elanco animal health (1997) which was used as support during the scoring (Appendix 2). The BCS card provided by Gillund *et al*., (1999) was used as a complement when scoring SRB cows (Appendix 3). The scoring was performed by the same person at every scoring occasion.

Rumen fill scoring. Scoring the Rumen fill was performed according to a scale by Hulsen (2006). The scale ranges from 1 to 5 were cows with an empty rumen are given low numbers and cows with a filled rumen are given high numbers (Appendix 4).

Back fat thickness. Back fat thickness was recorded using ultrasound technique, Dramiilski Animal profile L, a portable B- mode ultrasound scanner with a linear probe and a frequency of 7.5 MHz. When measuring back fat thickness, the probe was put vertically on the flat area between the hooks and the pins at the sacral location of the cow. The equipment and site for measurement was chosen according to suggestions by Schröder and Staufenbiel (2006). The hair was shaved and a marking was put at the given area of the cow which enabled repeatability of measurement location throughout the data collection period (Figure 2). The probe was put next to the marking at the right side of the cow and a gel for ultrasonography was used for best possible contact with the skin. For each cow, a series of three measurements per occasion were registered and the corresponding images were saved. For the measurement point in the image, see Figure 3.

Automatic data collection

Body weight and 3D images were collected automatically by a special designed installation twice daily during the entire data collection period. The installation was placed in an isle leading from the milking parlour and back to the feeding area and consequently, when the cow left the milking parlour she had to pass the installation after every milking session. The cows were milked with a 12 hour interval at 5 AM and 5 PM every day. The installation consisted of several detached parts (DeLaval ID reader, two DeLaval selection gate to trap a cow, a DeLaval scale, a DeLaval special camera, a PC and Alpro system to record the scale) and was designed as well as provided by staff at DeLaval, Tumba. For further details, see Figure 4, 5 and 6. For this trial, the cows were stopped on the scale for a few seconds which was only necessary for the camera recordings and not for recordings of body weight. The gates also made it possible to get comparable images from each occasion.

Installation parts and functions

Scale. BW was collected with the DeLaval Automatic Weight System (AWS 100) which is a commercial walk trough scale (Figure 5). The scale used in this study is constructed to measure weight as the cow walks through the scale without stopping. Therefore, the weight is calculated by an algorithm from several weighing as the cow by.

Camera. Collection of 3D images was accomplished with a DeLaval Time-of-flight MESA SwissrRanger™ SR4000 camera (MESA TOF), see Figure 6. The camera provides the time-of-flight principle; a technique whereby the distance of an ultra red light that is sent from the camera is reflected by the object of interest and measured. It is the time span of the light traveling form the camera to the object and back to the camera that is measured and this will reflect an image showing the shape of the object. A series of 10 images were collected at each occasion.

Data recording by installation, course of event

As the cow entered the scale (AWS 100), the exit gate was shut and the entrance gate closed behind her. Thereby the cow was stopped on the scale for a few seconds. When entering the scale, the cow was identified by a multi-reader and a signal with the cow's identification number was sent to a computer. The cow was weighed and the weight was stored together with the cow's identification number in Alpro System (DeLaval dairy management system). A signal was also sent to a computer program (alcom listener) controlling the MESA TOF camera and as the signal was received, the camera took 10 images and saved them together with the cow's identification number. Thereafter, the exit gate opened and cow was let out to proceed to the feeding area.

3D images analysis

The cow body was extracted from the 3D image and the body area, length, width and height were used for estimating of body weight (Figure 7). A specific area at the rear end of the cow body (a part of the spinal transverse process), was used for estimating BCS (Figure 8). From this range data, an artificial neural network model was created for estimations of body weight and BCS. The 3D images (Figure 9) were input to the model and output data was the estimated body weight and BCS. This was performed by engineers at DeLaval, Tumba. For estimation of both body weight and BCS, 10 % of the analyzed images were used for training the model and the remaining 90 % of the images were used as a validation set

Statistical analysis

Linear correlations, regressions and scattered plots were performed by using Microsoft Office Excel (2007). The correlations were used to investigate the statistical dependence between collected parameters and their change. The calculated parameters were measurements of back fat thickness; mean values of three measurements at each given measuring occasion were used in the data set. Furthermore, the mean of the back fat thickness was converted into BCS according to the table of Schröder and Staufenbiel (2006), Table 1. Coefficient of variation (CV) was determined for body weight data from the scale and the 3D camera model, for manual BCS and for BCS determined by the 3D camera model using the general linear model (GLM) procedure in SAS 9.2 (SAS institute 2008) using a model with the fixed effect of time of day (morning/evening) and the random effect of cow×day to calculate the random error for each parameter. CV was determined as the square root of the general error divided by the uncorrected overall mean.

RESULTS

The data collection was carried out successfully trough the 13 weeks of the trial and included data from 110 dairy cows. About 15 700 3D images were collected during the data collection period. Because of limitations with the current camera technique, black pigments on the cow body appeared as disturbances in the images. Therefore, photos of cows of the Swedish Holstein breed could not be analyzed and were discarded from the dataset, leaving only data from cows of the SRB breed in the results. Out of the data collected from SRB cows, about 70 % of the images taken could be used for image analysis. Remaining images were discarded due to problems such as the cows' position on the image or more than one cow in the image. Of the collected body weight from the scale, approximately 70 % of the weights could be used for analysis; remaining weights were missing due to problems with identification or unsuccessful weighing.

During the data collection period, maximal loss in body weight for an individual cow was 66 kg according to measurements by scale and 78 kg according to estimation by camera. The maximal gain in body weight according to measurements by scale was 90 kg while the camera estimated a maximal gain in body weight of 97 kg for an individual cow. The maximal loss in BCS was according to manual scoring 1.5 units, while maximal loss according to automatic BCS was 0.6 units. The maximal gain in BCS according to manual scoring was 1.0 unit while the estimation of the camera of maximal gain in BCS was 1.06 units (Table 5).

The collected parameters used for statistical analysis were body weight measured by scale (n= 6224), body weight estimated by camera (n= 8698), manual BCS (n=1329), automatic BCS (n= 9347) and measurements of back fat thickness (n=380), see Table 6 for descriptive statistics. The rumen fill score was excluded from the results due to inconsistency in scoring i.e. it was impossible to perform scoring at the same physical state for all animals (some cows have had time to go to eat after weighing before scoring) and therefore no comparable data could be obtained. A day to day variation of 5.33%, 2.83 % and 7.01 % was found for body weight estimated by camera, body weight measured by scale and automatic BCS respectively.

Highest significant correlation coefficient was found between estimated body weight by camera and measured body weight by scale ($R=0.87$; $P< 0.001$) (Figure 10 and Table 7). Correlation coefficient for estimated automatic BCS and manual BCS was also high and significant ($R= 0.84$; $P<0.001$) (Figure 11 and Table 7). Correlations between back fat thickness and automatic BCS and as well as back fat thickness and BCS were moderate and significant ($R= 0.59$; $P<0.001$ and R= 0:62; $P<0.001$ respectively) see Table 7. Correlation between manual BCS and converted BCS was $R=0.56$ ($P<0.001$), Figure 12. For the automatic BCS the correlation to converted BCS was $R=0.52$ ($P<0.001$).Correlation between mean body weight estimated by camera and mean body weight measured by scale was $R=0.95$ ($P<0.001$). Correlation between mean BCS and automatic BCS was also high and significant ($R= 0.95$; $P<0.001$)

When body weight estimated by camera was compared to body weight estimated by scale, 7.6 % of total body weights were overestimated by 5 kg or less, while 7.1 % of total body weights were underestimated by 5 kg or less (Table 8). Overall, the camera overestimated 26.4 % of body weights with 20 kg or less and underestimated 25.1 % of body weights with 20 kg or less if compared to measured body weight by scale. Of the automatic BCS 52.6% were overestimated, 45.8 % were underestimated and 1.6% were in total agreement, when compared to manual BCS. For details of over and under estimation, see Table 9. However, 69% of the automatic estimated scores were within ±0.25 increment of the manual BCS and 95% within ±0.50 score of the manual BCS.

The largest absolute error between the body weight measured by scale and body weight estimated by camera was overestimation of 255 kg, (56 %) Table 10, and underestimation of 393 kg, (41 %), Table 11. The largest absolute error between manual BCS and automatic BCS was overestimation of 1.37 units (46 %) and underestimation of 0.96 units (21 %).

No clear patterns between standing heat and body weight change could be observed, neither for body weight measured by scale or body weight estimated by camera (Figure 13). However, it was clear that the camera could detect changes in body weight (Figure 13) as well as BCS (Figure 14).

DISCUSSION

In this study, an improvement of the technique compared to previous studies by Krukowski (2009) and Foschi (2009) was that both body weight and 3D images could be collected automatically and simultaneous. However, there were some problems with the setup of the automatic installation regarding gates for cow traffic. It became clear that it is important that the exit gate is closed as the cow enters the scale. But even with that setup, cows manage to slip trough gates without getting weighed resulting in a number of 30 % missed weight data. If the camera could work as tool for body weight and BCS, the cow does not necessarily have to be stopped for the photograph alternatively the camera could be put in a feeding- or milking station where the cow is standing still. A higher number of successful measurements could therefore be achieved. Image quality was high with the 3D technique i.e. no images were discarded due to bad image quality, in contrast to the poor image quality when using 2D technique (Leroy *et al*., 2005; Bewely *et al*., 2008). This reflects one of the large advantages with the 3D technique i.e. it is not limited by poor lighting. Furthermore, the shape of the object is measured which gives more output data then with 2D technique.

The current camera has to be placed quite high to be able to estimate body weight. This could possibly be a limitation when not all dairy cow barns have sufficient height to the ceiling. Furthermore, if the camera is to be placed in a milking- or feeding station the same problem may occur. These problems can be solved by making a camera with a wider angle or using more than one camera. However, for now, the biggest limitation with the current technique is that the camera cannot estimate the shape of the area properly in black cows. Krukowski (2009) excluded images from black and white SLB cows in her training set due to technical issues i.e. contrast errors between black and white while Foschi (2009) only included cows of the SRB in the data collection. Therefore, the problem with the MESA TOF camera of measuring area on a black object was not known.

Body Condition Score

The correlation coefficient for estimated automatic BCS and manual BCS was high and significant (R=0.84) and similar to the correlation in previous work (R=0.83) by Foschi (2009) using the same technique. Fergusson *et al*. (1994) found the correlation between scorers to range from 0.76 to 0.86 which is in agreement with the correlation found between manual BCS and automatic BCS and shows that the accuracy for the estimated BCS by the camera is as good as when BCS is estimated by different scorers. No earlier studies have compared correlations for individual cows, only correlation between scorers (Edmonson *et al*., 1989; Ferguson *et al*., 1994) or between different body locations and overall BCS (Gillund *et al*., 1999). The low correlation between manual BCS and automatic BCS for individual cows is most likely due to insufficient amount of measurements or lack of distribution of different scores e.g. changes in body condition. For instance, the correlation between BCS and automatic BCS (Table 8) for cow 1440 was high (R=0.83), probably due to the change in BCS for this particular cow during the data collection period (Figure 14). The possibility of detecting change in BCS by the 3D imaging technique was also observed by Krukowski (2009). On the other hand, when comparing BCS change for manual estimation and automatic estimation in the same cow (1440) the change in BCS detected by manual BCS, in the end of the data collection period, does not show in the camera data, see Figure 14. This might either depend on underestimation of BCS by the scorer or as suggested by Ferguson *et al*. (1994); that it is harder to separate unit increments for scores lower than 2.5 as the change in absolute BCS is associated with distinct changes in specific body regions which are more difficult to see in animals with extreme body condition. Another possibility to this disagreement between manual BCS and automatic BCS is that only a small amount of score below 2.5 was included in the training set, e.g. camera does not predict BCS for lower scores that it does for intermediate, more common scores. From management point of view, it is important that the camera can detect a change in BCS even when body condition is extreme.

A day to day variation of 7.01 % was found for automatic BCS. This shows that the day to day variation of estimated automatic BCS was low despite that all outliers included in the statistical analyze. The detected variation might actually reflect the change in BCS. Mean BCS and mean automatic BCS corresponded well and correlation was high (R=0.95), which is in agreement with findings by Ferguson *et al*. (1994) comparing differences between mean BCS and scorer. In their study did mean BCS neither differ between scorers or from the BCS mode for each individual cow.

In the study Bewely *et al*. (2008) the best result showed that 100 % of the estimated BCS by image analysis were within 0.5 units of the manual BCS and 92.97% within 0.25 units. Compared to data in the current study, 69 % of the automatic estimated scores were within ±0.25 units of the manual BCS and 95 % within ±0.50 units of the manual BCS. However scores that derivate more than ±0.25 from preceding score were removed from the dataset of Bewely *et al*. (2008). In the current study all scores, including outliers were included in the dataset. This could explain the differences between the results found in the current study and the findings of Bewely *et al*. (2008). Furthermore, Bewely *et al*. (2008) excluded all images where both hooks were not clearly visible from their data set. Edmonson *et al*. (1989) found that overall BCS was most associated with the score of hooks and pin bones and Bewely *et al*. (2008) found highest correlations between posterior hook angle and BCS. In the current study, only a small area on the rump (a part of the spinal transverse process) was included in the image analysis and shape of hooks and pin bones are not used in the image analysis (Figure 8). If the area of hooks and pins would be included in image analysis, differences between manual BCS and automatic BCS might be smaller as when scoring manually, the area of hooks and pins are considered. Furthermore, the day to day variation might be even smaller and precision as well as accuracy of automatic BCS might be improved when including a larger area of the cows' rump in image analysis. Edmonson *et al*. (1989) suggested scoring one body area from the chart would be a good predictor for overall BCS. However, certain locations tend to give higher scores than others, such as the spinal transverse process (Edmonson *et al*., 1989). This might explain why the camera model in the current study overestimated 52.6 % of the scores, compared to manual BCS. Furthermore, it might also explain why the change in BCS for cow 1440, as discussed earlier, was not noticed by the camera i.e. camera overestimated BCS for this cow because only the transverse process was included in the image analysis.

The body condition of the cow is of continuous nature, while the manual BCS scale is divided into classes with increment steps, which might explain some of the smaller over-and underestimations of BCS by camera. The model estimating BCS automatically has the advantage of producing a continuous output while manual scoring can only give a categorical output data. However, the technique can only get as good as it is trained to be so the quality of the estimations relies on the quality of the data it is trained against.

The measurements of back fat thickness were not used as true reference to automatic BCS as suggested by Foschi (2009). Using the same technique as Foschi (2009) but on a larger number of animals, the result shows that the correlations between back fat thickness and BCS as well as automatic BCS were lower (R= 0.62 and R = 0.59 respectively) when compared with correlation found by Foschi (2009), R=0.75. Mahlkow-Nerge and Malchau (2009) found a lower correlation between back fat thickness and BSC for first lactation cows if compared to older cows. This might also explain the lower correlation in this study, thus the majority of the cows were in first lactation, (Table 2).

The agreement between converted BCS and manual BCS as well as automatic BCS was poor, see Figure 12. For instance, 10 mm of back fat thickness is suggested to correspond to a score of 2.0 on a 1 to 5 scale according to Schröder and Staufenbiel (2006), Table 2. When converted BCS was compared to manual BCS as well as automatic BCS in the current study, a back fat thickness of 10 mm rather corresponded to a score between 3 and 4. Similar findings were made by Mahlkow-Nerge and Malchau (2009), suggesting that a back fat thickness of 11 mm corresponds to a score from 2.6 to 2.75, rather than a BCS of 2.0 on a 1 to 5 scale. Their study included cows of Holstein breed, while cows in this study are of the SRB, a breed that has been breed for dual purpose over many years, which might explain correspondence of higher scores to mm of back fat thickness in the current study. Mahlkow-Nerge and Malchau (2009) argues that the suggestion by Staufenbiel and Schröder (2006) on how to convert back fat thickness into BCS scores and vice versa needs to be reconsidered since today, a lower back fat thickness is measured at a given BCS.

Body weight

The scale used in this study is constructed to calculate the body weight by an algorithm as the cow walks by the scale. The fact that cows were stopped on the scale does not affect measurement of body weight but it is uncertain if the collected weights from the scale are somewhat smothered by the algorithm calculations. This was not known in the initial phase of the study and it is therefore uncertain, if the body weight measured by scale is a proper reference for the estimation of body weight by the camera. However, correlation between mean body weight estimated by camera and mean body weight measured by scale was high and significant ($R=0.95$; $P<0.001$) which indicates an agreement between mean estimations by camera and measurement by scale.

No earlier studies have investigated the possibility of estimating body weight by 3D imaging technique. The results showed that the correlation between body weight measured by scale and estimated by camera was high ($R=0.87$). The lower correlation in this study, compared to the findings of Negretti *et al*. (2008), measuring the lateral profile of buffalos in order to estimate body weight ($R=0.98$), might be due to the different angle of measurement or differences between species in body composition. For instance, size of the udder also affects body weight (Gibb and Ivings, 1993) but is not estimated by 3D technique due to the top view of the image. Including the measurement of hip width might have improved the results since of various body parts; hip width has the largest correlation with body weight (Heinrichs *et al*. 1992; Enevoldsen and Kristensen, 1997). Furthermore, Enevoldsen and Kristensen (1997) improved their equation model for predicting body weight by adding factors such as BCS and day sin milk. This could also have been applied in the model for predicting body weight from 3D images, since BCS can also be obtained automatically from 3D images as well as mil yield that was recorded on daily basis.

The result showed that the over- and underestimation in body weight estimated by camera was large when compared with body weight measured by scale (Table 8, 10, 11). It is hard to draw any clear conclusion from this data, because of the insecurity of the weight data measured by scale. It is however of great importance that the camera estimates the body weight with as high accuracy as possible, since already a rather small change in body weight can tell something about the cows' welfare. A difference between measured and estimated body weight of ±20 kg in 50 % of weighing, as the results showed, is not acceptable for a commercial product. Therefore, the camera cannot be used for absolute weight measurement if the accuracy of less than 20 kg is required. However, if looking at Table 10 and 11, it is clear that largest over and underestimations are outliers e.g. the same cows are the ones with differing weights between body weight estimated by camera and body weight measured by scale. For overestimation by camera, it was mainly the scale that had failed to measure the weight properly. For instance, the cow 1454, had problems getting on the scale to get weighed because she was knock-kneed. Cow number 1467 is another good example of error in measuring body weight by scale e.g. an outlier. The cows 9393 and 1395 were often underestimated by the camera if compared to body weight measured by scale while the cow 1492 was always overestimated. It is important to try to find these types of cows, of which the camera often fail to estimate the body weight, and see if they have any common characteristics that disturbs the camera estimation. The error can be caused by different body shape, like big udder or small udder, which is not seen from the camera.

The higher day to day variation of body weight estimated by camera (5.33%) compared to body weight estimated by scale (2.83%) might be explained by the scale algorithm e.g. the calculations smother the weights. Moreover, the camera might be more sensitive to variation in body weight and from a management point of view that could be an advantage. As suggested by Maltz *et al.* (1997) it is the deviation from daily variation that will give information about heat or disease, rather than deviation from the daily average in body weight. In contrast to findings by Maltz *et al.*, (1997) no relationship was found between standing heat and change in body weight (Figure 13). In this study, the body weight was only measured twice daily contrary to several measurements of body weight on several occasions (and not only after milking) in the study of Maltz *et al*. (1997). Higher number of body weight measured by camera might also have improved the results. i.e. standard deviation and standard error is less for body weight estimated by camera if compared to measured body weight by scale (Table 6).

Relationship between BCS and body weight

Different correlation coefficients, from 0.13 to 0.66 (Veerkamp, 1998; Berry *et al.*, 2006; Foschi, 2009) or no correlations (Wildman *et al*., 1982; Maltz *et al*, 1997) between BCS and body weight has been reported. Foschi (2009) found low correlations between BCS and body weight and suggest that the low correlations are due to few measurements of the body weight. Despite higher frequency of body weight measurement in this study, the correlation between BCS and body weight measured by scale (R= 0.13) or body weight estimated by camera (R= 0.15) were still low and similar as in the findings of Foschi (2009) (R=0.13). Furthermore, Maltz *et al*. (1997) found no correlation between BCS and body weight despite additional measurements of body weight per day; in fact, change in BCS and body weight contradicted each other. It seems like the low correlations between body weight and BCS are a consequence of too few scoring occasions rather than too few weighing sessions. It is suggested that body weight is not a good estimation for energy reserves of dairy cattle (Schröder and Staufenbiel, 2006; Bewely and Schunz, 2008) which is only strengthened by the low correlations found between BCS and body weight. In this study, BCS was not added in the model for estimation of body weight, despite that both empty body weight (Yan *et al*., 2009) and body weight can be predicted with a higher accuracy when adding BCS or milk yield (Enevoldsen and Kristensen, 1997).

SUGGESTIONS FOR FUTURE WORK

Since breed difference have been found with regard to BCS (Koenene *et al*., 2001; Bewely and Schutz, 2008) it is of great interest to investigate if the estimation model for automatic BCS will work on several breeds. The same goes for automatic estimation of body weight. Enevoldsen and Kristensen (1997) suggest that different equation models might be required when predicting body weight of different breeds. The accuracy and precision of the 3D imaging technique has to be improved, the technique needs to be sensitive to small changes since it is the change in body weight or body condition score that will give information about the state of the animal rather than the actual weight or score. Body weight responds much faster and clearly to a drop of dry matter intake than milk yield does (Maltz *et al*., 1997) and can therefore powerful tool when monitoring heard health or fertility. If the technique manages to detect the small changes and deviation from the daily pattern, it will become a very important tool when monitoring animals in large heads or for research purposes.

To improve the model estimating body weight further, factors such as rumen fill degree and BCS can be included. It might be possible to estimate the empty body weight by adding these factors. As for the model estimating BSC, it would be of interest to include a larger part of the cow rump (angles of hooks and pins) in the model to compare, if higher accuracy of automatic scoring can be obtained. Furthermore, it should be investigated if it is possible to create a reference score for each cow e.g. a picture of the cow when she is in desirable body condition and thereby teach the camera to notify changes from this specific condition. This would make the application animal specific the accuracy of the estimation might be further improved. It is very important that further studies are performed on cows in early lactation, if possible monitored during the dry period as well. Change in body condition as well as body weight is largest during early lactation and it is therefore important to investigate the sensitivity of the technique during this period.

CONCLUSION

It was concluded that body weight can be estimated by the 3D imaging technique, but this could only be verified in SRB cows. The limitation of the method was that the current camera could not estimate body shape of cows with black pigment. The correlation between manual BCS and automatic BCS is in agreement with previous studies; however, the estimation of BCS has only been done in SRB cows. A low day to day variation was found both for estimations of body weight and body condition by the camera. This implies that the repeatability, precision and sensitivity of the method were good. Change in body weight as well as BCS was detected by the3D imaging method. If the output data from the 3D imaging technique show even small changes in body weight, BCS or eating behavior (rumen fill degree) it can be a powerful tool monitoring health, fertility and welfare on large dairy farms.

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TABLES

Table 1. Converted BCS from back fat thickness suggested by Schröder and Staufenbiel (2006) and Mahlkow-Nerge & Malchau (2009)

Schröder & Staufenbiel (2006)		**Mahlkow-Nerge & Malchau (2009)**	
BCS	**Back fat thickness (mm)**	**BCS**	**Back fat thickness (mm)**
1.0	<5		
1.5	5		
2.0	10	2.4	9
2.5	15	2.7	11
3.0	20	2.85	13
3.5	25	3.2	16
4.0	30	3.4	20
4.5	35		
5.0	>35		

Table 2. Distribution of cows of different breeds with regard to lactation number

	Number of cows	**Lactation number**			
		1	**2**	**3**	**≥4**
SLB	70	36	19	9	6
Swedish Holstein	40	18	13	8	1
Total	**110**	**54**	**32**	**17**	**7**
Percent (%)	100	49	29	15	6

Table 3. Table of feed components and their energy content metabolizable energy (MJ/kg dry matter)

Feedstuff	**MJ/kg dry matter**
Silage	9,6-11,4
Straw	6,6
Barley seed	13,8
Maize	11,1
Rape seed meal	12,4
Soy bean meal	14,6
Mingla 30	14,7

Table 4. Overview of the manual data collection of body condition score (BCS), rumen fill score (RFS) and back fat thickness measurements (BFTM) for group 1,2 and 3

Trial week	Wednesday	Thursday
1		BCS + RFS
2	BCS+RFS+ BFTM 2,3	BCS+RFS +BFTM 1
3		BCS + RFS
4		BCS + RFS
5	BCS+RFS+ BFTM 2,3	BCS+RFS+ BFTM 1
6		BCS + RFS
7		BCS + RFS
8	BCS+RFS+ BFTM 2,3	BCS+RFS+ BFTM 1
9		BCS + RFS
10		BCS + RFS
11		BCS + RFS
12		BCS + RFS
13		BCS + RFS

Table 5. Maximal gain and loss of BCS and body weight according to manual scoring, camera and scale

Max change	kg	COW ID	Max change	Score	COW ID
SBW lost	-66	1440	BCS lost	-1,5	1454
CBW lost	-78	1440	ABCS lost	-0,60	1450
SBW gain	90	1406	BCS gain	1	1395
CBW gain	97	1428	ABCS gain	1,06	1425

ABCS= Automatic BCS, CBW= camera BW, SBW= Scale body weight.

Table 6. Descriptive statistics over the collected parameters

Statistics	ABCS	BCS	CBW	SBW	BFT
Mean	3.40	3.39	615	620	8.33
SE	0.00	0.01	0.67	0.85	0.21
Median	3.33	3.25	613	620	7.33
SD	0.41	0.49	62	67	4.02
Variance	0.17	0.24	3920	4548	16
Minimum	2.11	2.25	477	453	1.67
Maximum	4.84	4.75	819	948	21
Total (n)	9374	1329	8638	6224	380

ABCS= Automatic BCS, CBW= camera BW, SBW= Scale body weight, BFT= back fat thickness

Table 7. Linear correlation coefficients for the parameters SWB (n= 6224), CBW (n=8638), BCS (n= 1329), ABCS (n= 9347), BFT (n=380), CBCS (n=380) and mean value $(\bar{x})$ of BCS and ABCS as well as mean value of CBW and CBW

	SBW	CBW	BCS	ABCS	BFT	CBCS	SBW $(\bar{x})$	CBW $(\bar{x})$	ABSC $(\bar{x})$	BCS $(\bar{x})$
SBW	1.000									
CBW	0.868***	1.000								
BCS	0.144***	0.128***	1.000							
ABCS	0.146***	0.132***	0.844***	1.000						
BFT			0.620***	0.585***	1.000					
CBCS			0.565	0.525		1.000				
SBW $(\bar{x})$							1.000			
CBW $(\bar{x})$							0.948***	1.000		
ABSC $(\bar{x})$									1.000	
BCS $(\bar{x})$									0.954***	1.000

†P<0.1; *P< 0.05; **P<0.01; ***P<0.001

SBW= scale body weight, CBW= camera BW, BCS= body condition score, ABCS= Automatic BCS, BFT= back fat thickness, CBCS= converted BCS

Table 8. Over and under estimation of body weight estimated by camera if compared to body weight measured by scale

Camera over estimation (kg)	% of total weights	no of total weights
>100	0,2	12
>50�100	2,7	167
>40�50	3,8	234
>30�40	6,1	378
>20�30	8,0	496
>10�20	11,4	712
>5�10	7,3	456
�5	7,6	473
0	1,6	97
Camera under estimation (kg)	**% of total weights**	**no of total weights**
�5	7,1	444
>5�10	6,4	396
>10�20	11,6	724
>20�30	8,7	543
>30�40	5,2	321
>40�50	4,0	247
>50�100	7,5	469
>100	0,9	55
Total	**100**	**6224**

Table 9. Over and underestimation of automatic BCS estimated by camera if compared to manual BCS

Camera over estimation (units)	% of total scores	no of total scores
>1.0	0,1	1
>0.5�1.0	2,2	29
>0.25�0.5	13,1	174
>0�0.25	37,2	495
0	1,6	21
Camera under estimation (units)	**% of total scores**	**no of total scores**
>0�0.25	30,5	406
>0.25�0.5	12,2	162
>0.5�1	3,1	41
>1.0	0,0	0
Total	**100**	**1329**

Table 10. Six highest overestimation of body weight by camera if compared to body weight measured by scale

Cow ID	Body weight scale	Body weight camera	Absolute error	Relative error (%)
1454	453,00	708,00	255,00	56,29
1454	453,00	706,00	253,00	55,85
1454	477,00	717,00	240,00	50,31
1430	492,00	673,00	181,00	36,79
1492	512,00	689,00	177,00	34,57
1492	476,00	611,00	135,00	28,36

Table 11. Six highest underestimation of body weight by camera if compared to body weight measured by scale

Cow ID	Body weight scale	Body weight camera	Absolute error	Relative error (%)
1467	948	555	-393	-41,46
1454	800	525	-275	-34,38
9393	730	575	-155	-21,23
1412	710	560	-150	-21,13
1395	658	513	-145	-22,04
1423	660	519	-141	-21,36

FIGURES

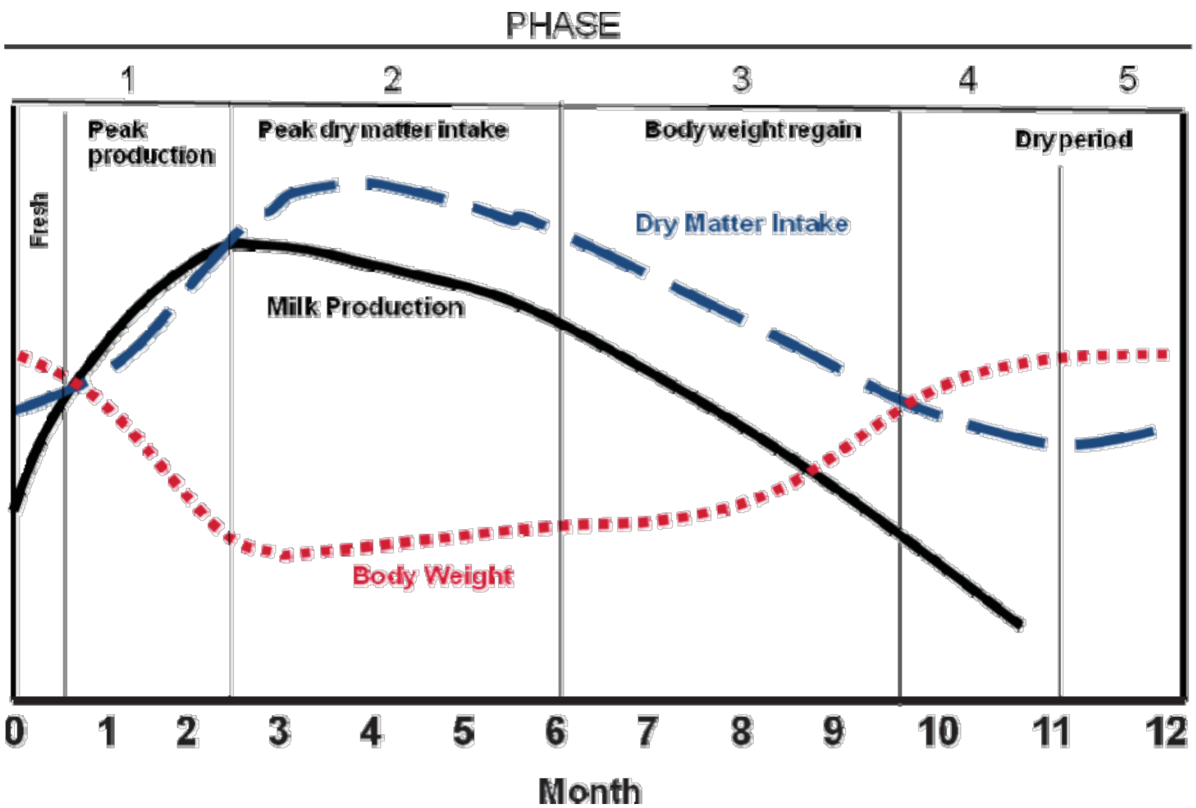


Figure 1. Changes in milk production, dry mater intake and body weight in a typical dairy cow, modified after Phillips (2001). The peak in milk yield usually occurs before the animal returns to energy balance while the ability for dry matter intake reaches its maximum when milk yield. starts to decline.

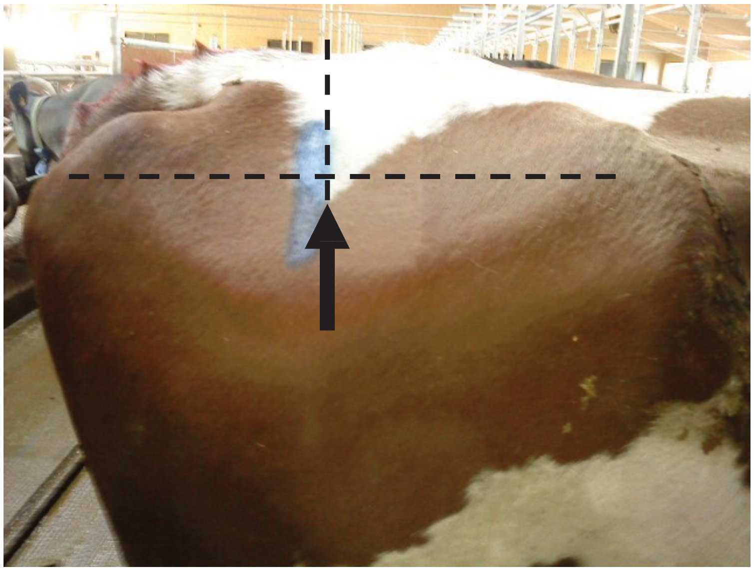


Figure 2. The sacral location of the cow where the flat area between the hooks and the pins is pointed out.

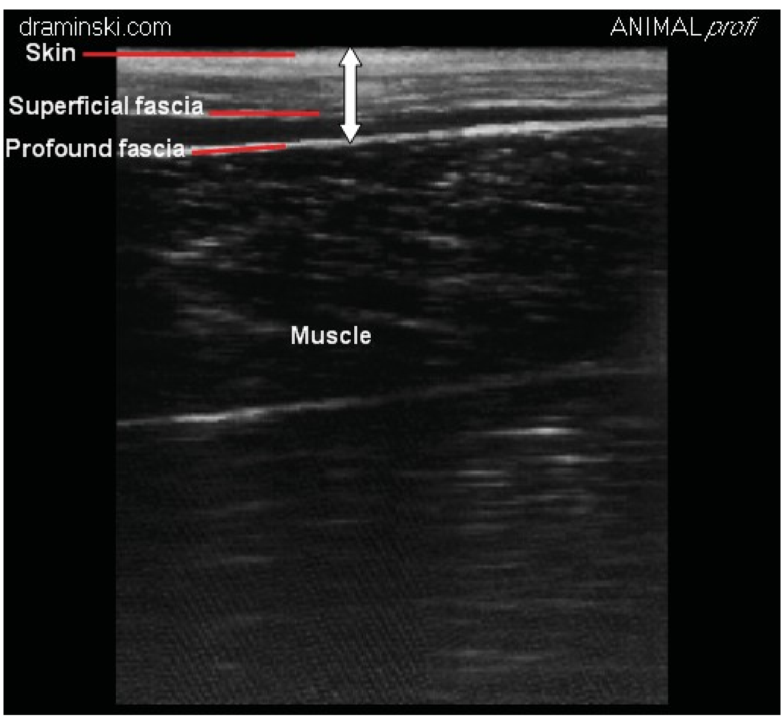


Figure 3. Ultrasonic image, point of measurement in image.

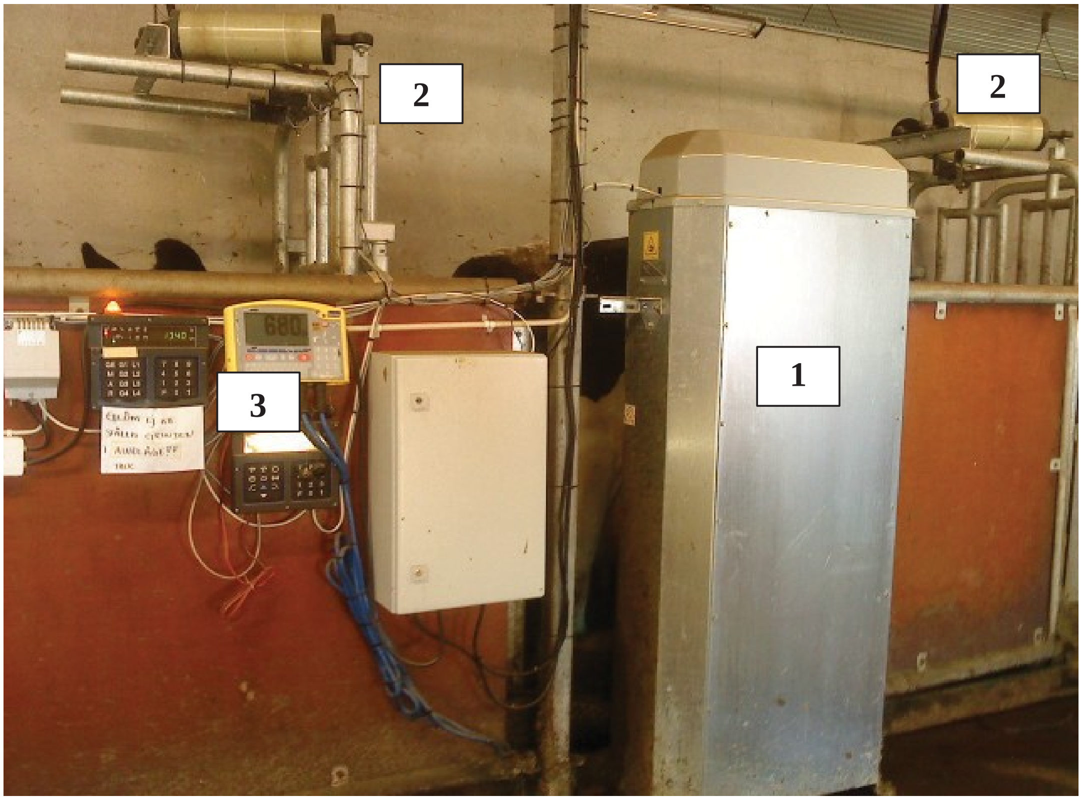


Figure 4. The installation collecting body weight and 3D images automatically the components; a Multi-reader for identification of cows (1), two DeLaval tandem saloon gates to stop the cows on the scale (2), DeLaval gate controller (3).

Figure 5. The automatic scale, DeLaval Automatic Weight System (AWS 100).

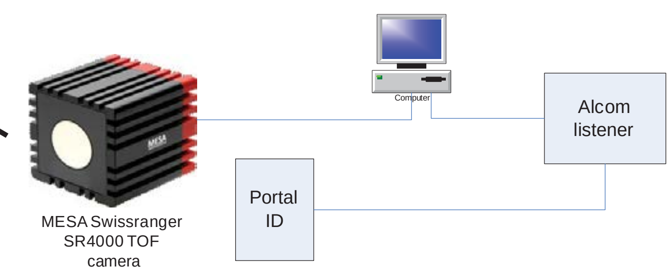


Figure 6. MESA time-of-flight (TOF) DeLaval camera for 3D image collection, an Alcom listener; the connecting units and a computer storing collected data.

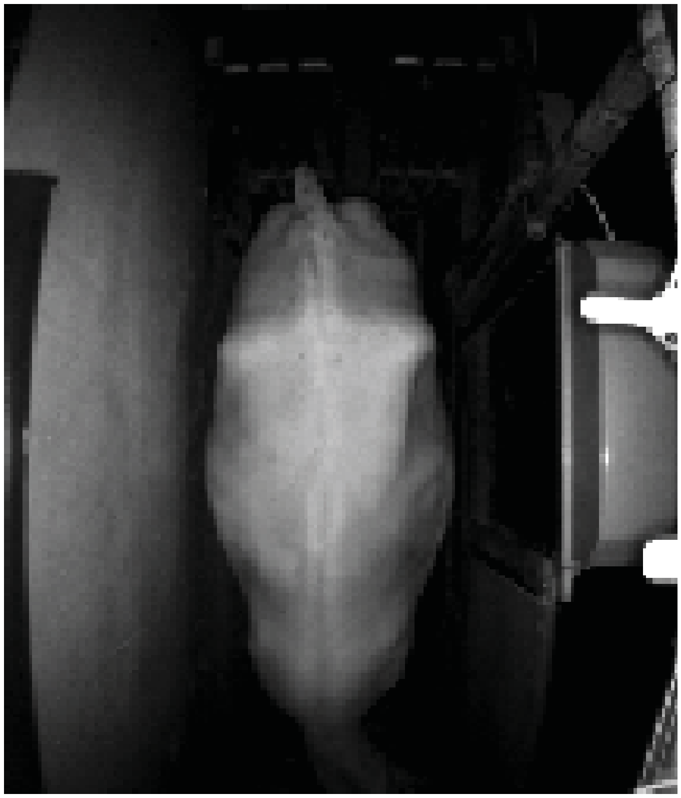


Figure 7. The cow body area used for estimating of body weight.

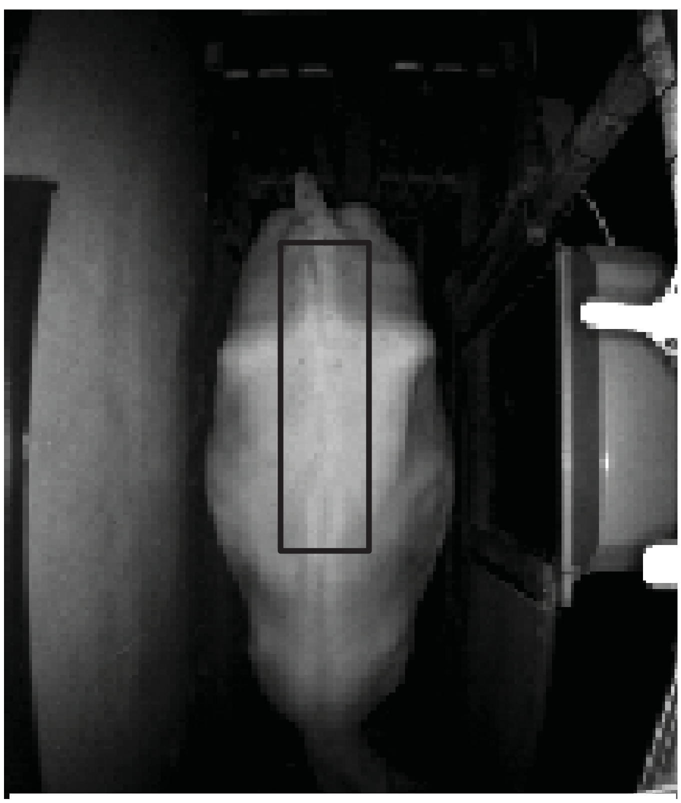


Figure 8. The area at the rear end of the cow body image used for estimating BCS.

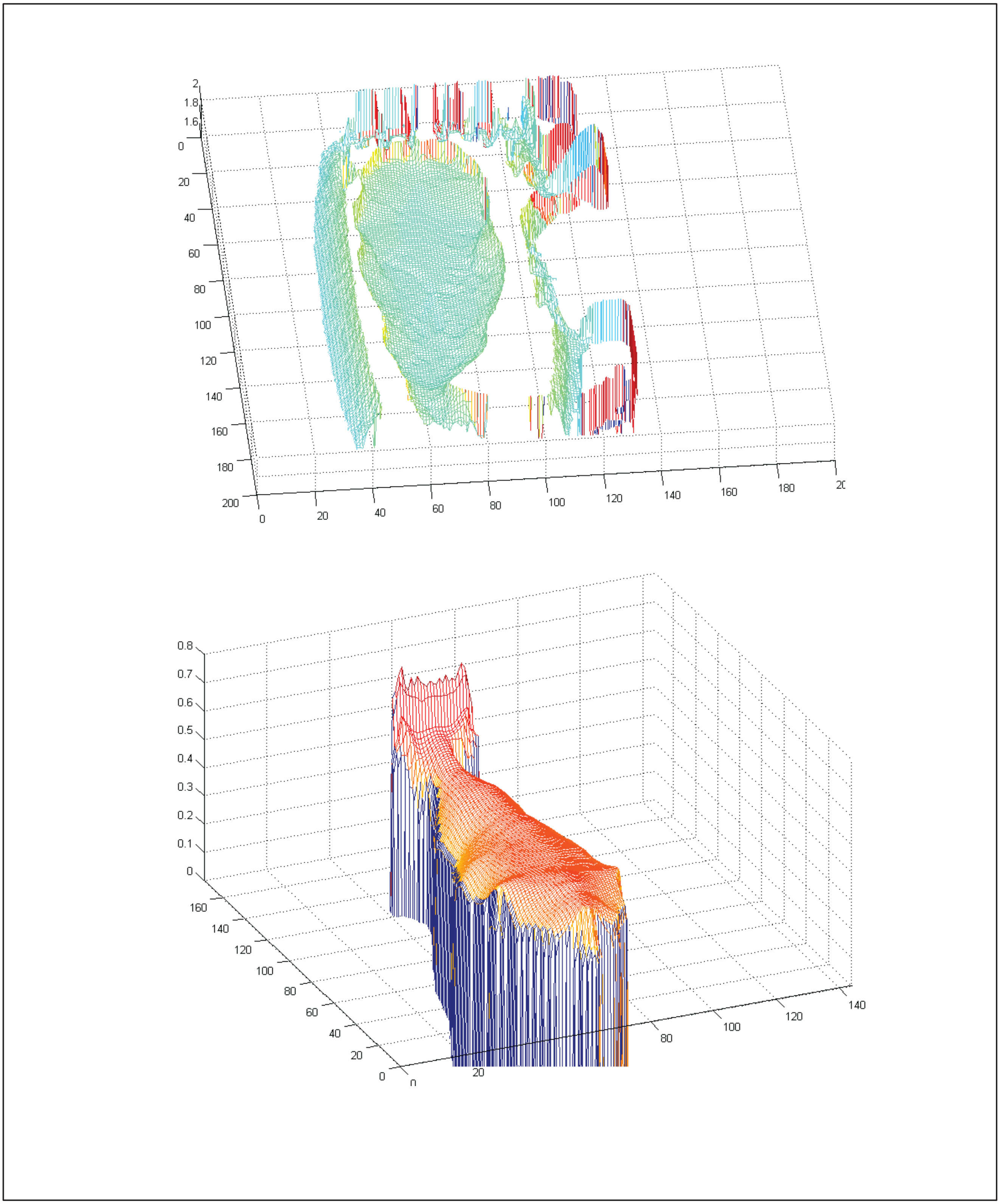


Figure 9. The 3D images obtained by the MESA (TOF) camera used in the image analysis.

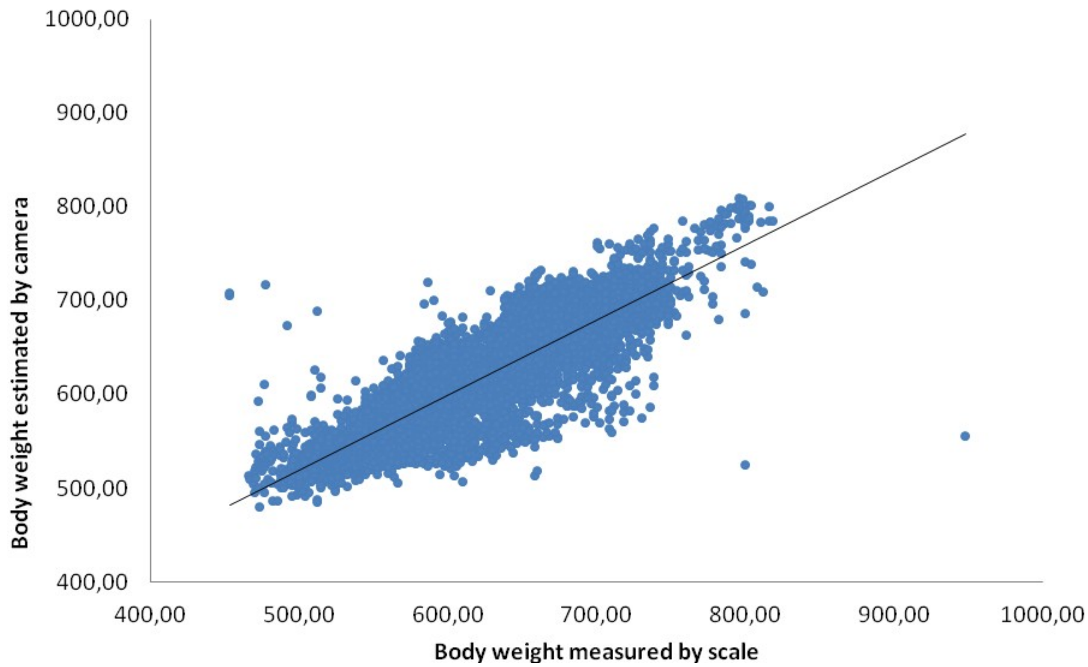


Figure 10. Scatter plot between estimated body weight by camera and measured body weight by scale (R=0.87; P< 0.001).

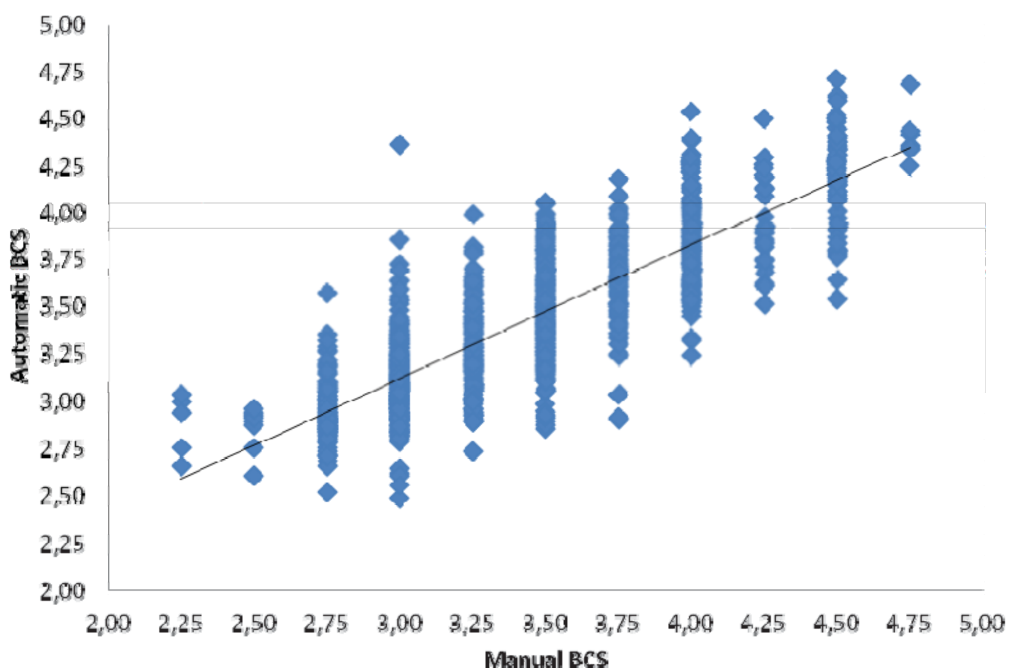


Figure 11. Scatter plot between automatic estimated BCS and manual BSC (R= 0.84; P<0.001).

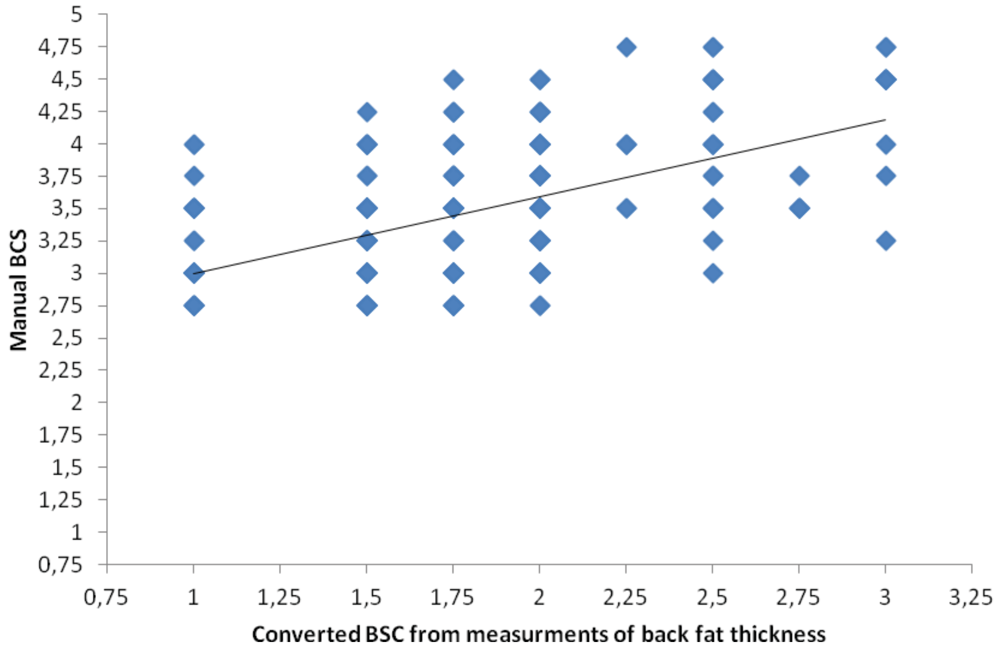


Figure 12. Scatter plot between manual BCS and converted BCS from back fat thickness measurements (R=0.56; P<0.001).

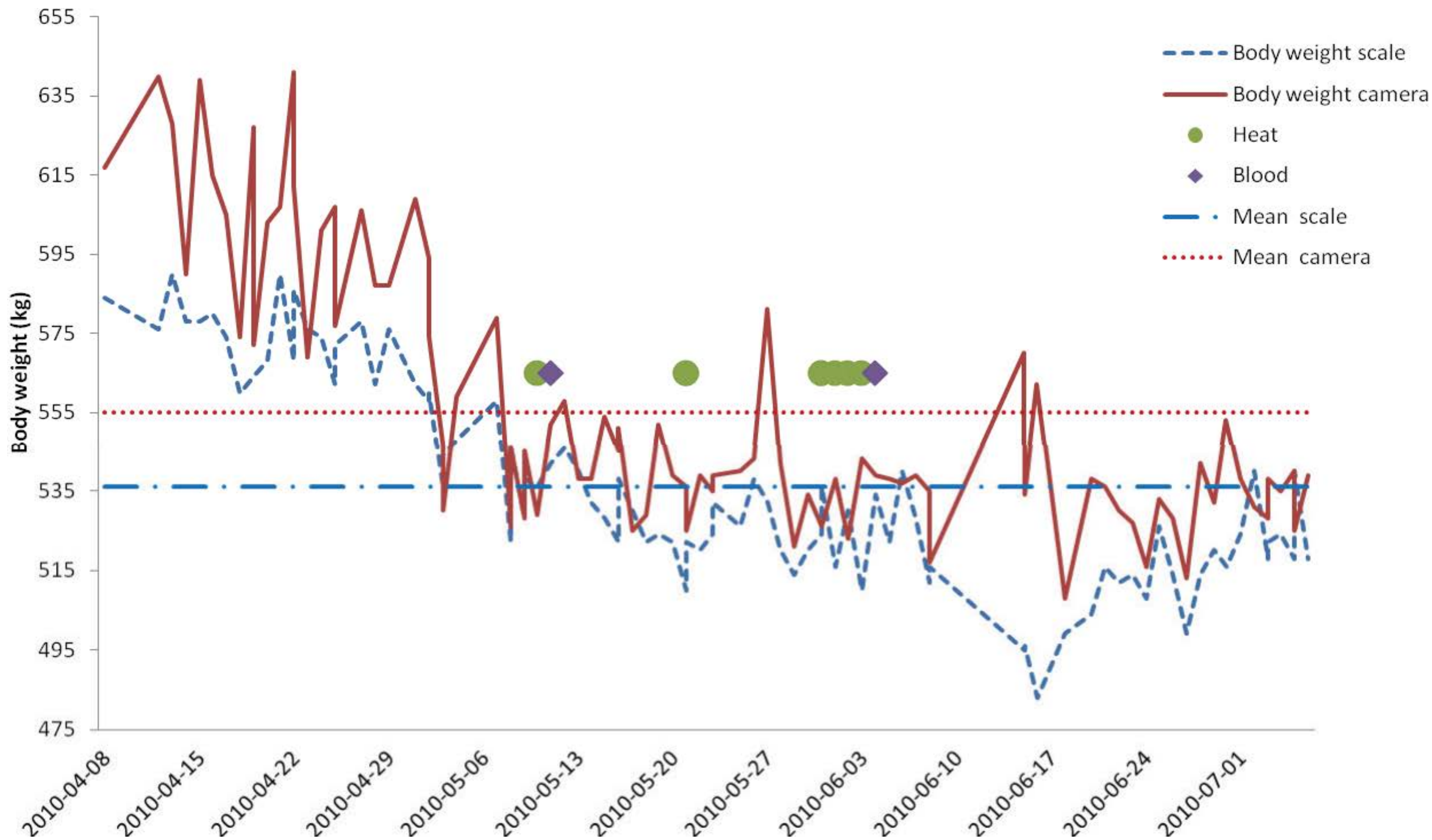


Figure 13. Body weight measured by scale and estimated by camera, mean body weigh measured by scale and estimated by camera for cow 1440 during the trial period. Occasions of standing heat and blood are also included.

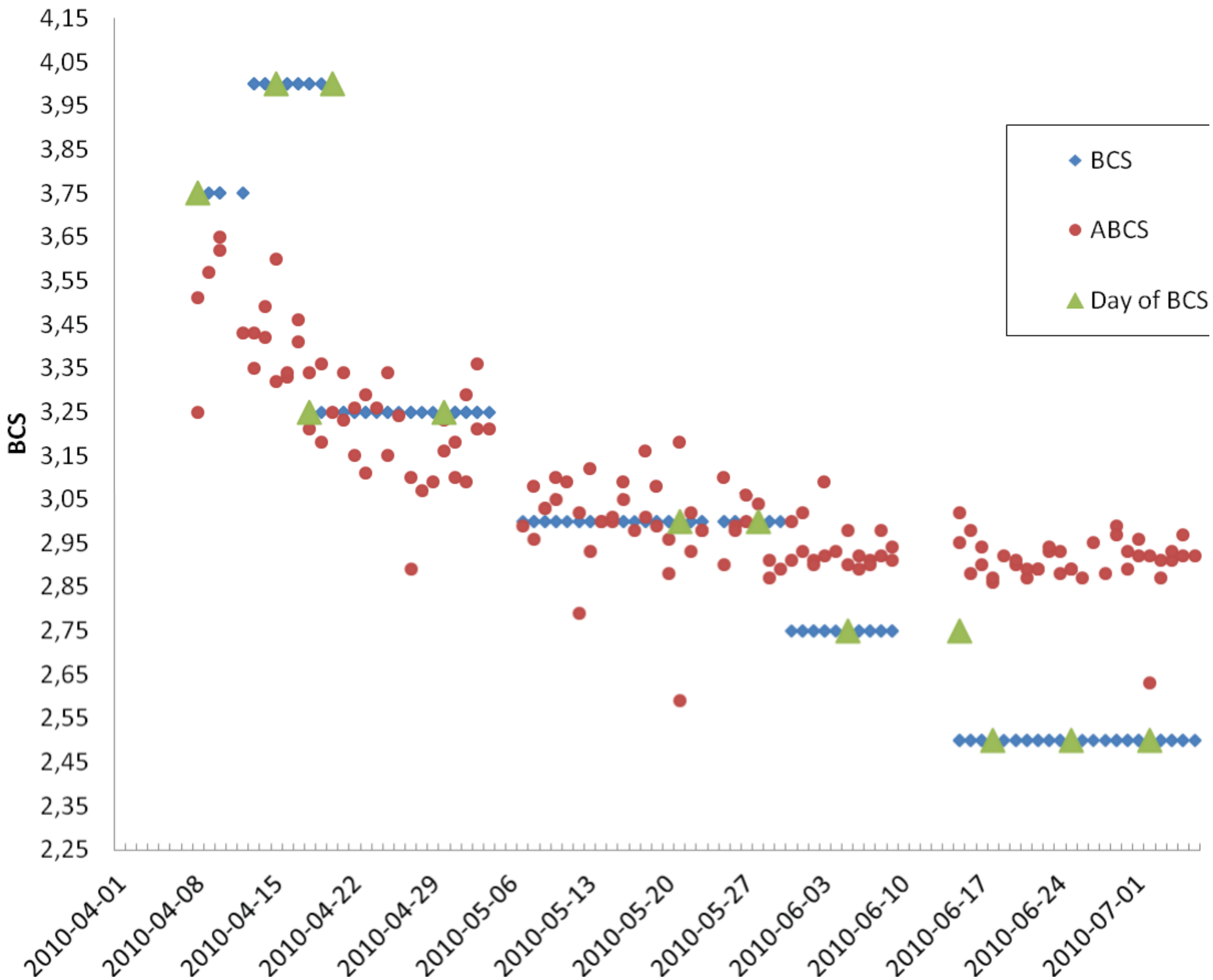
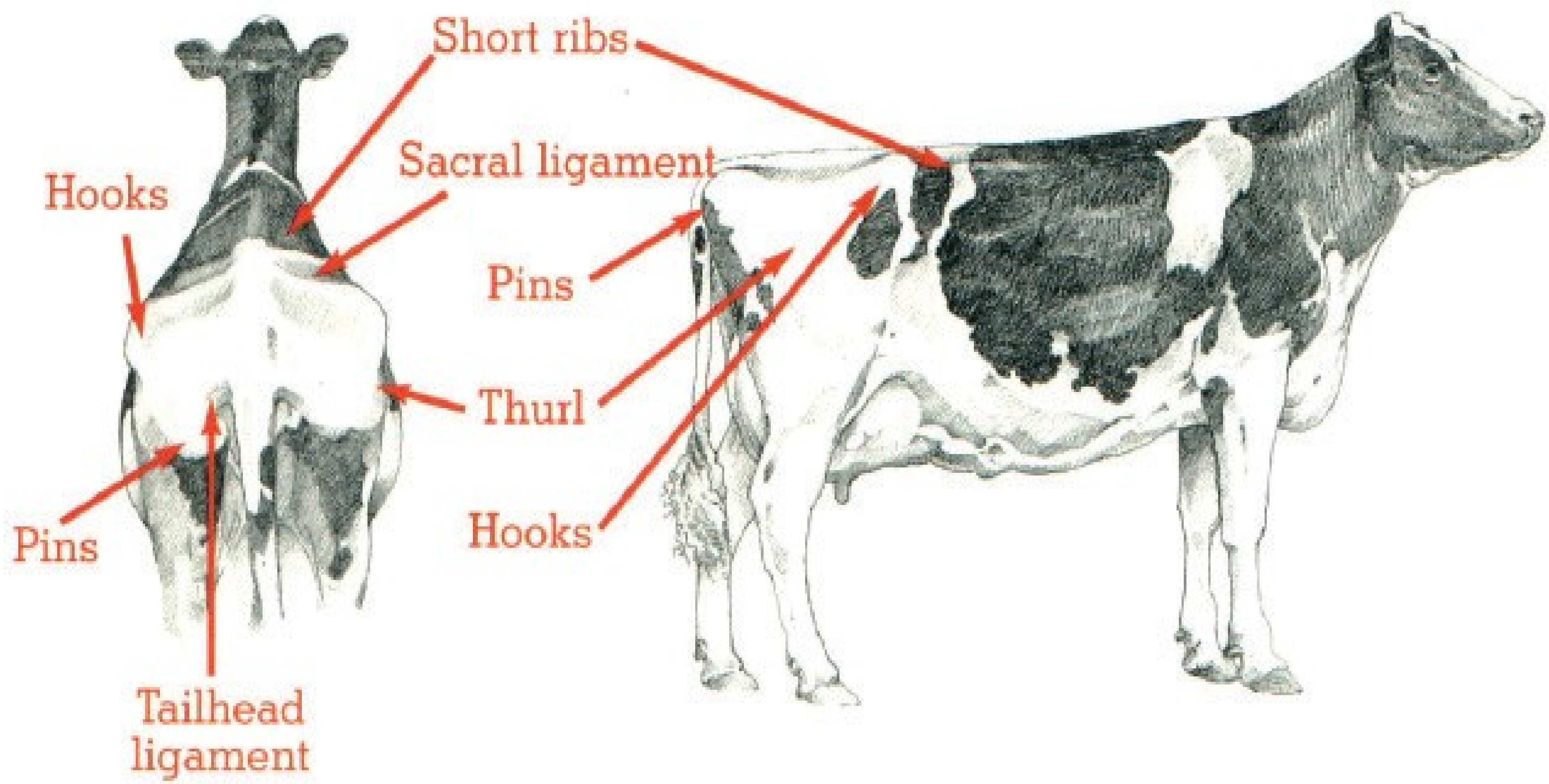


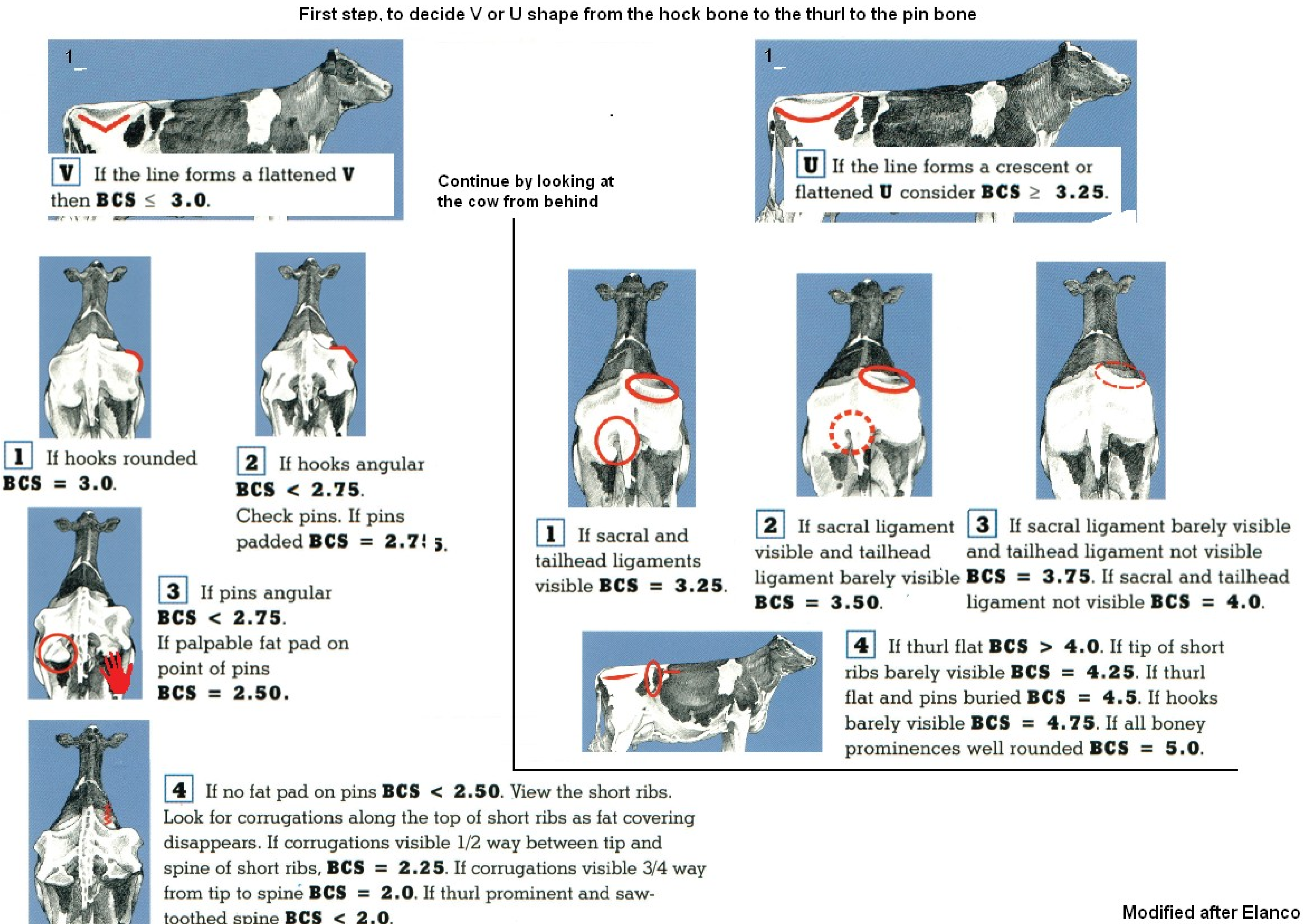
Figure 14. Occasion of scoring, manual body condition score as well as automatic condition score (ABCS) for cow 1440 during the trial period.

APPENDIX

1. Important parts to look at when scoring the body condition



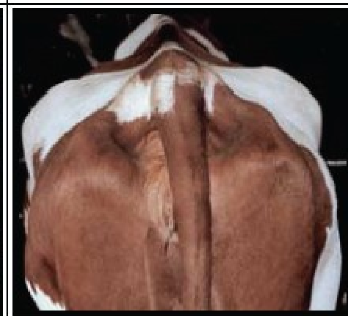
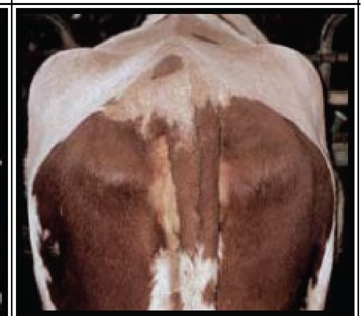
2. The BCS card provided by Elanco animal healt

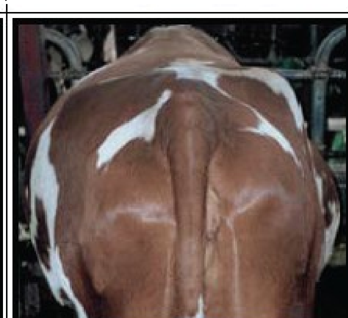


Modified after Elanco Animal Health (1997)

3. The BCS chart by **Gillund** *et al.* (1999)

Holdvurderingsskjema for NRF-kyr

	Holdpoeng 2,0	Holdpoeng 2,5	Holdpoeng 3,0
			
Rygg/rygg takker	Hver enkelt ryggtakk tydelig	skarp, utstående rygglinje	Noe avrundet rygglirnje
Området mellom ryggtakker og sidetakker	Tydelig innsunket	Tydelig konkav bue	Lett konkav bue
Hofteknoker og setebeins-knoker	Utstående og tydelig kantele	Noe utstående og litt kante e	jevne, ikke kantele
Halegropa	Framstående knokler, U-formel rom under halerota	Uthulet, men tendens til fettavleiring	Avrundede knokler, grunn halegrop med noe fett-avleiring

	Holdpoeng 3,5	Holdpoeng 4,0	Holdpoeng 4,5
			
Rygg/rygg-takker	Avrundet rygglinje,rygg-takkene 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	Avrumdede knokle grunn halegrop med tydelige fett-av leiring	Avrundet, utfyll med fett. Antydning til vevsfold ved halefeste	Knakler tildekket, gjemt i fett, tydelige vevsfolder

4. Rumen fill scoring according to a scale by Hulsen (2006)

Våmfyllnad, 1-5

1.Djupt insjunken vänster sida. Huden under tvärutskotten djupr insjunken. Hudvecket från höftknölen går lodrätt neråt. Hungergropen bakom revbenen är mer än en handsbredd. Sett från sidan är flanken rektangulär.

2. Huden under tvärutskotten böjer sig inåt. Hudvecket från höftknölen går snett framåt revbenen. Hungergropen bakom revbenen är en handsbredd. Sett från sidan liknar området en trekant.

3. Huden under tvärutskotten går först en handsbredd lodrätt nedåt och går sedan utåt. Hudvecket från höftknölen är inte synlig. Hungergropen bakom revbenen är synlig.

4. Huden under tvärutskotten buktar utåt. Hungergropen syns inte.

5. Tvärutskotten syns inte pga av den mycket fyllda våmmen. Övergången från flank till revben är inte synlig.

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