Predicting internal adipose from selected computed tomography images in sheep

PL Johnson[a*], JL Juengel[a] and WE Bain*[a]

[a]*AgResearch Invermay, Puddle Alley, Mosgiel, New Zealand*

**Corresponding author.* Email: tricia.johnson@agresearch.co.nz

Abstract

Dairy cattle preferentially lay down internal (INT) (e.g., kidney) adipose relative to sub-cutaneous adipose (SCF) tissue, but this pattern is the opposite in beef cattle, which preferentially deposit adipose subcutaneously. It is proposed that these differential patterns of fat distribution evolved to match the different production drivers of these breeds. As the New Zealand sheep industry has become more diverse in terms of breeds and production systems, the role that differential adipose distribution could play in supporting different production systems is of interest. The potential to use commercially obtained Computed Tomography (CT) images (i.e., six images, selected to predict carcass attributes in the live animal), to additionally predict INTF in addition to carcass fatness, was investigated using a full set (i.e., 30-32) of CT images available on 50 maternal ewe lambs. The R^2 between the full- and sub-set of images for absolute amounts ranged from 0.25 for bone to 0.92 for SCF, with INTF 0.77 ($P<0.001$). When adjusted for total weight, correlations were slightly reduced, but still supported the ability of the analysis of the six images to accurately identify animals with differential fat distribution. Future work will include analysis of a further 550 animals from the same data set to determine the genetic correlation between the full and subset of images. If successful, adipose distribution can be predicted from existing and future commercial CT data sets and used to investigate its genetic and phenotypic relationship with production traits.

Keywords: internal adipose; subcutaneous adipose; computed tomography

Introduction

Selection for different production outcomes has been shown to drive differences in body composition in cattle. Specifically, it has been demonstrated that beef-cattle breeds, bred for meat production, lay down more adipose tissue subcutaneously versus internal adipose deposits, the opposite being true for dairy-cattle breeds, bred for milk production (Berg & Butterfield 1976; Wright & Russel 1984). There is evidence that internal deposits are more labile and, therefore, suit the energy demands presented by intensive milk-production systems (Lambe et al. 2005). Overseas, there is similar literature suggesting breed differences in the distribution of body adipose tissue in sheep (McClelland & Russel 1972; Lirette et al. 1984; Chay-Canul et al. 2011).

There is increasing interest in understanding adipose distribution in sheep as it has possible links to many production outcomes. Capturing of such data requires the use of full-body dissection data collected after slaughter or the use of Computed Tomography (CT) scanning. Computed Tomography scanning is used in the New Zealand sheep industry to estimate carcass composition of live animals. Whilst full-body CT images can be generated, the cost of such an approach is prohibitive from a commercial perspective, and research determined that six selected images can accurately predict carcass composition (Kvame et al. 2004) and these are collected routinely as part of commercial scanning systems in New Zealand (Jopson et al. 2009).

The aim of this study was to determine the accuracy with which the commercial sub-set of CT images could be used to describe body adipose distribution compared to a full set of body images, utilising a data set from ewe lambs (approximately one year of age) that had been full- body CT scanned.

Materials and methods

Computed tomography (CT) images were taken on live ewe lambs approximately one year of age as part of a larger study investigating genetic variation in feed efficiency as described by Johnson et al. (2018). In brief the animals were sourced from one of three progeny-test flocks which were based on New Zealand maternal breeds. A sub-set of 50 animals was randomly selected from 400 ewes CT scanned in year two of the study, for further analysis.

The live animals were CT scanned at the end of the feed-efficiency trial period. The animals were scanned with a GE LightSpeed 5.X Pro16 scanner (GE Healthcare, Australia) using the procedures described by Jopson et al. (1997) with a starting position before the 2nd or 3rd cervical vertebrae and an end position at the distal femur/proximal tibia. Images for this study were collected at 30-mm intervals resulting in between 30 and 32 images per animal. Each image was segmented such that the subcutaneous adipose (SCF), adipose associated with muscles (intermuscular adipose), and adipose within the body cavity (internal adipose: INT) were separated. Adipose depot, lean and bone areas were calculated in each image based on the Hounsfield unit (HU) ranges of the three tissues using AUTOCAT (Jopson et al. 1995). HU value ranges were -176 to -26, -25 to 144, 145 to 3017 HU for adipose, lean and bone areas respectively. Tissue area (count of pixels) from each image was numerically integrated and multiplied by the distance between images to estimate the tissue volume for subcutaneous, intermuscular and visceral adipose deposits as well as total lean and total bone calculations (Gundersen et al. 1988). Average pixel density was determined by weighting the average density in the individual images by the pixel area in each image. Pixel density was converted to physical density using the relationship shown between HU value and density by Fullerton (1980), which provided the conversion from volume to weight. All weights within a tissue type were summed for an animal to produce an estimate of subcutaneous-, intermuscular- and visceral-adipose, muscle and bone weight.

A second data set was generated, through selecting six images from all available images that represent the images used in commercial CT scanning of industry animals. Specifically, two scans were obtained from each region: forequarter (5th thoracic vertebrae and 7th cervical vertebrae), the loin (6th lumbar vertebrae), the rack (13th thoracic vertebrae) and the hindleg (2nd caudal vertebrae and 3rd sacral vertebrae). Calculations were made on the resulting data set using the methodology described above to generate data on the same traits of subcutaneous-, intermuscular- and visceral-adipose, muscle and bone weight.

The ratio of SCF to INT (SCF:INT) was calculated using the absolute weights of the two tissues. The correlation between estimates of the different adipose deposits as measured from the full set of CT images and the sub-set of CT images, together with the ratio trait were calculated using the correlation procedure in SAS. The raw weights were used in one analysis, and the residuals from a general linear model fitting TOTAL as a covariate were used in a second analysis.

Results and discussion

Literature from cattle has shown that there are significant differences among breed types in their adipose distribution, e.g., dairy type breeds having higher levels of INT relative to SCF, with more labile adipose type (Berg & Butterfield 1976; Wright & Russel 1984). Breed differences are known to exist in sheep, but the link through to production outcomes has not been shown (McClelland & Russel 1972; Lirette et al. 1984).

The animals from which the images were taken represent New Zealand maternal-breed genetics. A summary of the weights of adipose tissues estimated from both approaches in Table 1. The largest amount of variation was for the weight of subcutaneous adipose, with the weight of lean most consistent between the two groups of images. There was significant tissue-dependent variation in the weight of tissue reported, based on the sub-set compared to all of the images, with the six images underestimating the weight of SCF, INT and non-adipose visceral components and overestimating the weight of intermuscular adipose. These differences occurred because the weight of tissues is calculated including a measure of distance between the different images, and the start and end point for the six images did not include the full length of the carcass that the full scan includes. Additionally, tissues were not uniformly distributed, meaning that the six image approach will predict that some tissue types extend further or less than they actually do.

The correlation between the absolute weights of the tissues estimated from the six images and all images is in Table 2. The set of six images used commercially was selected through analysis to optimise predictions of lean and adipose only within the carcass component of the body, (Kvame et al. 2004; Jopson et al. 2009). Unsurprisingly, the highest correlations existed for subcutaneous adipose and lean tissue weight. The correlation for absolute weights were consistent with the results of Kvame et al. (2004), of R^2 0.87 to 0.98 across carcass cuts for subcutaneous adipose, and R^2 0.80 to 0.99 for lean. They also reported lower correlations for bone of R^2 0.65 to 0.90 for different carcass cuts, although still higher than those reported in the current study. Although internal adipose was not used in determining which images should be used in the commercial scanning, the resulting correlation for absolute weights of internal adipose tissue was high. The correlations between the weight-adjusted estimates (Table 2) were lower for all tissues, although still high for SCF and INT, with bone again the lowest. This indicates that some of the correlations for the absolute weights reflects that heavier animals will

Table 1 Summary statistics for measures of body composition of yearling maternal ewes made using computed tomography scanning using all images taken (n=32), or using a sub-set of six images.

		All images					Sub-set of six images					Difference between six & all images
	N	Mean	Std dev	CV	Min	Max	Mean	Std dev	CV	Min	Max	
Subcutaneous adipose	50	7.8	1.5	19%	4.7	12.2	5.5	1.1	19%	3.4	8.4	71%
Intermusuclar adipose	50	2.9	0.5	18%	1.6	4.2	3.5	0.6	18%	2.2	4.9	119%
Internal adipose	50	6.6	1.0	16%	4.5	9.3	5.4	1.0	18%	3.7	7.7	81%
Carcass lean	50	21.0	1.8	8%	16.4	25.2	20.7	1.6	8%	15.7	24.4	99%
Non-adipose visceral components	50	12.0	1.2	10%	9.6	15.4	9.8	1.2	12%	7.8	12.9	81%
Bone	50	4.7	0.4	8%	3.9	5.4	4.7	0.5	10%	3.8	5.9	100%
Subcut:internal	50	1.18	0.17	14%	0.9	1.7	1.03	0.15	15%	0.75	1.4	87%

Table 2 Correlations (R^2) between estimates of tissue types made using computed tomography scanning using all images or a sub-set of six images. Absolute weights or residuals after adjustment for total weight are shown. All correlations were highly significant ($P<0.001$), with the exception of residual bone (*) which was significant ($P=0.008$).

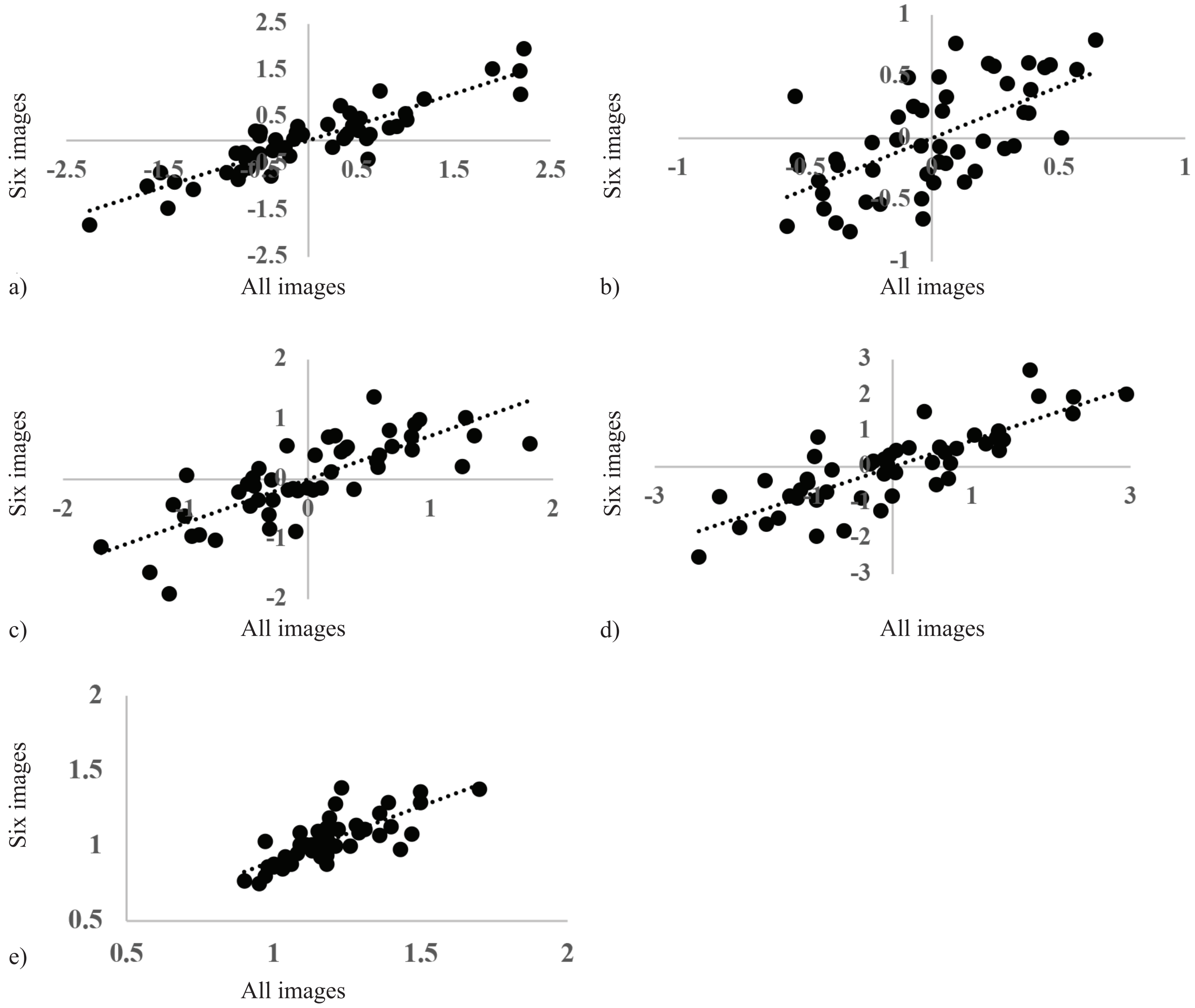
	Correlation (R^2) All Images vs six Images	
	Absolute	Residual (total weight adjusted)
Subcutaneous Adipose	0.92	0.81
Intermuscular Adipose	0.74	0.40
Internal Adipose	0.77	0.62
Lean	0.83	0.68
Non-adipose visceral components	0.59	0.51
Bone	0.25	0.14*
Subcutaneous:Internal	0.61	

have more of all tissue types than do lighter animals, but that there are differences in adipose distribution beyond differences in total weight. The correlation for the SCF:INT ratio was moderate.

The correlations for the total weight-adjusted tissue weights and the ratio trait are graphically represented in Fig. 1. The plots show that individual animals do not appear to significantly re-rank, and animals that have very low, or very high levels of a tissue type do so whether based on all images, or on the subset of images. This further indicates that the differences that are being reported are not strictly due to total weight differences among the animals, but rather that the subset of images is able to identify animals that have differential adipose deposition, i.e., those that are laying down more or less subcutaneous adipose, relative to internal adipose.

These results support further analysis of the remaining data set of 550 animals associated with the feed-efficiency trial to confirm the findings of this study. If successful, it would open up the option of re-analysing existing

Figure 1 Relationship between all computed tomography images and a sub-set of six images for total-body-weight adjusted weights of a) subcutaneous adipose; b) intermuscular adipose; c) internal adipose and d) lean and e) the ratio of subcutaneous adipose to internal adipose based on absolute weights of the respective tissues.



commercial images to determine their internal adipose content. However, the majority of the commercially scanned animals are rams around eight months of age, so further work would be required to determine whether or not they also differentially lay down adipose tissue into different depots. An alternative to using CT scanning to predict internal fat reserves would be to develop predictions based on ultrasound measures of internal adipose depots as has been done recently by Morales-Martinez et al. (2020) in Pelibuey sheep, a breed which reportedly lay down more adipose in internal adipose depots compared with the subcutaneous adipose depot (Chay-Canul et al. 2011). Through measuring kidney adipose thickness using ultrasonography, they were able to predict internal adipose reserves relative to dissected internal adipose reserves with a high level of accuracy ($R^2 = 0.71$).

Ultimately, the aim is to investigate whether or not there is a link between differences in relative body adipose deposition and production traits that can be exploited to improve production outcomes. The results from this study support the use of a lower-input (fewer images) method that will enable generation of more data for further analysis to investigate links between internal fat and production outcomes.

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