Prediction of carcass tissue weight *in vivo* using live weight, ultrasound or X-ray CT measurements

M.J. YOUNG, S.J. NSOSO, C.M. LOGAN AND P.R. BEATSON

Animal & Veterinary Sciences Group, P.O. Box 84, Lincoln University, Canterbury, New Zealand.

ABSTRACT

Twenty-one Dorset Down ewe hoggets (49.4kg body weight, 9months old) were scanned by ultrasound and X-ray computer tomography (CT). Total carcass tissue (fat, muscle and bone) weights were assessed by the Cavalieri procedure from 16-18 CT slices per animal. Additional CT slices were taken at four anatomical reference sites; 7th thoracic (TV7), 2nd lumbar and 5th lumbar vertebrae (LV5), and mid-shaft of the femur. Subcutaneous fat depth and muscle depth were assessed over the last rib using ultrasound. Body weight, ultrasound measurements and reference slice carcass tissue areas were used to predict total carcass tissue weights by multiple regression techniques.

In combination with BW, single CT slices predicted tissue weight more accurately than ultrasound measurements with BW for fat (R2=72-84% vs. 63%) but not for muscle (R^2=79-87% vs. 83%) or bone (R^2=62-66% vs. 65%). The best combination of two CT slices was TV7 & LV5. In combination with BW these improved prediction accuracy further (fat, R^2=92%, muscle, R^2=91%, bone, R^2=71%).

It is possible that data from a single CT slice predict carcass tissue weight less accurately than expected due to anatomical registration errors despite CT producing better quality images than ultrasound. These errors are attributed to scanning protocol constraints for CT equipment.

Two or more CT slices need to be scanned in order to predict tissue weight more accurately than ultrasound.

Keywords: X-ray computer tomography; CT; ultrasound; carcass composition; fat; muscle; bone; sheep; Cavalieri.

INTRODUCTION

Establishment of X-ray computer tomography (CT) scanning facilities in New Zealand has created the opportunity to measure more accurately the body composition of live sheep and other animals of similar size.

Ultrasound measurements are commonly used in selection programmes designed to change carcass composition in sheep and cattle (Simm, 1987; Fogarty, 1995). Ultrasound technology is fast, cheap and portable compared to higher resolution imaging technologies such as X-ray CT (Young, 1994).

More accurate assessment of body composition *in vivo* will lead to increased rates of gain from selection (Simm, 1987; Jopson *et al*, 1995). Simm (1987) estimated that if X-ray CT were used simply to measure the same tissue linear dimensions as ultrasound, rates of response to selection would improve by as much as 50% due to more accurate measurement of tissue dimensions from the higher resolution images obtained. As well, X-ray CT imaging offers the opportunity to introduce new traits to selection programmes *e.g.* fat partitioning between carcass and internal fat depots (Young, 1994).

A feature of X-ray CT imaging is the extremely large amount of information that can be produced for any given animal. There can be as many as 100-200 "slice" images collected per animal. Subsequently this must be subjected to image analysis to quantify traits of interest. Therefore, reduced scanning protocols using scans at specific anatomical reference sites would be desirable to speed up the processes of scanning and image analysis.

This paper compares the relative accuracies with which ultrasound and X-ray CT anatomical reference site data can predict weight of the major carcass tissues.

MATERIALS & METHODS

Data were available for 21 Dorset Down female sheep (49.4kg body weight, 9months old) from a larger X-ray CT scanning trial. Body weight (BW), ultrasound fat depth (UFD) and ultrasound muscle depth (UMD) were measured prior to CT scanning. These sheep were scanned by X-ray CT at four specific anatomical reference sites and then comprehensively scanned using the Cavalieri procedure to estimate weights of carcass fat, muscle and bone.

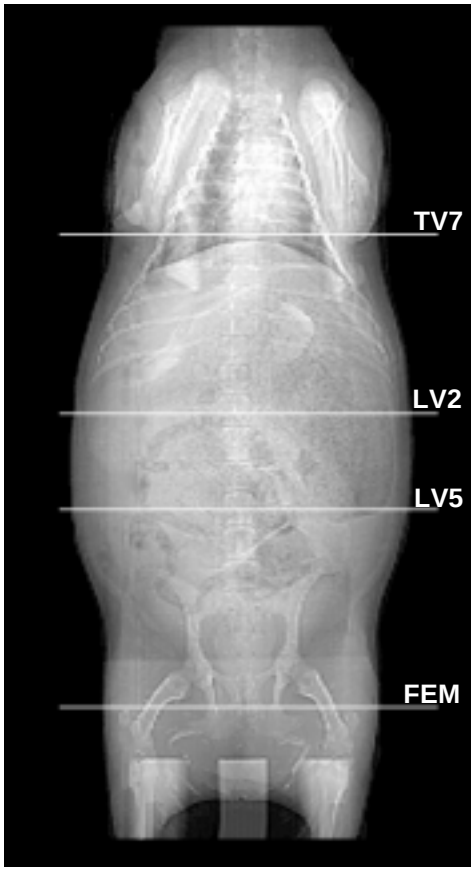
Body weight of each animal was obtained using electronic scales and ultrasound measurements were fat depth (C) and muscle depth (B) as described by Young *et al.* (1992).

Thirty minutes prior to scanning animals were injected intramuscularly with a tranquilliser (1ml of 10mg/ml acepromazine; ACEPRIL 10, Troy laboratories Pty. Ltd.). Animals were scanned lying on their backs with their hindlegs extended and forelegs strapped along their chest.

Animals were first scanned at the four anatomical reference sites (see Plates 1 & 2);

- through the 7th thoracic vertebra (TV7);
- through the 2nd lumbar vertebra (LV2);
- through the 5th lumbar vertebra (LV5);
- mid-shaft of the femur (FEM);

PLATE 1: Ventral view of the skeleton to show the position of anatomical reference slices. Typical reference slices are shown in Plate 2.



They were then scanned using a modified Cavalieri procedure. The Cavalieri procedure allows estimation of the volume of irregular shaped objects provided there are 10-15 evenly spaced slices perpendicular to an axis through the object and that the first slice position is chosen at random (Gundersen & Jensen, 1987). Consequently, the exact position of slices varies from animal to animal. Volume was estimated by totalling the areas across slices and multiplying by the distance between slices. This method is reported to have a 95% accuracy (Gundersen & Jensen, 1987).

The procedure was modified with regard to the way in which the first scanning position was selected in order to suit CT scanning conditions. Instead of being precisely positioned in terms of the scanner table bed position, or anatomical position, and then moved a randomly determined distance from this for the first scan, animals were roughly positioned so that the first scan was in the neck region in front of the shoulder. All sheep were scanned at 18-20 sites with 55mm intervals between slices. For image analysis, a series of images was selected from those collected for each animal, such that the first slice was in front of the shoulder, but the shoulder was apparent in the second slice. The last slice was below the knee without any traces of thigh muscle (see Plates 3 & 4). This yielded 16-18 slices for analysis per sheep. Resulting tissue volumes were converted to weights using standard tissue density values (fat, 0.925; muscle, 1.031; bone, 1.549 kg/dm^3; N.P. Jopson, pers. comm.)

Image analyses were performed on all CT slice images using software written by Dr N.P. Jopson (AgResearch, Invermay). Internal organs and material outside the body were removed from the image by an operator leaving the carcass and the skin. Areas of fat, muscle and bone in each of these images were determined. In addition, eye muscle (*M. longissimus dorsi*) dimensions (width, A; depth, B and area) were measured on the LV2 and LV5 slices.

Cavalieri tissue "weights" were used as dependent variables in predictions. Body weight, ultrasound and CT reference slice measurements were used as predictors. Multiple regression analyses were performed using the MINITAB statistical package. Accuracies of prediction were expressed in terms of the coefficient of determination (R^2) and the residual standard deviation (rsd).

RESULTS

Summary statistics for the variables measured are presented in Tables 1 and 2. Equivalent data (mean ± sd) for BW, UFD and UMD were 49.4 ± 5.30kg, 5.8 ± 1.41mm and 29.2 ± 1.95mm. These characterise the animals as moderately fat (32% of carcass, based on Cavalieri data). While similar coefficients of variation were seen for the Cavalieri scan and the reference slices in fat (c.17%) and muscle (c.12%), values for bone were considerably higher in the reference scans (average of 19%) than the Cavalieri scan (11%) indicating that bone was less accurately measured using reference scans. UFD had a higher coefficient of variation (24%) than CT fat measurements (15-20%).

UFD was considerably less accurate at predicting fat than BW (Table 3). UFD + BW were the most accurate combination using ultrasound measurements. Adding UMD

TABLE 1: Summary statistics (mean and standard deviation) for carcass tissue data from total scan and anatomical reference site scans. Total tissue weights were derived by the Cavalieri method (see text). Reference slice data are carcass tissue areas. Weights in kilograms and areas in cm^2.

variable	fat	muscle	bone
total	7.89	13.17	3.92
	(1.302)	(1.747)	(0.433)
reference slices			
TV7	122.2	116.7	49.4
	(21.15)	(13.93)	(7.82)
LV2	74.1	87.1	17.9
	(14.87)	(10.88)	(4.00)
LV5	57.0	84.5	16.4
	(10.20)	(9.99)	(1.71)

TABLE 2: Summary statistics (mean and standard deviation) for eye muscle data collected from reference slice CT images.

reference slice	width, A mm	depth, B mm	area cm^2
LV2	66.2	27.3	16.61
	(3.50)	(2.19)	(1.700)
LV5	75.1	28.5	18.99
	(3.92)	(2.85)	(2.135)

PLATE 2: Typical anatomical reference slices at the 7th thoracic vertebra (TV7), 2nd lumbar vertebra (LV2), 5th lumbar vertebra (LV5) and mid shaft of the femur (FEM). Positions of these slices in the animal are shown in Plate 1. Fat is dark grey, muscle light grey and bone white, reflecting differences in density.

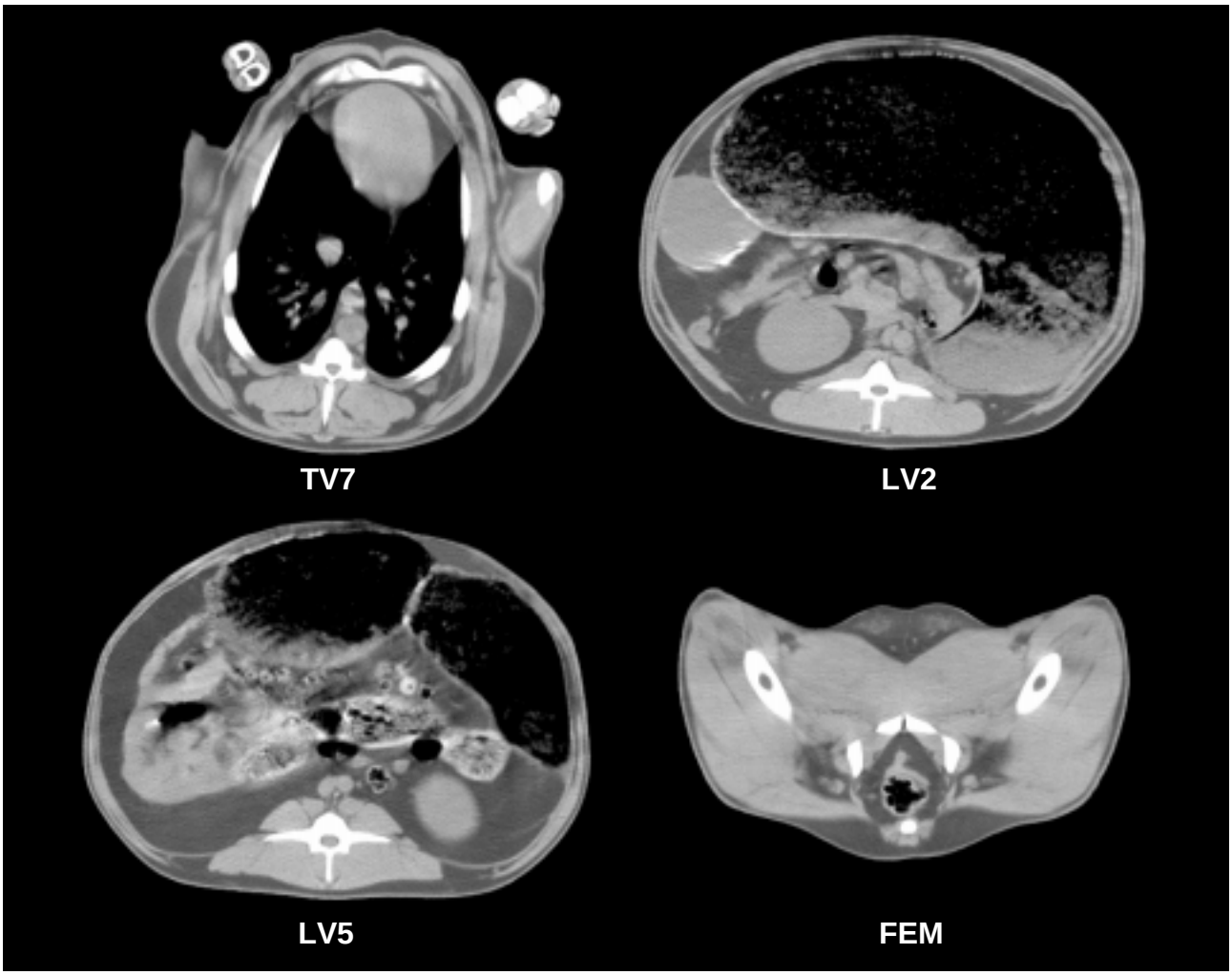


TABLE 3: Predicting carcass fat weight (kg). Goodness of fit (R^2) and residual standard deviation (rsd) for fat weight with different combinations of predictors.

predictors		R^2 (%)	rsd
none		-	1.302
body weight (BW)		50	0.942
ultrasound fat depth (UFD)		19	1.200
UFD	+ BW	63	0.838
UFD + UMD	+ BW	63	0.860
Slice fat area			
TV7 fat		84	0.530
LV2 fat		83	0.557
LV5 fat		72	0.710
FEM fat		74	0.679
TV7 fat	+ BW	88	0.480
LV2 fat	+ BW	87	0.497
LV5 fat	+ BW	88	0.479
FEM fat	+ BW	78	0.643
best 2 CT slices			
TV7 fat + LV5 fat	+ BW	92	0.409
all four CT slice fat areas			
TV7 + LV2 + LV5 + FEM	+ BW	93	0.406

did not improve accuracy. Substantially better prediction accuracies were obtained using fat areas from single CT slices. In combination with BW these increased still further. Using data from more than one slice led to accuracies approaching that reported for the Cavalieri procedure (c.95%) from which the dependent variable was derived.

UMD had a similar accuracy to BW for predicting muscle weight (Table 4). Together they provided a better prediction of muscle weight. Adding UFD did not improve accuracy. Eye muscle dimensions measured on CT images, were not greatly different in terms of accuracy of prediction (Table 5). If anything, CT linear dimensions tended to yield slightly less accurate predictions. However, area and the product of depth and width (A*B) were as good as or slightly better than ultrasound measurements. Reference slice muscle areas (Table 4) were less good than UMD on their own but in combination with BW they were similar to UMD + BW. Using data from more than one slice led to improvements similar to those seen for fat.

For bone, BW was a slightly better predictor than UMD (Table 6). Together they predicted bone weight

PLATE 3: Approximate position of CT slices for the Cavalieri procedure for comparison with the reference slice scanning approach (see Plate 1). Slices were evenly spaced at 55mm intervals. While reference slices were positioned accurately, exact cavalieri slice position varied from sheep to sheep due to "random" selection of the first scanning position. A typical sequence of Cavalieri slices is shown in Plate 4.

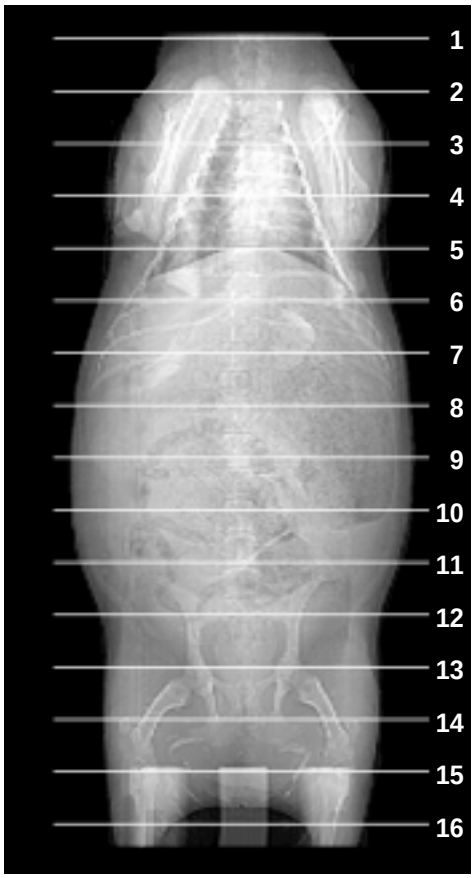


TABLE 4: Predicting carcass muscle weight (kg). Goodness of fit (R^2) and residual standard deviation (rsd) for muscle weight with different combinations of predictors.

predictors		R^2 (%)	rsd
none		-	1.747
body weight (BW)		74	0.911
ultrasound muscle depth (UMD)		74	0.910
UMD	+ BW	83	0.768
UMD + UFD	+ BW	83	0.790
Slice muscle area			
TV7 muscle		54	1.220
LV2 muscle		68	1.016
LV5 muscle		70	0.975
FEM muscle		69	0.997
TV7 muscle	+ BW	79	0.836
LV2 muscle	+ BW	80	0.824
LV5 muscle	+ BW	87	0.663
FEM muscle	+ BW	83	0.764
best 2 CT slices			
LV5 muscle + FEM muscle	+ BW	91	0.566
all four CT slice muscle areas			
TV7 + LV2 + LV5 + FEM	+ BW	94	0.508

TABLE 5: Predicting carcass muscle weight (kg) from CT eye muscle measurements. Goodness of fit (R^2) and residual standard deviation (rsd) for muscle weight with different combinations of predictors.

predictors		R^2 (%)	rsd
none		-	1.747
LV2 muscle width, A		60	1.140
LV2 muscle depth, B		62	1.101
LV2 A*B		84	0.723
LV2 muscle area		67	1.034
LV5 muscle width, A		41	1.380
LV5 muscle depth, B		67	1.025
LV5 A*B		77	0.852
LV5 muscle area		74	0.922
LV2 muscle width, A	+ BW	88	0.650
LV2 muscle depth, B	+ BW	79	0.849
LV2 A*B	+ BW	90	0.594
LV2 muscle area	+ BW	85	0.711
LV5 muscle width, A	+ BW	77	0.879
LV5 muscle depth, B	+ BW	79	0.840
LV5 A*B	+ BW	83	0.765
LV5 muscle area	+ BW	86	0.688
LV2, A + B		85	0.712
LV5, A + B		77	0.879
LV2, A + B	+ BW	91	0.556
LV5, A + B	+ BW	83	0.789

TABLE 6: Predicting carcass bone weight (kg). Goodness of fit (R^2) and residual standard deviation (rsd) for bone weight with different combinations of predictors.

predictors		R^2 (%)	rsd
none		-	0.433
body weight (BW)		61	0.278
ultrasound muscle depth (UMD)		55	0.298
UMD	+ BW	65	0.271
UMD + UFD	+ BW	66	0.272
Slice bone area			
TV7 bone		28	0.377
LV2 bone		21	0.394
LV5 bone		44	0.331
FEM bone		13	0.415
TV7 bone	+ BW	63	0.277
LV2 bone	+ BW	62	0.282
LV5 bone	+ BW	66	0.267
FEM bone	+ BW	65	0.269
best 2 CT slices			
TV7 bone + LV5 bone	+ BW	71	0.252
all four CT slice bone areas			
TV7 + LV2 + LV5 + FEM	+ BW	73	0.262

with a slightly greater accuracy than BW alone. Adding UFD did not improve accuracy. Reference slice bone areas estimated bone weight much less accurately than BW or UMD. Adding BW led to reference slice data having similar accuracy to ultrasound data but in both cases improvements in accuracy were only marginal compared to BW on its own. Using data from more than one slice led to small improvements, but the overall accuracies were less than those seen for fat and muscle.

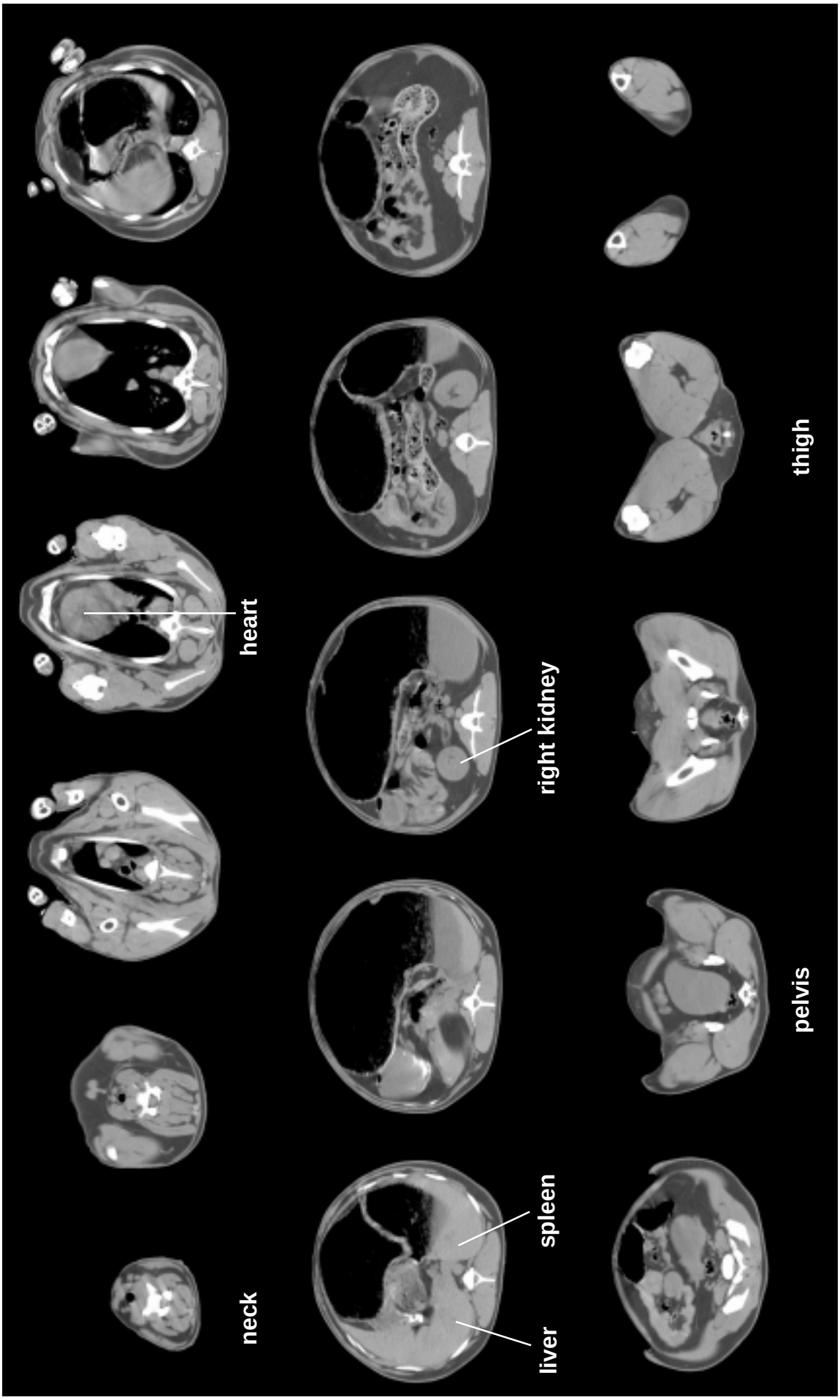


PLATE 4: A typical sequence of Cavalieri slices from the neck (top left) to the upper leg (lower right). Slices are 55mm apart. Fat is dark grey, muscle light grey and bone white, reflecting differences in density.

Consideration was given to whether certain particular combinations of pairs of slices were better than others across all three tissues. These results are not presented here in full. The best slice pair combination is presented for each tissue (Tables 3, 4 & 6). Consideration of all the data showed that the TV7 and LV5 slices together gave the best predictions across all three tissues. For muscle, using these two slices together with BW as predictors gave an accuracy that was almost identical (R^2=91%, rsd=0.568) to that of the best CT slice pair combination (R^2=91%, rsd=0.566 for LV5,FEM,BW).

DISCUSSION

For all measurements, adding BW to the prediction improved accuracy. This is expected since BW is an overall measure of body size and therefore is affected by the size of other tissues and other sites in the body. When using ultrasound measurements, muscle was predicted most accurately, with fat and bone having similar but lower accuracies. These figures are similar to those reported by Simm (1987) for ultrasound and CT measurements and by Waldron *et al.* (1992) for carcass dissection data.

It was initially surprising that individual CT reference slices were not more accurate predictors than ultrasound measurements. Images were of high quality and more information was used than in the study of Simm (1987) because total tissue areas in the carcass cross-section were measured. We believe the poorer than expected accuracy is due to less accurate anatomical registration of X-ray CT images compared to ultrasound images.

In the case of ultrasound, operators interact with a real-time display to obtain an image that is positioned precisely anatomically. They can move the head of the scanner to take account of animal posture and orientation as well as delay image collection when animal movement occurs. Once a good image is achieved it is frozen and measurements made on it. In comparison, registration errors occur with X-ray CT due to variation in animal posture and to animal movement. The scanning plane is relatively fixed so that variation in animal posture affects anatomical registration. As well, the delay between planning a scan and that scan being performed allows animal movement to contribute to registration errors. Consequently, tissues can "move" in and out of the plane of the scanned slice relative to the scanning site reference point.

Such registration effects may explain why eye muscle linear dimensions measured on CT images were less accurate as predictors than UMD. They would also give rise to the poor predictions obtained for bone from single CT reference slices due to the more complex shape of this tissue. Registration errors can cause bones to move into or out of images while having relatively less effect on fat or muscle.

It should be emphasised that while ultrasound compared favourably with CT, this was only so when data for a single CT slice was used. Use of data from two or more CT slices produced more accurate predictions. Thus the conclusion of Simm (1987) that increased rates of response to selection will occur where CT is used to collect the same measurements as ultrasound would not be correct where only one reference slice is scanned.

Increasing the numbers of predictors will theoretically increase prediction accuracy and these data demonstrate this well. Kirton & Johnson (1979) showed this for linear dimensions measured on the carcass. While no reports are available showing this for multiple measurements assessed by ultrasound it is expected that the approach of scanning at more than one site could be used with ultrasound.

These data clearly show UMD is very strongly related to total carcass muscle. However, CT measurements on the eye muscle suggest width is as good as or better than muscle depth as a predictor. While the product of width and depth (A*B) was better than linear dimensions when used as a single predictor, when used in combination with BW results were equivocal. Caution should be exercised in applying these findings to justify the use of muscle width as measured by ultrasound. Theoretically the ultrasound imaging modality will measure width less accurately than depth and ultrasound muscle width has been reported to be measured with low accuracy (Fogarty, 1995). However with the advent of new generation ultrasound scanners, increasingly muscle width is being measured in New Zealand sheep. Repeatability of this trait needs to be determined.

The sheep in this study were moderately fat (33% of carcass). Many sheep in New Zealand are leaner and lower levels of fat would be expected to reduce the accuracy with which UFD predicted carcass fat weight as measurement errors become more significant. There should not be a great change in the accuracy of prediction for CT reference slice measurements since measurement errors were similar to those of estimating total fat. This assumption requires verification.

Locations of the anatomical reference sites were based on educated guesses and on the aim of using the images to assess other traits not reported here such as muscularity, fat distribution and fat partitioning. There may be better reference sites. Further work needs to assess how well these sites suit other genotypes and whether better sites exist for predicting carcass tissue weight.

CONCLUSIONS

CT produces higher resolution images but image registration errors are greater compared to ultrasound which provides lower resolution images but where the operator has more control over image registration.

CT can yield more accurate predictions of tissue weight than ultrasound but more data must be collected and analysed. Two or more reference sites need to be scanned. This study found the 7th thoracic vertebra and 5th lumbar vertebra to be the best predictors of carcass tissue size from the four reference sites studied. Body weight should be included as a predictor.

It is most likely that CT will be used primarily in animal research examining the genetic and nutritional control of growth and body composition. However, CT imaging can be

usefully applied in breeding programmes for;

1. breed development, where ultrasound cannot be used to assess traits of interest, such as internal fat or tissue shape and distribution,
2. greater discrimination between potential elite sires in a two stage selection programme where initial screening uses ultrasound data (Simm, 1987; Jopson *et al*, 1995).

ACKNOWLEDGMENTS

The New Zealand Meat Producer's Board and the Lotteries Grant Board for financial assistance in establishing the X-ray CT facility at Lincoln University; R Barton of BITS Ltd, New York for recommissioning the CT scanner; ST Bell for maintenance and troubleshooting of scanning hardware; Dr NP Jopson for image analysis software; JC McEwan, Dr JM Thompson & GH Shackell for discussions on the Cavalieri procedure; Dr G Simm, Dr R Banks & Dr JM Thompson for discussions leading to choice of the anatomical reference sites. SJN was the recipient of a Commonwealth Postgraduate Scholarship during the time of this study.

REFERENCES

Fogarty, N.M. 1995. Genetic parameters for live weight, fat and muscle measurements, wool production and reproduction in sheep: a review. *Animal breeding abstracts* **63:** 101-143.

Jopson, N.B.; McEwan, J.C.; Dodds, K.G.; Young, M.J. 1995. Economic benefits of including computed tomography measurements in sheep breeding programmes. *Proceedings of the Australian association of animal breeding and genetics* **11:** 194-197.

Gundersen, H.J.G.; Jensen, E.B. 1987. The efficiency of systematic sampling in stereology and its prediction. *Journal of microscopy* **147:** 229-263

Kirton, A.H.; Johnson, D.L. 1979. Interrelationships between GR and other lamb carcass fatness measurements. *Proceedings of the New Zealand society of animal production* **39:** 194-201.

Simm, G. 1987. Carcass evaluation in sheep breeding programmes. *In.* New techniques in sheep production. p125-144. editors Marai, I.F.M & Owen, J.B. Butterworths: London.

Waldron, D.F.; Clarke, J.N.; Rae, A.L.; Kirton, A.H.; Bennett, G.L. 1992. Genetic and phenotypic parameter estimates for selection to improve lamb carcass traits. *New Zealand journal of agricultural research* **35:** 287-298.

Young, M.J. 1994. CT scanning - applications in animal science and breeding. *Proceedings of the 1994 Central Districts sheep and beef farmers' conference*, Massey University, 28-29 June 1994. p94-99.

Young, M.J.; Deaker, J.M.; Logan, C.M. 1992. Factors affecting repeatability of tissue depth determination by real-time ultrasound in sheep. *Proceedings of the New Zealand society of animal production* **52:** 37-39.