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Final report

NUCTECH DEXA prediction of lamb carcase lean meat yield

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Abstract

Lean meat yield (LMY) is an important lamb carcase trait as consumers demand lean meat, making carcases with higher proportions of lean muscle more valuable. Dual energy X-ray absorptiometry (DEXA) has demonstrated capacity to predict computed tomography (CT) LMY% (the gold standard) with high precision and accuracy when scanning lamb carcases at abattoir line speed. NUCTECH have designed, manufactured and installed a commercial DEXA system with a small footprint in an Australian abattoir. This study assessed the precision and accuracy with which the NUCTECH DEXA can predict CT fat, lean and bone% in 50 lamb carcases varying widely in carcase weight and fatness. The carcases were DEXA scanned at line speed before being quartered, frozen and CT scanned. The NUCTECH DEXA system predicted lamb carcase CT fat, lean and bone% with high precision, and this high precision was maintained when prediction equations were trained and validated in subsets of the data. The validation process also demonstrated that NUCTECH DEXA predictions are highly accurate. These excellent results now need to be validated in a larger set of lambs representing the full variation in weight and fatness typically encountered in Australian lamb supply chains to provide industry confidence in this promising commercial system.

Executive summary

Background

In response to the growing demand for precise objective measurement of key carcase traits, including lean meat yield, the NUCTECH engineering team have undertaken a series of iterative development phases to construct a commercial DEXA system for the Australian lamb industry. This system has been successfully installed at a sheepmeat processing plant (Wagstaff Meats) in Victoria.

Objectives

This study evaluated the precision and accuracy with which the commercial NUCTECH DEXA system can predict the CT fat, lean and bone % of lamb carcases DEXA scanned at abattoir line speed.

Methodology

The precision and accuracy of NUCTECH DEXA prediction of CT composition was tested using 50 lamb carcases selected from the Wagstaff Meats kill floor to represent a wide range in carcase weight and fatness. All carcases were chilled overnight and then NUCTECH DEXA scanned at abattoir line speed the following day. The carcases were then split into sections (fore, rack, loin and hind), boxed and transported frozen to Murdoch University for CT scanning. NUCTECH DEXA scans were analysed to produce DEXA predictions of fat, lean and bone according to previously established methods. CT scans were standardised using the XTE-test piece before being analysed according to standard protocols to determine the CT fat%, lean% and bone% of carcase sections and entire carcases. Data was analysed using general linear mixed models in SAS.

Results/key findings

The results of this experiment demonstrate that the NUCTECH DEXA system can predict lamb carcase CT fat%, lean% and bone% with high precision, and that this high precision was maintained when the prediction equations were trained and validated in subsets of the data. The validation process also demonstrated that NUCTECH DEXA predictions of CT composition are highly accurate.

Benefits to industry

The NUCTECH DEXA system represents potential benefit to the Australian lamb industry by providing a highly precise, accurate and objective measure of lamb LMY at abattoir chain speed whilst having a smaller footprint compared to alternate DEXA systems.

Future research and recommendations

The NUCTECH DEXA prediction algorithms now need to be validated in a larger set of lambs representing the full variation in weight and fatness typically encountered in the Australian lamb supply chain. This will provide industry confidence in the ability of this system to output precise and accurate measurements of CT LMY% in a commercial processing environment.

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1. Background

Developing technologies for objective measurement of carcase traits is a high priority for the Australian lamb industry. Lean meat yield (LMY) is an important carcase trait as consumers demand lean meat and thus carcases with higher proportions of lean muscle are more valuable. Carcase LMY can be accurately and precisely measured using medical computed tomography (CT), which provides a complete virtual dissection of a carcase into muscle, fat and bone components (Gardner et al., 2018). However, the slow speed of medical CT technology currently prevents its application in commercial abattoirs. An alternative approach taken in Australia in recent years has been to measure carcase composition using dual energy X-ray absorptiometry (DEXA). These systems have demonstrated excellent accuracy and precision for determining carcase CT fat, lean muscle and bone % at line-speed in lamb abattoirs, and also have the advantage of being adapted to automated robotic boning systems to guide cutting and de-boning of carcases.

Aside from automation, DEXA presents multiple opportunities for the lamb meat industry. A reliable measure of carcase composition will enable trading on LMY rather than just carcase weight. It will also underpin reliable feedback to producers enabling them to improve genetic selection, nutrition and stock management to improve LMY; and for processors to predict carcase cut weights and optimise the cutting specifications for different lamb carcases. Given the potential value of DEXA for the Australian lamb meat industry, substantial incentive exists to develop alternative DEXA systems that are cheaper, easier to deploy, and small-in-size, thus minimising the abattoir footprint. In response to this demand, NUCTECH have developed a DEXA system for the prediction of lamb carcase CT composition. NUCTECH have designed, manufactured and installed a commercial DEXA unit at Wagstaff Meats abattoir in Victoria. This system requires calibration against CT composition measures of Australian lambs to develop equations to predict CT fat, lean and bone %, and to demonstrate the precision and accuracy of these predictions. This report details the NUCTECH DEXA calibration experiment where 50 lamb carcases were DEXA scanned at abattoir line speed to predict CT LMY%.

2. Objectives

Following previous work with Murdoch University demonstrating the capacity of the prototype NUCTECH DEXA device to predict CT LMY% in lamb carcases, this project required the NUCTECH engineering team alter their original design of the commercial prototype DEXA system to suit the abattoir site restrictions. Following the successful installation and commissioning of the NUCTECH system at Wagstaff abattoir, this project assessed the precision and accuracy with which this commercial DEXA system can predict CT LMY% at abattoir line speed in sheep carcases that varied in their carcase weight and fatness.

3. Methodology

3.1 Animal selection

A selection grid (Table 1) was used to guide the selection of lamb carcases to maximise the range in hot standard carcase weight (HSCW) and fatness for the calibration of the NUCTECH DEXA against CT measures of lamb composition.

Table 1. Selection grid demonstrating the ideal carcase selection for calibration of NUCTECH DEXA against CT LMY% based on carcase weight and CT Fat % of the carcases.

	CT Fat %						
Carcase weight	<20 %	20-24 %	24-28 %	28-32 %	32-36 %	>36%	Total
Light (HCWT < 22kg)	4	4	4	4			16
Medium (HCWT 22 - 28 kg)		4	4	4	4		16
Heavy (HCWT > 28kg)			4	4	4	4	16

Given that CT Fat% of carcases are not known at the time of carcase selection, palpated Fat Scores were used to guide selection of lamb carcases of varied fatness within each range of HSCW. The 50 lamb carcases were selected on the kill floor of Wagstaff abattoir over one day's kill.

3.2 DEXA scanning

The lamb carcases were chilled overnight following standard abattoir protocols before being scanned on-line by the NUCTECH DEXA system. Carcase DEXA images were generated using a single emission from a 120kV X-ray tube, captured using 2 photodiodes separated by a copper filter enabling the simultaneous acquisition of a set of 2 images. A rail stabilises the carcases and maintains them in a standard position (brisket facing the X-ray source) with minimal swinging motion during the DEXA imaging. An example NUCTECH DEXA scan of a lamb carcase on-line is shown in Fig. 1.

Figure 1. A NUCTECH DEXA scan (high and low energy images) of a standard lamb carcase captured on-line at Wagstaff Meats.

3.3 Carcase cutting and transport

Carcases were then manually dissected into forequarter, rack, loin and hindquarter sections according to established AUSMEAT cutting protocols for lamb carcase CT scanning. The fore section was separated from the saddle by a cut between the fourth and fifth ribs; the rack was separated from the loin between the 12th and 13th ribs; and the hind section was separated from the saddle by a cut through the mid-length of the sixth lumbar vertebrae. One lamb was mistakenly cut into four portions down the midline and across the thoracic-lumbar junction. This lamb was retained in the study with the knowledge that the differing cutting lines may have a small influence on LMY% measurement using CT. Carcase sections were labelled (linking carcase ID with their corresponding DEXA scan), boxed and frozen for trucking to Murdoch University for CT scanning.

3.4 CT scanning

Following a 4 week period of frozen storage the boxed lamb carcases sections were defrosted in a refrigerator before each section was re-weighed and CT scanned in multiple sessions over 2 days. Following standard calibration of the CT scanner (a Siemens Somatom Scope 16 slice CT scanner) using air and water, all carcase sections were CT scanned at settings of 110 mA, 120 KV and at 5mm slice thickness. The CT scanner has a field of view of 480mm, a pitch of 1, rotation time of 0.8 seconds and was set to an Abdomen soft tissue algorithm. An XTE-CT calibration test piece was scanned before and after each lamb carcase scanning session.

3.5 DEXA image analysis

DEXA images were analysed to determine the weight of fat, lean, and bone using the method developed in Project 1 and described in MLA final report P.PSH.0933. A multivariable linear relationship between these weights and the CT weights of each tissue type was assumed:

$$ctWfat$$

$$ctWlean = M \cdot (1, Wfat, Wlean, W\_bone)$$

$$ctWbone$$

The data of all 50 carcass was then split into training set and test set (the training set and test set can be the same). M is estimated using the training set as $\tilde{M}$, and the weight is adjusted as:

$$adWfat$$

$$adWlean = \tilde{M} \cdot (1, Wfat, Wlean, Wbone)$$

$$adWbone$$

The adjusted weights are then used to determine the DEXA predicted percentage of fat, lean and bone tissue in a carcase.

3.6 CT image analysis

CT images were analysed in DICOM format using ImageJ software (version 1.52a, National Institutes of Health, Bethesda, MD, USA in combination with Microsoft excel). CT images were analysed using established protocols for differentiation of carcase lean, fat and bone tissue %. Pixels lower than -500 were determined to be air and deleted from the image sets. The Hounsfield units thresholds used to associate pixels with fat, muscle and bone tissues were −235 to 2.3 for fat, 2.4 to 164.3 for lean muscle and >164.3 for bone. These thresholds were then adjusted to calibrate all scans to the standard XTE-CT calibration block (Synergy4Tech), using the mean Hounsfield unit value of ABS (acrylonitrile butadiene styrene) material within the XTE-CT scanned before and after carcase scan. Cavalieri's method (Gundersen et al., 1988; Gundersen & Jensen, 1987) was used to estimate volume according to the calculation:

$$Volume_{Cav} = d \times \sum_{g=1}^{m} area_g - t \times area_{max}$$

where m is the number of CT scans taken; d is the distance between cross-sectional CT scans (5mm); t is the thickness of each slice (g) (in this example 5 mm), and area max is the maximum area of any of the m scans.

The average Hounsfield units of the pixels of each tissue was then determined and converted into density (kg/L) using a simple linear equation based on XTE-CT scan values and combined with the volume of each tissue to determine the weight of fat, lean and bone in each carcase. These weights were then expressed as a percentage of cold carcase weight at the time of scanning to produce CT fat, lean and bone % values.

3.7 Statistical Analysis

Data was analysed using general linear mixed models in SAS. NUCTECH DEXA variables and their squared terms were included as covariates to predict CT fat, lean and bone %. Non-significant ($P > 0.05$) terms were removed from the models.

Firstly, data of all 50 lambs was used to train and test prediction equations. Secondly, an outlier in the data was removed and the prediction models were re-trained and tested in this truncated data set (n=49). Lastly, the truncated data set was randomly divided into 5 subsets, or groups, balanced for carcase weight and fatness to allow prediction models to be trained in 80 % of the data (4 groups) and tested or validated in the remaining 20% of the data (1 group). This validation procedure was repeated a further 4 times so that models were sequentially validated in all subsets of data to determine the precision (R-square or R^2 and root mean square error or RMSE) and accuracy (bias and slope) of NUCTECH DEXA predictions of CT fat, lean and bone %.

Finally, the ability of NUCTECH DEXA variables to predict CT fat, lean and bone % of each lamb carcase section (forequarter, mid-section and hindquarter) was tested. NUCTECH DEXA variables and their squared terms were included as covariates to predict the CT lean, fat and bone % of carcase sections, with non-significant ($P > 0.05$) terms again removed from models.

4. Results

4.1 Descriptive statistics

The lambs (n=50) ranged in HSCW from 15.6 to 32.8 kg, with an average of 24.1 kg (±3.48) and ranged from 18.6 to 36.5 CT fat %, with an average of 24.65 % (±3.69). The distribution of carcase CT fat% and HSCW of the selected lambs is shown in Fig. 2.

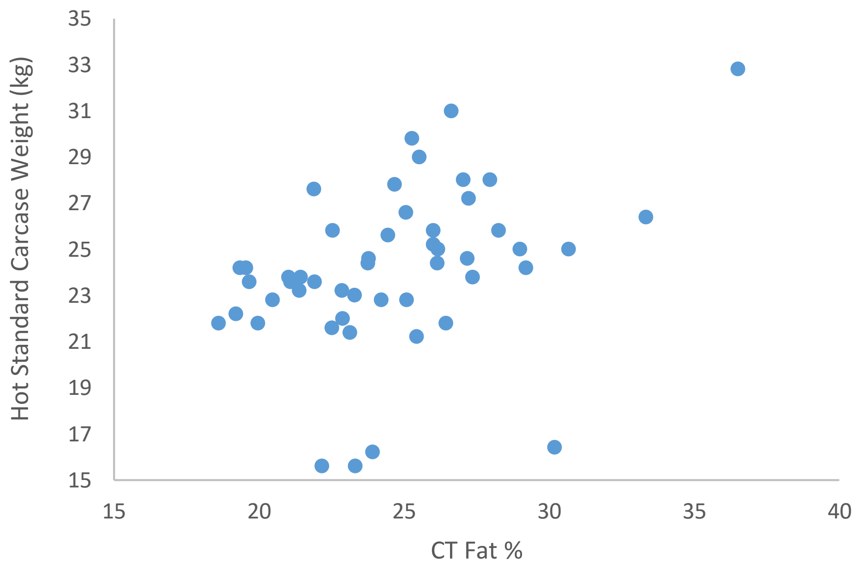

Figure 2. Hot standard carcase weight (kg) and Computed Tomography (CT) Fat % of the 50 selected lamb carcases.

The distribution of lamb carcases relative to the selection grid (Table 1) is shown below (Table 2). When compared to the animals sought (Table 1), this table demonstrates that a greater number of light (<22 kg), heavy (>28 kg) and high fat (> 32 %) lamb carcases are needed to better represent the full spectrum of LMY variation encountered in the Australian industry.

Table 2. The hot standard carcase weight (HSCW) and CT fat % distribution of the selected lambs according to the selection matrix categories.

	CT Fat %						
HSCW category	<20 %	20-24 %	24-28 %	28-32 %	32-36 %	>36%	Total
Light (HCWT < 22kg)	2	5	2	1			10
Medium (HCWT 22 - 28 kg)	4	13	14	4	1		36
Heavy (HCWT > 28kg)			3	0	0	1	4

4.2 NUCTECH DEXA prediction of carcase composition

The precision of NUCTECH DEXA predictions of lamb carcase CT LMY% are shown in Table 3. The NUCTECH DEXA was able to predict CT fat% with moderately high precision (R^2 of 0.82 and RMSE of 1.59 CT fat % units) when predictions were trained in the entire data set; and this precision increased to an R^2 of 0.90 and RMSE of 1.22 CT fat % units when the outlier lamb was removed from the data set. NUCTECH DEXA prediction of CT fat % maintained high precision when the prediction equations were sequentially trained in 80% of the data (4 groups) and tested in the remaining 20% (Table 3). The variation in precision between the different groups of training and validation data was small, with the R^2 varying from 0.84 to 0.95 with a mean of 0.89, and RMSEP varying from 0.55 to 1.58 with a mean of 1.15 CT fat % units.

CT lean % was predicted by the NUCTECH DEXA with slightly lower but nonetheless high precision, with an R^2 of 0.86 and RMSE of 1.14 in the truncated data set (Table 3). Like CT fat %, the precision of these predictions held up well when tested or validated within subsets of the data; with R^2 ranging from 0.72 to 0.93 with a mean of 0.84; and RMSEP ranging from 0.79 to 1.6 with a mean of 1.19 CT lean % units. NUCTECH DEXA prediction of CT bone % was also precise, with an R^2 of 0.88 and RMSE of 0.532 in the truncated data set, and a mean validated R^2 of 0.87 and RMSEP of 0.54 CT bone % units. The minimal reduction in precision estimates from trained to validated predictions demonstrates the robustness of the NUCTECH DEXA predictions of CT composition.

Table 3. The precision estimates (R-squared or R^2 and root mean square error or RMSE) for NUCTECH DEXA predictions of CT fat, lean and bone % when trained in a) the entire data set (n=50); b) the data set with one outlier removed (n=49) and c) in 4 groups (80%) of truncated data for validation in the remaining group (20%) of data.

	CT Fat %		CT Lean %		CT bone %	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
a) Training (n=50)	0.820	1.585	0.832	1.232	0.794	0.710
b) Training (n=49)	0.897	1.218	0.858	1.143	0.884	0.532
c) Validation test						
Group 1	0.911	0.549	0.874	0.792	0.801	0.695
Group 2	0.905	1.066	0.843	1.039	0.918	0.407
Group 3	0.838	1.386	0.719	1.340	0.916	0.636
Group 4	0.839	1.572	0.806	1.604	0.774	0.531
Group 5	0.954	1.183	0.933	1.168	0.944	0.404
Mean of validation tests	0.889	1.151	0.835	1.189	0.871	0.535

The accuracy of NUCTECH DEXA predictions of CT composition are shown in Table 4, represented by the bias and the deviation of the slope from 1 for the validated prediction equations. The absolute bias and absolute slope deviation from 1 of the 5 validation tests were averaged to give a value representing the mean accuracy of predictions. Overall, the predictions were highly accurate, with CT fat, lean and bone % predicted with a mean absolute bias of only 0.53, 0.36 and 0.16 units respectively, and with slopes varying from 1 by only 0.06, 0.07 and 0.1 respectively (Table 4).

Table 4. The accuracy estimates (bias and deviation of the slope from 1) for NUCTECH DEXA predictions of CT fat, lean and bone % when the prediction equations are validated in 5 subsets or groups of the data. Absolute bias and slope values are averaged to produce mean accuracy results of these predictions.

	CT Fat %		CT Lean %		CT bone %	
Validation test	Bias	Slope from 1	Bias	Slope from 1	Bias	Slope from 1
Group 1	-0.037	0.037	0.154	0.042	-0.050	0.089
Group 2	0.572	0.113	-0.497	0.132	-0.107	-0.012
Group 3	0.660	-0.036	-0.313	0.055	-0.296	-0.137
Group 4	-0.659	-0.094	0.289	0.037	0.127	0.240
Group 5	-0.717	0.037	0.557	-0.093	0.199	0.007
Mean of absolute values	0.529	0.063	0.362	0.072	0.156	0.097

The associations between validated NUCTECH DEXA predicted CT fat, lean and bone % and actual CT fat, lean and bone % are shown in Fig. 3-5, along with the precision (R^2 and RMSE) of these predictions.

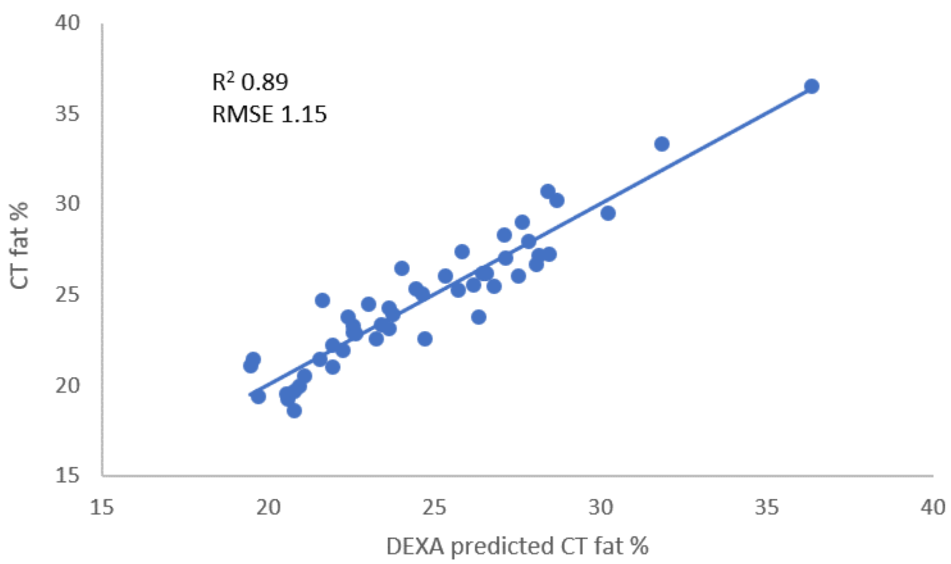

Figure 3. Association between CT fat % of lamb carcases and validated DEXA predictions of these values. Dots represent individual carcase values, and the line represents the prediction equation. The R-square (R^2) and root mean square error (RMSEP) of each prediction are shown.

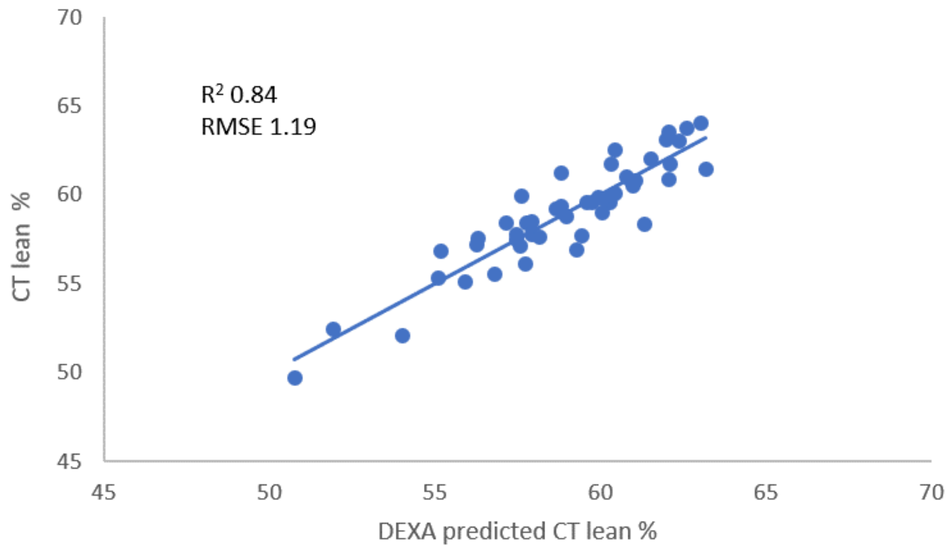

Figure 4. Association between CT lean % of lamb carcases and validated DEXA predictions of these values. Dots represent individual carcase values, and the line represents the prediction equation. The R-square (R^2) and root mean square error (RMSEP) of each prediction are shown.

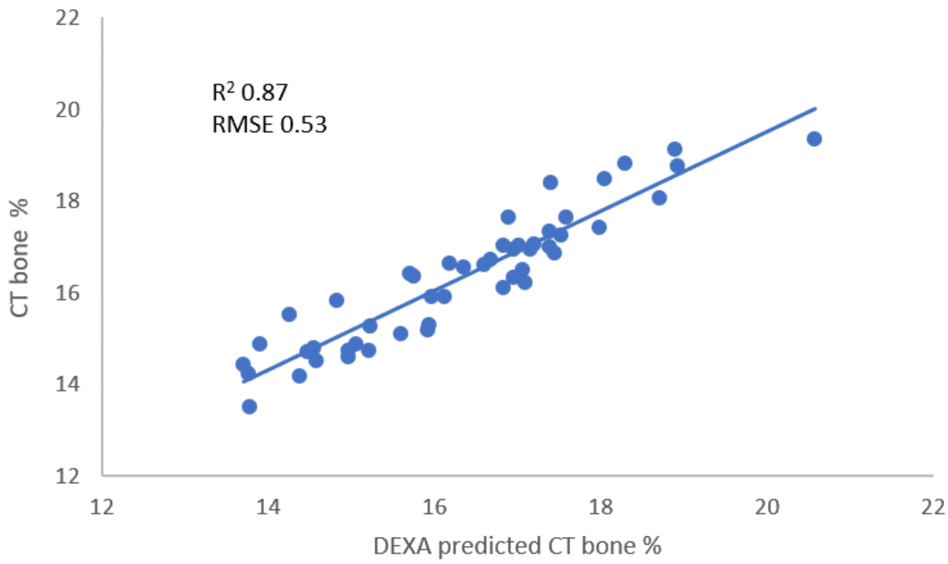

Figure 5. Association between CT bone % of lamb carcases and validated DEXA predictions of these values. Dots represent individual carcase values, and the line represents the prediction equation. The R-square (R^2) and root mean square error (RMSEP) of each prediction are shown.

4.3 NUCTECH DEXA prediction of CT LMY% of carcase sections

The precision with which NUCTECH DEXA predictions of carcase CT fat, lean and bone % could predict the CT composition of each carcase section is shown in Table 5. CT fat and lean % was predicted with the highest precision in the hindquarter, CT fat % predicted with lower error in this section (Table 5) than the entire carcase (Table 3). Prediction of CT fat % was also highly precise in the mid-section, while CT lean % was lower, and both traits were predicted with only moderate precision in the forequarter (Table 5). In contrast, CT bone % was predicted with good precision by NUCTECH DEXA variables in all three sections, and slightly better in the forequarter than the mid or hindquarter (Table 5).

Table 5. The precision estimates (R-squared or R^2 and root mean square error or RMSE) for NUCTECH DEXA predictions of CT fat, lean and bone % within the forequarter, mid-section (rack and loin) and the hindquarter (HQ) within a dataset with one outlier and one incorrectly quartered carcase removed (n=48).

	CT Fat %		CT Lean %		CT bone %	
	R^2	RMSE	R^2	RMSE	R^2	RMSE
Forequarter (FQ)	0.694	1.647	0.497	1.782	0.838	0.643
Mid-section	0.835	2.449	0.778	2.295	0.795	0.824
Hindquarter (HQ)	0.885	0.890	0.816	1.01	0.809	0.588

5. Conclusion

5.1 Key findings

This work demonstrates that the commercial NUCTECH DEXA scanner can predict the CT composition of entire lamb carcases scanned at abattoir line speed with high precision and accuracy. The precision estimates of NUCTECH DEXA predicting lamb CT LMY% are similar to those reported from other commercially operating lamb DEXA systems in Australia (Gardner et al., 2018). However, the precision and accuracy estimates of the NUCTECH DEXA reported in this work have been captured on a relatively small number of lambs. Therefore, this work should be extended across greater numbers of lambs carefully selected to represent the full range in carcase weight and fatness encountered in the Australian industry (represented in Table 1) to further train and test the NUCTECH DEXA prediction equations. Validation of NUCTECH prediction equations between larger and more varied data sets will provide the wider industry with full confidence in this commercial DEXA system.

The commercial robustness of this system also needs to be tested by demonstration of the repeatability of lamb carcase LMY measures through this system, both when carcases are scanned repetitively within a short period of time (short term repeatability) and when lamb carcases are scanned at different intervals post-slaughter (12- 72 hours). This would ensure that lambs could be DEXA scanned the morning after slaughter or after spending a long in the chiller without impacting DEXA estimates of CT LMY%.

Finally, this work has shown the association between the NUCTECH DEXA prediction of lean%, fat%, and bone% versus the CT LMY% within each section of the lamb carcase. The stronger association with CT fat and lean % in the hindquarter suggests that DEXA differentiation of soft tissues is superior in this section of the carcase. The reduced precision of CT fat and lean % prediction in the fore and mid-section is not unexpected when a whole carcase NUCTECH DEXA variable is used, and further work is needed to investigate if partitioning DEXA images virtually at the level of carcase sectioning could improve DEXA prediction of CT LMY% within lamb carcase sections.

5.2 Benefits to industry

This calibration study has produced excellent results demonstrating that the commercial NUCTECH DEXA device is capable of predicting lamb carcase CT LMY% with high precision and accuracy. However, the transportability of the NUCTECH DEXA prediction equations needs to be tested in a larger data set of Australian lambs with more varied carcase phenotypes to provide industry confidence in this DEXA system. If the precision and accuracy of CT LMY% predictions can be maintained in a larger more-variable set of lambs this DEXA system will present a valuable proposition to the Australian lamb industry given its inbuilt radiation shielding and consequent smaller footprint in processing plants.

6. Future research and recommendations

There are several items to address in future experimental work. These include:

a) Repeating this work in a larger more varied data set to sufficiently assess the transportability of NUCTECH DEXA predictions of lamb carcase CT composition.

b) Demonstrating the repeatability (immediate and over time post-mortem) of the commercial NUCTECH DEXA system by repeated lamb carcase scanning.

c) Determine if partitioning of lamb DEXA images into fore, mid and hind sections improves the precision of CT LMY% prediction in these carcase sections.

d) Assessing the stability of lamb carcases and incidence of image errors during on-line DEXA scanning of large lamb numbers in-production.

7. References

- G.E. Gardner, S. Starling, J. Charnley, J. Hocking-Edwards, J. Peterse, A. Williams (2018) Calibration of an on-line dual energy X-ray absorptiometer for estimating carcase composition in lamb at abattoir chain-speed. *Meat Science*. Vol 144, pp 91-99. https://doi.org/10.1016/j.meatsci.2018.06.020.