Final report

Re-accreditation of Lamb DXA for the prediction of fat %, lean %, and bone %

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Abstract

The Scott Automation and Robotics (SAR) lamb DXA system installed in six Australian sheep meat abattoirs has achieved accreditation from AUS-MEAT and AMILSC in 2023, and as per the requirements or objective carcass measurement accreditation, must repeat this in the 12 months following the initial accreditation. This involves the collection of a minimum of 240 carcasses across a range of carcass weights and carcass fatness, which was achieved for the accreditation in 2023. The collection of carcasses, and the DXA scanning, will be performed at WAMMCO (Katanning, WA) over the course of 2024, which will produce the DXA predictions of carcass fat %, lean %, and bone %. These will be compared to the computed tomography (CT) determined carcass fat %, lean %, and bone%, scanned at Murdoch University (MU). To meet the accreditation requirements set out for objective carcass composition devices, 67% of DXA predictions must fall within 3% of the CT fat % and lean % values, and 1.6% of the CT bone % values, and 95% of DXA predictions must fall within 6% of the CT fat % and lean % values, and 3.2% of the CT bone % values.

A total of 269 lamb carcasses were DXA and CT scanned for the purpose of re-accreditation, between March 2023 and October 2024. The reaccreditation report was submitted to AMILSC in October 2024, and the re-accreditation was accepted in December 2024 as per the following grid:

HCWT category	Tissue Type		
	Carcase Fat%	**Carcase Lean%**	**Carcase Bone%**
<22kg	13.9% - 31.8%	52.6% - 64.5%	14.3% - 21.4%
22-28kg	16.4% - 35.2%	50.0% - 64.7%	13.7% - 19.3%
>28kg	22.0% - 40.0%	48.9% - 62.4%	12.5% - 16.2%

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Executive summary

This report has been prepared by ALMTech on behalf of the manufacturer of the LEAP DXA (Scott Automation and Robotics) for the re-accreditation of DXA to predict CT Fat%, CT Lean% and CT Bone% of sheep carcases. The re-accreditation trial was conducted at WAMMCO, Katanning, using sheep carcases collected between March 2023 and October 2024 (n=269). Through a previous submission the DXA has already been awarded accreditation for predicting Fat%, Lean%, and Bone% across all carcase categories, and this re-accreditation seeks to demonstrate that the accuracy of the DXA is unchanged.

The experimental and analytical procedure used to assess the repeatability and accuracy performance of the DXA device has been described. The performance of the DXA device was compared against version 1 of the AMILSC approved guidelines for experiments to achieve accreditation of technologies for predicting fat%, lean%, and bone% in sheep carcases ("A carcase composition trait for sheep meat grading technologies" presented to AMILSC on the 17/2/2022). As total carcase composition is loosely associated with hot carcase weight, the accreditation requirements for DXA are tested within three weight categories: light (<22kg); medium (22-28kg); and heavy (>28kg). This report only assessed prediction accuracy for Lean% in the heavy carcase category. The previous accreditation submission (August 2022) did not seek accreditation for this category as the carcase range was not adequately represented.

The accuracy reported in this document is comparable to the original accreditation submission (as seen in ***Table 1***), and we recommend re-accreditation of DXA for predicting composition in carcases with composition ranges seen in ***Table 2***. Due to the poor spring and summer seasons in the South-West of Western Australia in 2023-2024, there was a smaller range of available lambs, particularly at the extremes (fat and heavy carcases, as well as well-muscled carcases). This artificially constrained some of the re-accreditation ranges, and it should be noted that this was not due to accuracy issues.

Table 1 - Original accreditation ranges for LEAP DXA

HCWT category	Tissue Type		
	Carcase Fat%	**Carcase Lean%**	**Carcase Bone%**
<22kg	10.9% - 30.3%	53.2% - 65%	14.9% - 25.0%
22-28kg	14.0% - 35.0%	50.9% - 66.2%	13.3% - 18.0%
>28kg	22.0% - 37.1%	49% - 60.6%	11.6% - 17.5%

As presented in the original accreditation report, the repeatability of LEAP DXA has been tested on the JBS Bordertown DXA device, with the results published in a scientific journal (Connaughton, Williams et al. 2020). This experiment showed that coefficients of correlation between three repeated scans were close to 1 (0.992-0.995).

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Table 2 - Recorded re-accreditation ranges for LEAP DXA (2023/24)

	Tissue Type		
HCWT category	**Carcase Fat%**	**Carcase Lean%**	**Carcase Bone%**
<22kg	13.9% - 31.8%	52.6% - 64.5%	14.3% - 21.4%
22-28kg	16.4% - 35.2%	50.0% - 64.7%	13.7% - 19.3%
>28kg	22.0% - 40.0%	48.9% - 62.4%	12.5% - 16.2%

Installation and utilisation of a synthetic phantom block at each site has been used to adjust the accreditation algorithm according to start of day scan results. This process has been described.

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1. Background

A key focus of the Advanced Livestock Measurement Technologies project (ALMTech) was the development and integration of Dual Energy Xray Absorptiometers (DEXA) into lamb abattoirs, culminating in the installation of six of these systems across Australia. At the completion of the project, attention was focused upon the accreditation by AUS-MEAT of DEXA as a predictor of carcase fat, lean, and bone percentage, that was successfully achieved in May 2023. However, it is an AUS-MEAT accreditation requirement that this accreditation process is repeated within 12 months of initial provisional accreditation first being awarded to achieve full accreditation.

In parallel, ALMTech, through the Industry Calibration Working Group, introduced a new AUS-MEAT trading language in 2022 for whole carcase bone, muscle, and fat percentage, as measured through a standardised computed tomography (CT) scanning protocol. Therefore, in the final year of ALMTech, attention was focused upon the accreditation of this DEXA system as a predictor of carcase fat, lean, and bone percentage. This was successfully achieved using the WAMMCO DEXA system in May 2023. However, it is an AUS-MEAT requirement that this accreditation process is repeated within 12 months of it first being awarded, after which the technology is officially recognised as fully accredited subject to on-going auditing. Therefore, to establish DEXA as an accredited technology for industry it is crucial that this process is repeated. The project sought to ensure that any future installations remain accredited so hot DEXA data can be used to trade upon by processors and feedback provided to producers.

2. Objectives

The objective was to seek re-accreditation of the on-line lamb DXA device against the AMILSC accreditation standards of measuring CT Fat %, CT Lean % and CT Bone %, by demonstrating the same level of accuracy as the original accreditation.

3. Methodology

3.1 Experimental Design

The re-accreditation was conducted across 2023 and 2024 at WAMMCO, Katanning. It was conducted over 5 site visits:

21st March 2023 – 94 carcases

25th April 2023 – 50 carcases

29th May 2023 – 45 carcases

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13th February 2024 – 33 carcases

15th May 2024 – 13 carcases

24th October 2024 – 34 carcases

This protocol assumes that all carcases comply with the AUS-MEAT defined hot standard carcase weight trim, hence the exclusion of carcases that did not comply. Furthermore, during routine commercial operation protocols must be in place to ensure that carcases are correctly oriented with the brisket facing toward the x-ray tube during scanning.

Carcases were selected to achieve a spread of weights and fat percentages that would represent the distribution seen commercially by Australian LEAP abattoirs. **Table *3*** shows the number of carcases that were selected across a carcase weight by CT Fat% matrix. The areas of the table shaded in grey represent carcase phenotypes rarely found in Australian abattoirs and have therefore not been acquired.

Table 3. Carcase selection matrix consisting of a wide range of hot carcase weights and CT Fat %

	CT Fat %					
	<20%	**20-24%**	**24-28%**	**28-32%**	**32-36%**	**>36%**
<22kg	31	26	37	12		
22-28kg		24	25	25	11	
>28kg			26	23	20	9

Figure 4, **Figure *5*** and **Figure 6** demonstrate the raw data range for CT Fat%, Lean%, and Bone% of the carcases acquired during this accreditation process, in all cases plotted against their corresponding DXA prediction.

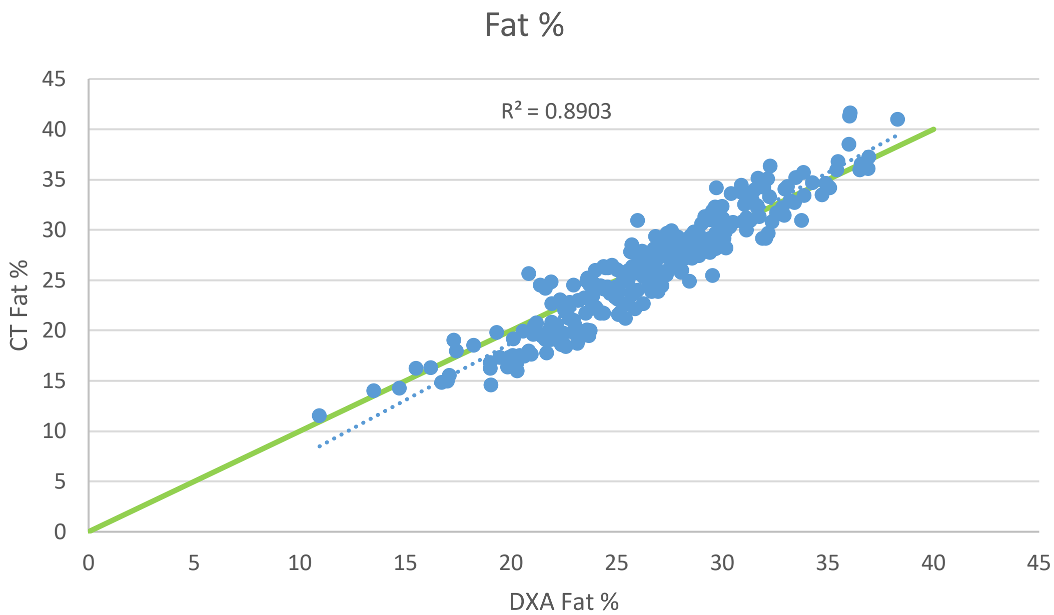

Figure 1. Comparison of CT Fat % and DXA predicted Fat %. Carcases have been pooled across all carcase weight categories.

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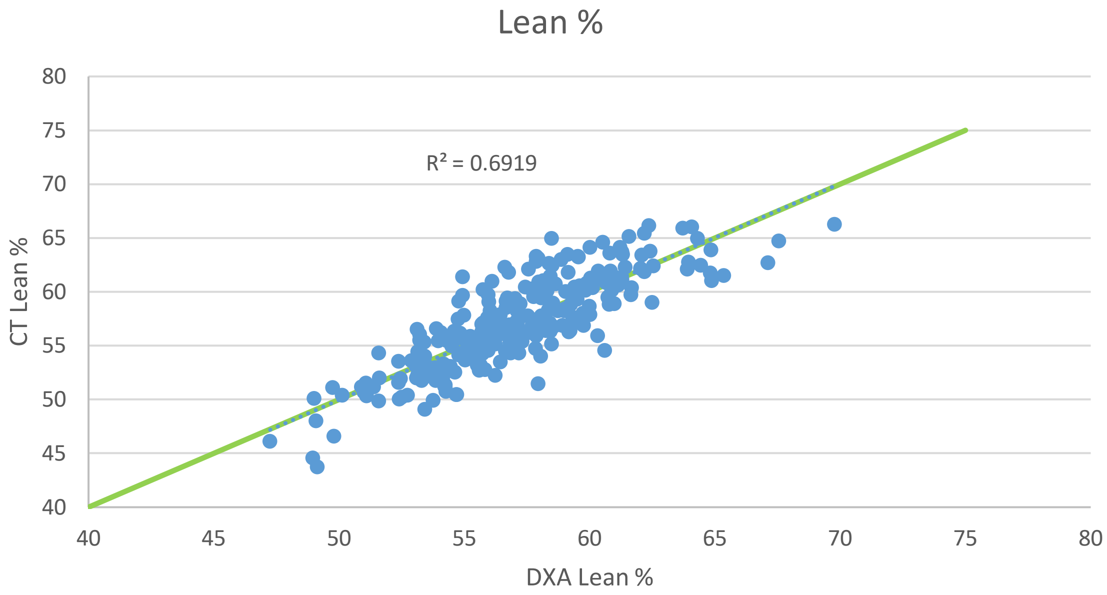

Figure 2 - Comparison of CT Lean % and DXA predicted Lean %. Carcases have been pooled across all carcase weight categories.

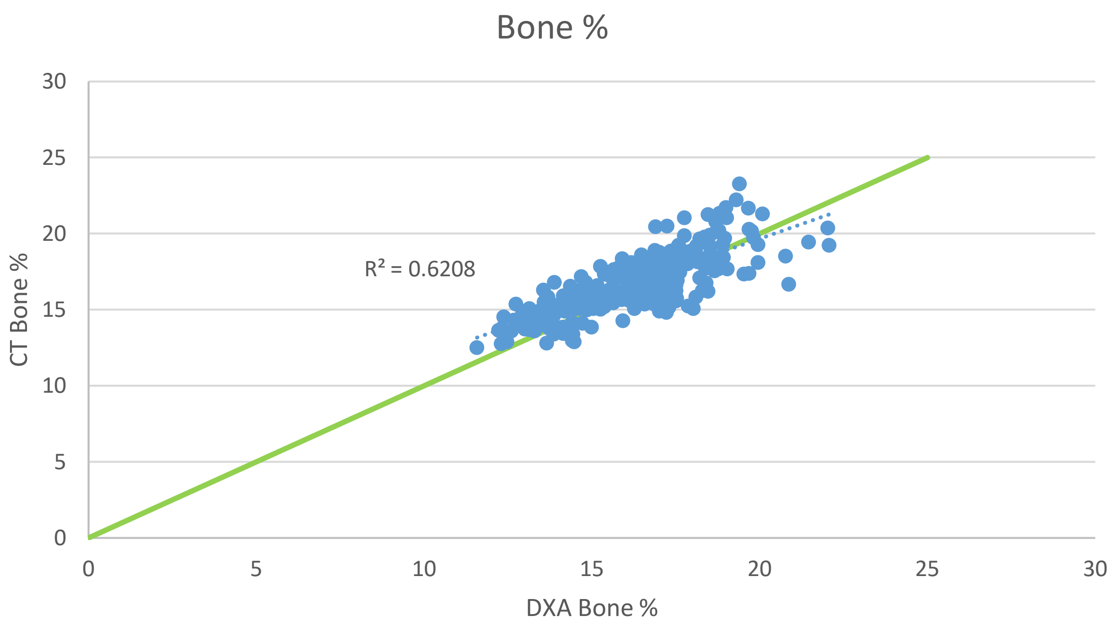

Figure 3. Comparison of CT Bone % and DXA predicted Bone %. Carcases have been pooled across all carcase weight categories.

3.2 DXA Scanning

The sheep carcases were scanned as they passed beyond the weigh station and electrical stimulator at the end of the production floor, immediately prior to marshalling for chiller allocation.

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The WAMMCO DXA device operates at 140kV, 10mA tube current, and will typically operate at chain speed anywhere between 7 and 9 carcases per minute. The order of carcases was noted manually as they passed the DXA terminal and were labelled as returning to Murdoch University.

The DXA images were acquired immediately after the scanning of the final carcase through the DXA research computer in the DXA systems room at WAMMCO. These files were saved and can still be accessed in their raw state at any time if required. The algorithm for accreditation was applied to these images and the results were saved.

All carcases were transported back to Murdoch University 24 hours after DXA scanning.

All raw DXA files were saved and are still available for future analysis if required.

3.3 CT Scanning

CT scanning was conducted at The Animal Hospital Murdoch University on a Canon CT device at 120kV, 5mm slice width. The DICOM images for each LEAP carcase was analysed using Image J v1.52a to determine fat, lean and bone densities, and pixel count, which was multiplied through the 5mm slice width to arrive at a final CT Fat %, CT Lean % and CT Bone % value. This is consistent with the protocol established for the sheep meat carcase composition trait, as described in the AMILSC submission "A carcase composition trait for sheep meat grading technologies" on the 17/2/2022.

All raw DICOM files were saved and available for analysis if required.

3.4 Statistical Analysis

Analysis of the accuracy standards were undertaken using the method described in the AMILSC submission "A carcase composition trait for sheep meat grading technologies (17/2/2022)".

The allowable error tolerances for carcase Lean%, Fat%, and Bone % are:

- Within ±3% CT Fat% and Lean% for at least 67% of sample collected, and ±6% CT Fat% and Lean % for at least 95% of samples collected, and;
- Within ±1.6% CT Bone% for at least 67% of sample collected, and ±3.2% CT Bone% for at least 95% of samples collected

To ensure that the accuracy threshold was met across each quarter of the accreditation range, a Markov Chain Monte Carlo (MCMC) stochastic simulation was applied to the data to characterise the distribution of residuals (observed – predicted). Accuracy was then assessed within quarters of the data range that the technology was seeking accreditation for. This simulation is available using the online application:

https://accreditationapps.shinyapps.io/Sheep_Meat_IMF_Percent_V4/

4. Results

The results are displayed for fat%, lean% and bone% predictions within their weight categories (<22kg, 22-28kg, >28kg).

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Table 4 outlines the accuracy results of the DXA devices predicting carcase composition in the nine discrete accreditation groups. The carcase composition range for fat%, lean% and bone% is listed within each weight category.

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Table 4. Mean error (Fit mean), standard deviation of error (Fit SD), percentage of samples within 1 times the accreditation threshold, percentage of samples within 2 times the accreditation threshold, and sample count for each quarter of the accreditation range for each tissue component, is shown within the low (<22kg), medium (22-28kg), and heavy (>28kg) weight bands.

		Low Weight (<22kg)					**Mid Weight (22-28kg)**					**High Weight (>28kg)**				
		Fit (mean)	Fit (SD)	% within 3 Fat/Lean, 1.6 Bone	% within 6 Fat/Lean, 3.2 Bone	Count	Fit (mean)	Fit (SD)	% within 3 Fat/Lean, 1.6 Bone	% within 6 Fat/Lean, 3.2 Bone	Count	Fit (mean)	Fit (SD)	% within 3 Fat/Lean, 1.6 Bone	% within 6 Fat/Lean, 3.2 Bone	Count
Range		Fat% accreditation range = 13.9% - 31.8%					Fat% accreditation range = 16.4% - 35.2%					Fat% accreditation range = 22.0% - 40.0%				
Fat	Q 1	-2.28	1.49	68.75	99.31	18	-2.31	1.49	67.86	99.32	10	-1.2	1.64	85.94	99.76	11
	Q 2	-2.03	1.47	74.54	99.59	28	-1.12	1.45	90.13	99.94	26	-0.52	1.61	92.26	99.95	29
	Q 3	0.2	1.47	95.65	99.98	38	-0.41	1.45	95.39	99.99	30	0.67	1.62	91.35	99.93	21
	Q 4	0.91	1.48	91.73	99.97	20	1.67	1.47	82.04	99.8	17	1.32	1.66	84.01	99.75	9
		Lean% accreditation range = 52.6% - 64.5%					Lean% accreditation range = 50.0% - 64.7%					Lean % accreditation range = 48.9% - 62.4%				
Lean	Q 1	-1.9	2.09	69.33	97.45	17	-1.76	2.11	71.07	97.73	16	-1.01	1.6	88.68	99.9	18
	Q 2	-0.66	2.07	83.25	99.36	33	-0.32	2.1	84.4	99.5	30	-0.25	1.6	93.43	99.97	21
	Q 3	1.48	2.08	75.39	98.39	27	0.81	2.11	81.45	99.15	20	-0.29	1.59	93.65	99.96	22
	Q 4	1.67	2.08	72.73	98.06	19	1.79	2.12	70.71	97.59	16	1.17	1.62	86.88	99.81	11
		Bone% accreditation range = 14.3% - 21.4%					Bone% accreditation range = 13.7% - 19.3%					Bone% accreditation range = 12.5% - 16.2%				
Bone	Q 1	-0.85	1.28	69.35	96.58	11	0.04	1.19	82.26	99.17	6	-0.28	0.74	95.69	99.99	7
	Q 2	-0.06	1.25	79.98	98.88	37	0.5	1.12	80.8	99.07	30	0.52	0.7	93.6	99.99	21
	Q 3	0.6	1.24	75.32	98.1	40	1.12	1.13	65.94	96.66	19	1.1	0.71	76.32	99.82	23
	Q 4	0.98	1.27	66.7	95.95	13	1.01	1.18	67.89	96.88	7	1.24	0.71	69.74	99.71	16

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Low weight (<22kg)

Fat

For the low carcase weight category, the DXA estimated Fat% meets the accreditation requirements between 13.9% - 31.8% (original accreditation was 10.9% - 30.3%) across all 4 quarters of the range (see **Table *4***, and **Figure *7***).

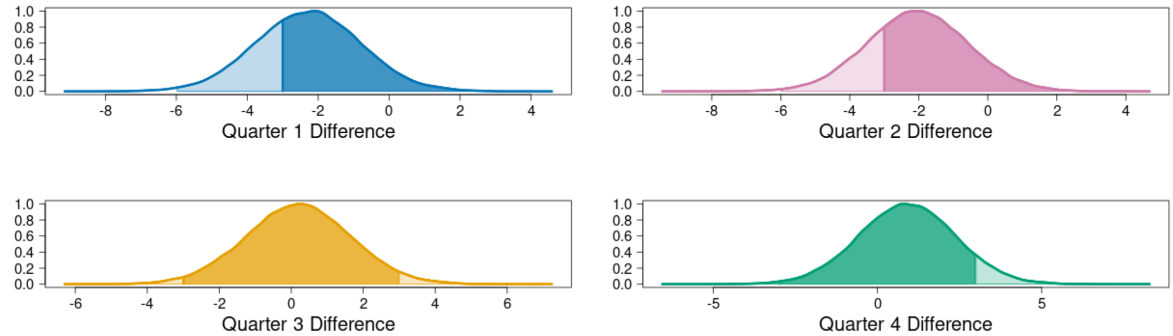

Figure 4 - Fitted Posterior Distributions of DXA device predicting CT Fat % for each quarter of the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Fat% and DXA predicted Fat% is shown in Figure 8. CT Fat % was predicted by DXA with an RMSEP of 1.85%, and an R^2=0.82. The slope was 1.17 and had a bias of -0.65 CT Fat%.

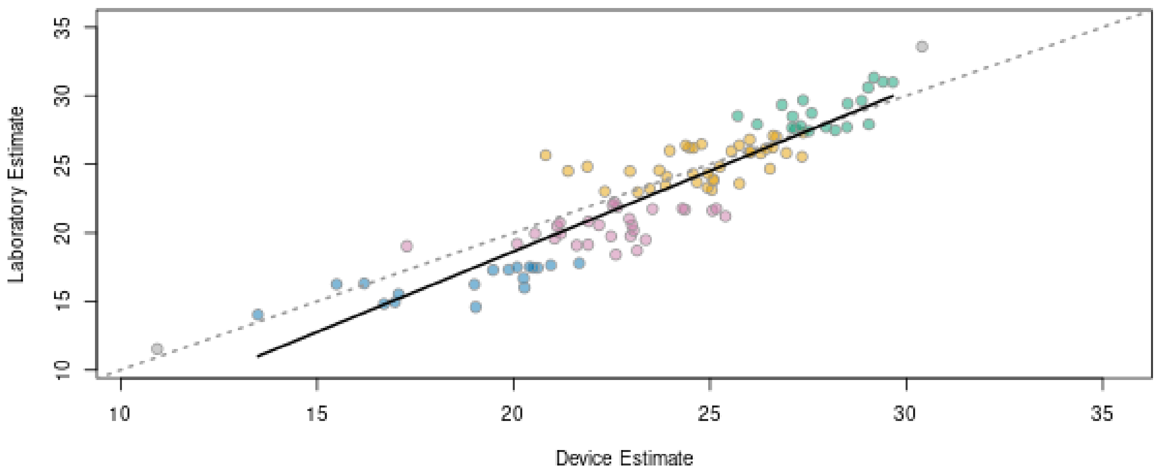

Figure 5. Relationship between CT Fat % (laboratory estimate) and DXA fat % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship.

Lean

For the low carcase weight category, the DXA estimated Lean% meets the accreditation requirements between 52.6% - 64.5% (original accreditation 53.2% - 65.0%) across all 4 quarters of the range (see Table 4, and Figure 9).

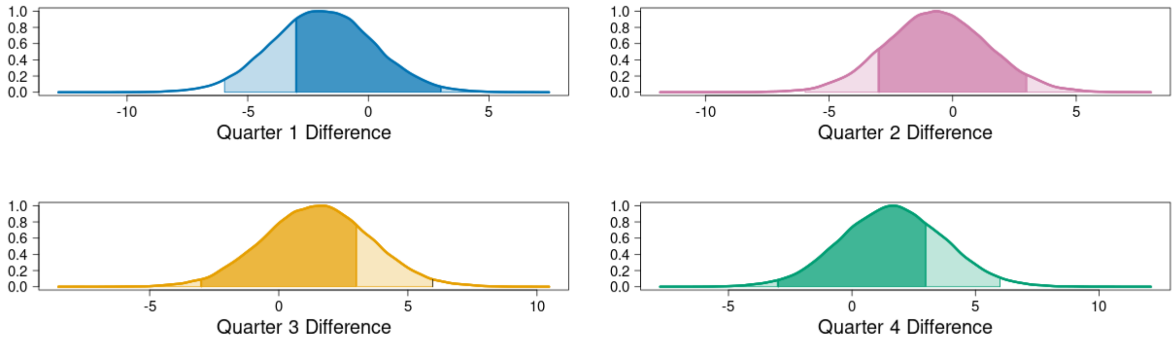

Figure 6. Fitted Posterior Distributions of DXA device predicting CT Lean % for each quarter of the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Lean% and DXA predicted Lean% is shown in Figure 10. CT Lean % was predicted by DXA with an RMSEP of 2.4%, and an R^2=0.39. The slope of this relationship was 0.75 and had a bias of 0.31 CT Lean %.

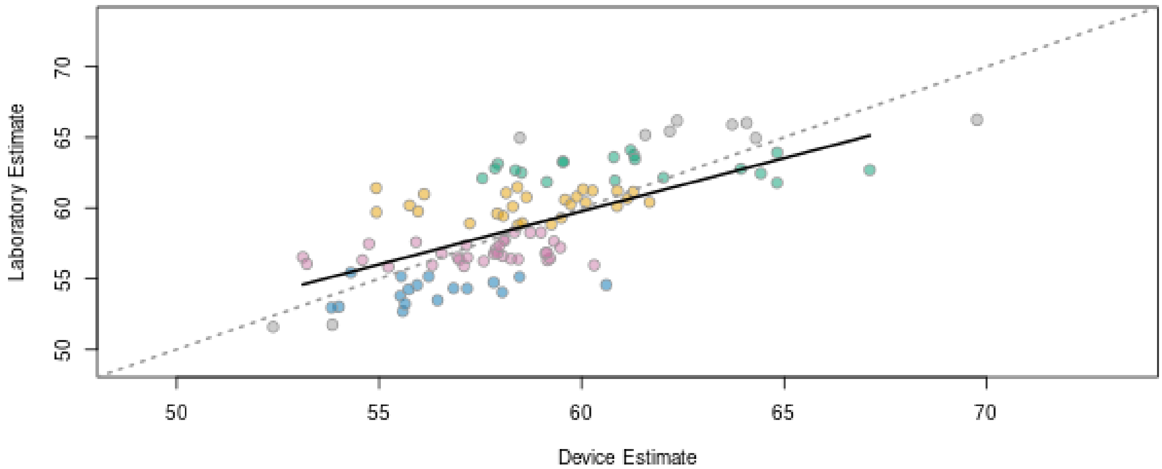

Figure 7. Relationship between CT Lean % (laboratory estimate) and DXA lean % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship. Raw data is coloured to represent the quarter to which it is assessed, with grey points representing data falling outside the accreditation range and not used by the analysis.

Bone

For the low carcase weight category, the DXA estimated Bone% meets the accreditation requirements between 14.3% - 21.4% (14.9% - 25.0% original accreditation) across all 4 quarters of the range (see Table 4, and **Figure 11**).

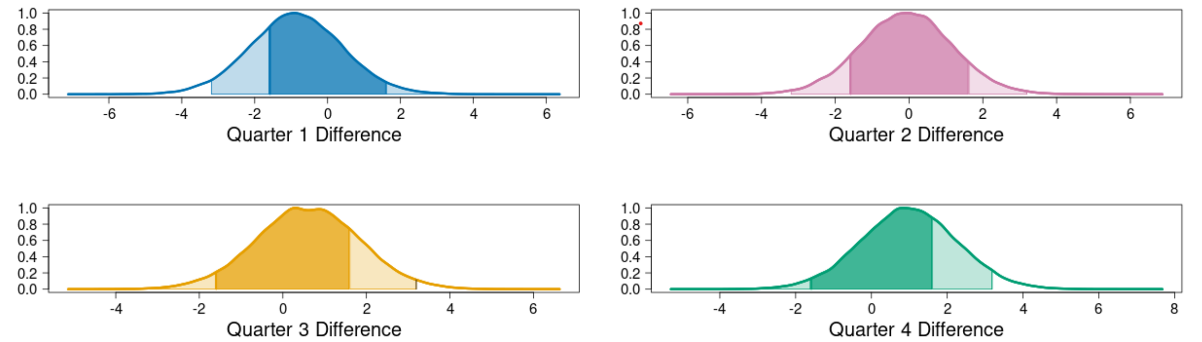

Figure 8. Fitted Posterior Distributions of DXA device predicting CT Bone % for each quarter of the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Bone% and DXA predicted Bone% is shown in **Figure 12**. CT Bone % was predicted by DXA with an RMSEP of 1.15%, and an R^2=0.35. The slope was 0.57 and had a bias of 0.32 CT Bone %.

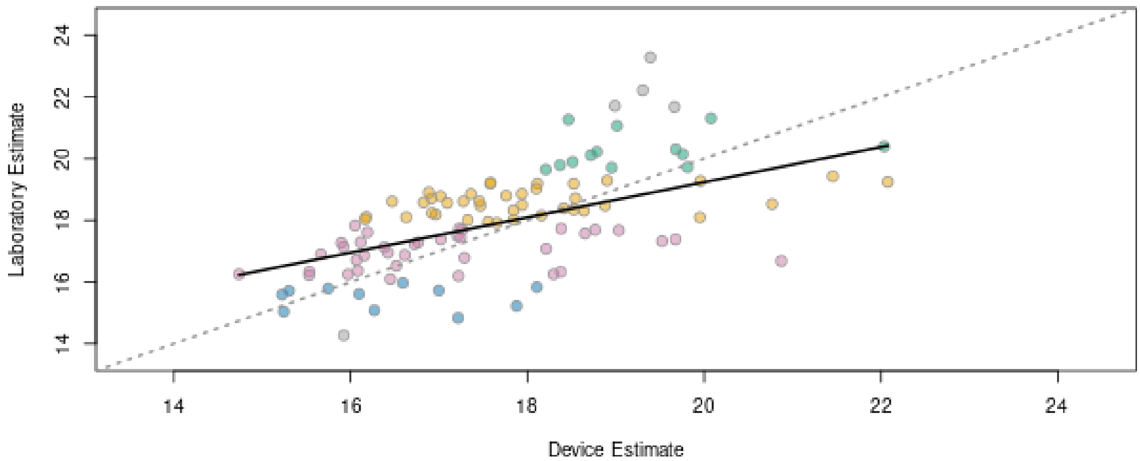

Figure 9. Relationship between CT Bone % (laboratory estimate) and DXA bone % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship.

Mid weight (22-28kg)

Fat

For the mid carcase weight category, the DXA estimated Fat% meets the accreditation requirements between 16.4% - 35.2% (14.9% to 35.0% original accreditation) across all 4 quarters of the range (see Table 4, and **Figure 13**).

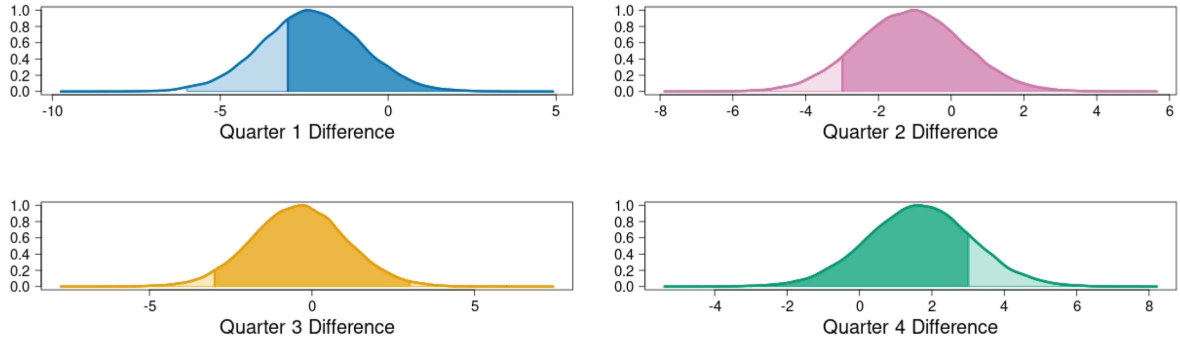

Figure 10. Fitted Posterior Distributions of DXA device predicting CT Fat % for each quarter of the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Fat% and DXA predicted Fat% is shown in **Figure 14**. CT Fat % was predicted by DXA with an RMSEP of 1.77%, and an R^2=0.84. The slope was 1.17 and had a bias of -0.47 CT Fat %.

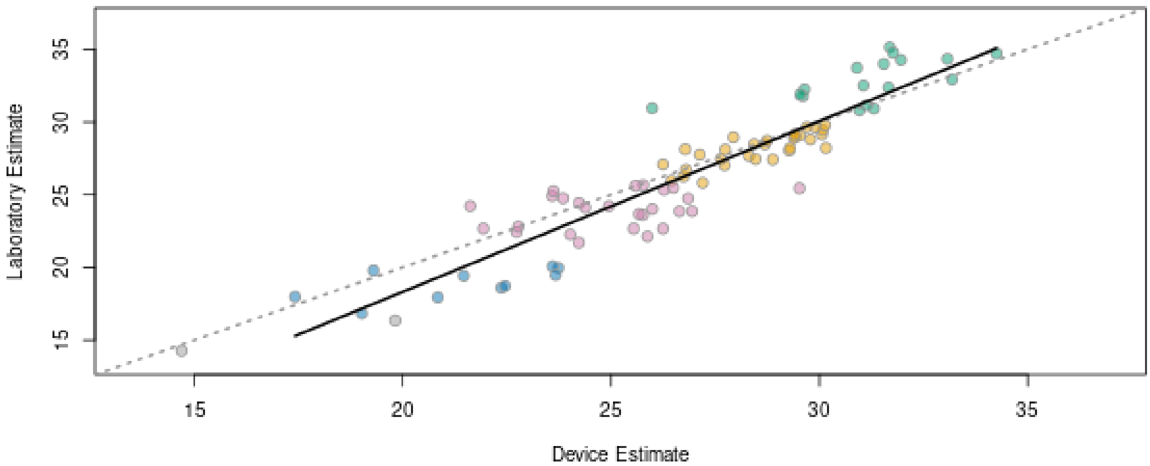

Figure 11. Relationship between CT Fat % (laboratory estimate) and DXA fat % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship.

Lean

For the mid carcase weight category, the DXA estimated Lean% meets the accreditation requirements between 50.0% - 64.7% (50.9% - 66.2% original accreditation) across all 4 quarters of the range (see Table 4, and **Figure 15**).

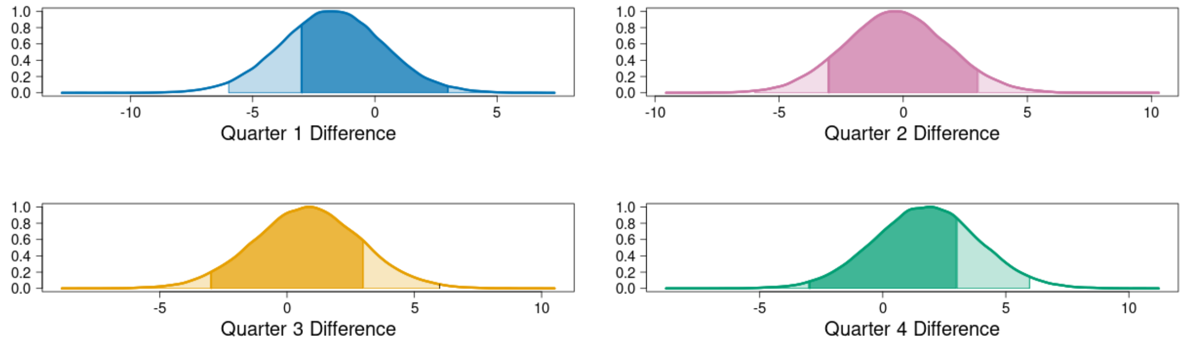

Figure 12. Fitted Posterior Distributions of DXA device predicting CT Lean % for each quarter of the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Lean% and DXA predicted Lean% is shown in **Figure 16**. CT Lean % was predicted by DXA with an RMSEP of 2.38%, and an R^2=0.60. The slope was 0.94 and had a bias of -0.04 CT Lean %.

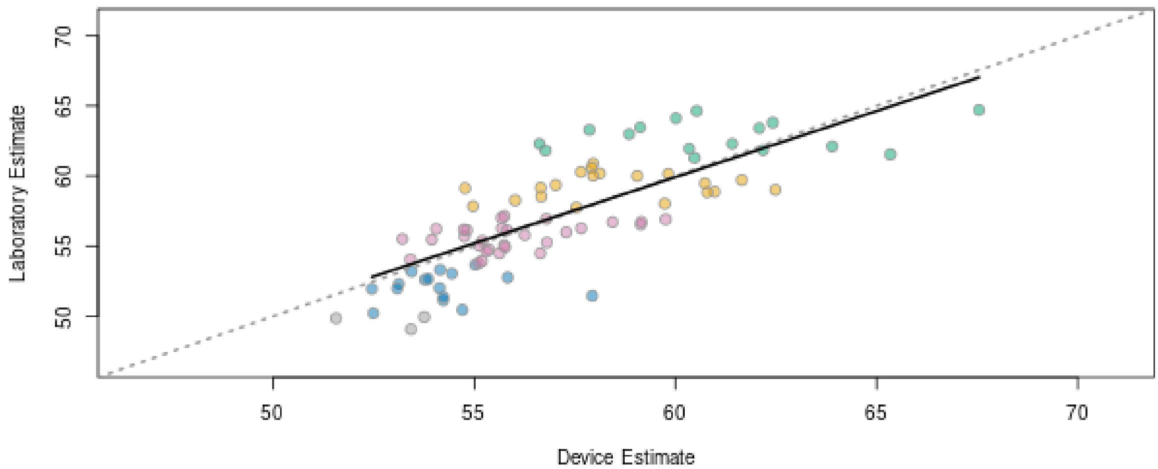

Figure 13. Relationship between CT Lean % (laboratory estimate) and DXA lean % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship.

Bone

For the mid carcase weight category, the DXA estimated Bone% meets the accreditation requirements between 14.3% - 17.8% (13.3% - 18.0% original accreditation) across all 4 quarters of the range (see Table 4, and **Figure 17**).

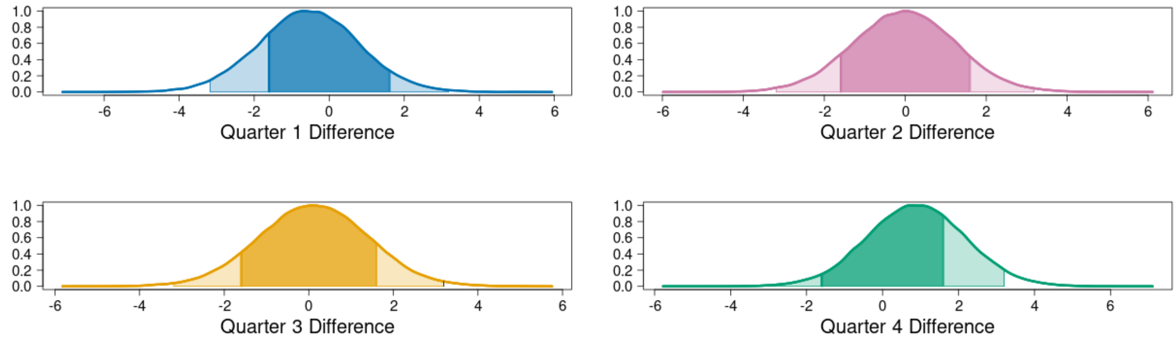

Figure 14. Fitted Posterior Distributions of DXA device predicting CT Bone % for each quarter of the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Bone% and DXA predicted Bone% is shown in **Figure 18**. CT Bone % was predicted by DXA with an RMSEP of 0.75%, and an R^2=0.07. The slope was 0.15 and had a bias of 0.44 CT Bone %.

The poor R^2 and slope values for the bone predictions in this weight category are mostly driven by the small range available. The accuracy is still within the accreditation limits, and the precision is still comparable to the original accreditation, as seen by the RMSEP value (0.75% original accreditation).

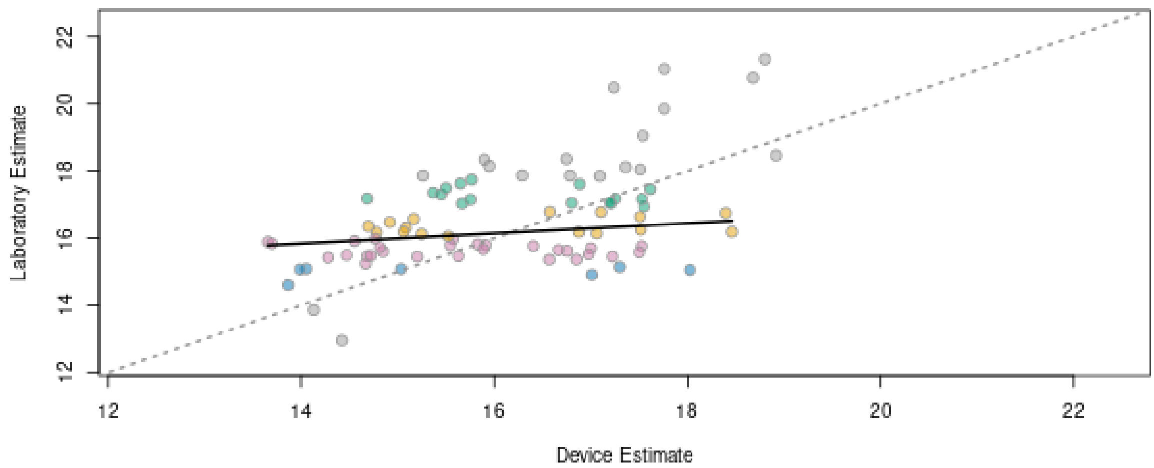

Figure 15. Relationship between CT Bone % (laboratory estimate) and DXA bone % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship.

High weight (>28kg)

Fat

For the high carcase weight category, the DXA estimated Fat% meets the accreditation requirements between 22.0% - 40.0% (22.0% to 37.1% original accreditation) across all 4 quarters of the range (see Table 4, and **Figure 19**).

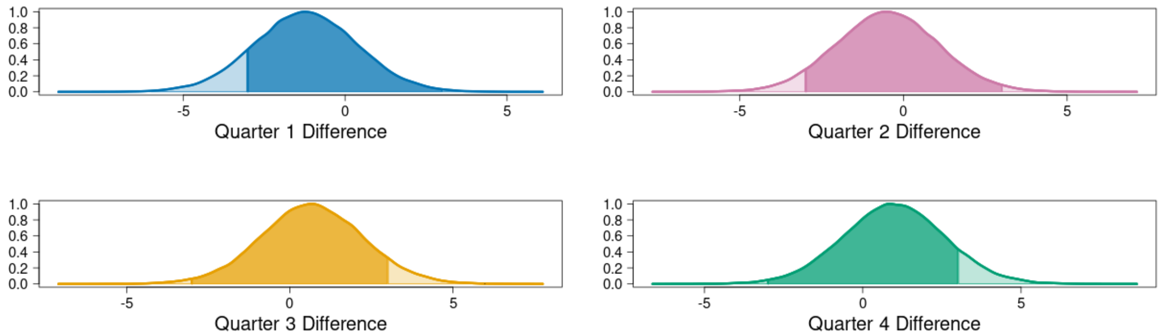

Figure 16. Fitted Posterior Distributions of DXA device predicting CT Fat % for each quarter the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Fat% and DXA predicted Fat% is shown in **Figure 20**. CT Fat % was predicted by DXA with an RMSEP of 1.69%, and an R^2=0.79. The slope was 1.03 and had a bias of 0.05 CT Fat %.

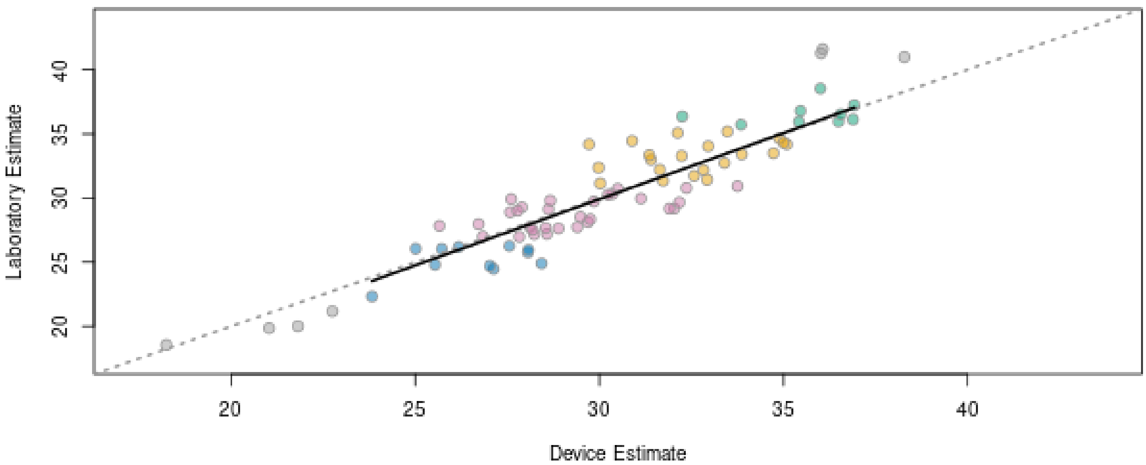

Figure 17. Relationship between CT Fat % (laboratory estimate) and DXA fat % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship.

Lean

For the high carcase weight category, the DXA estimated Lean% meets the accreditation requirements between 48.9% - 62.4% (49% - 60.6% original accreditation) across all 4 quarters of the range (see Table 4, and **Figure 21**).

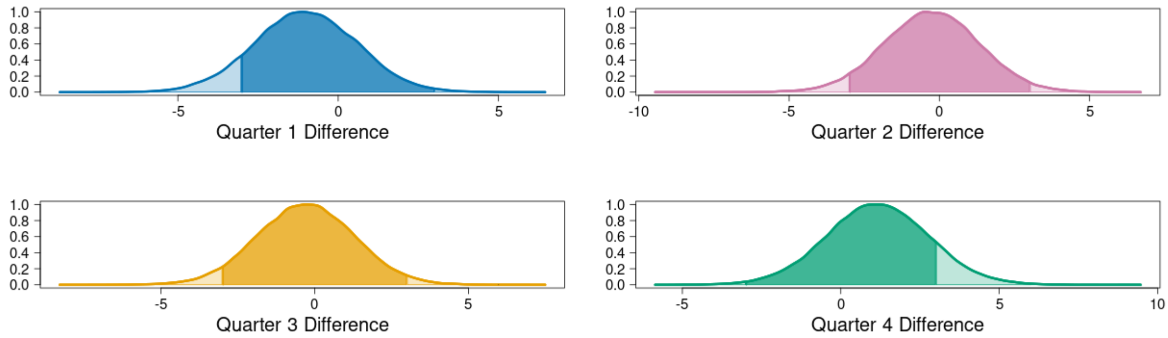

Figure 18. Fitted Posterior Distributions of DXA device predicting CT Lean % for each quarter of the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Lean% and DXA predicted Lean% is shown in **Figure 22**. CT Lean % was predicted by DXA with an RMSEP of 1.64%, and an R^2=0.74. The slope was 0.91 and had a bias of -0.42 CT Lean %.

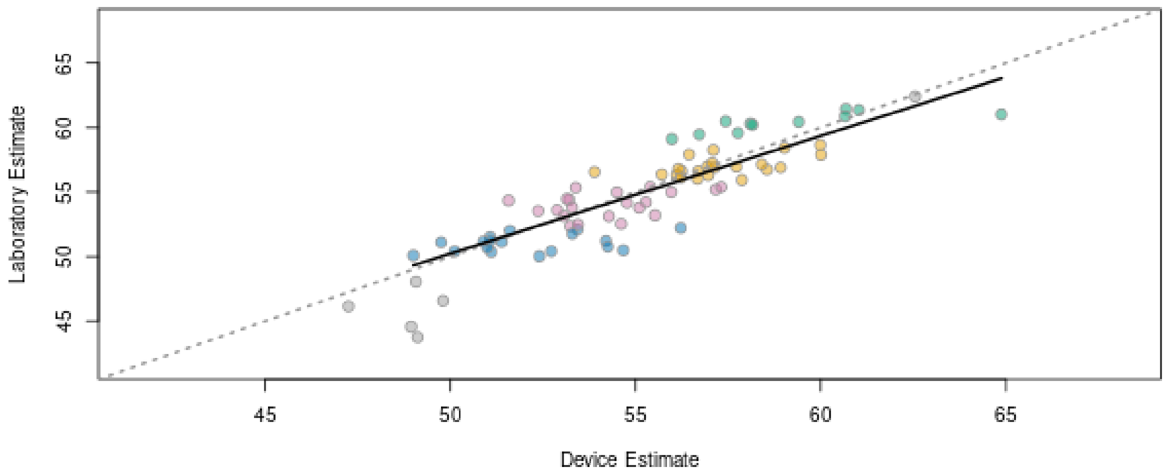

Figure 19. Relationship between CT Lean % (laboratory estimate) and DXA lean % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship.

Bone

For the high carcase weight category, the DXA estimated Bone% meets the accreditation requirements between 12.5% - 16.2% (11.6% - 17.5% original accreditation) across all 4 quarters of the range (see Table 4, and **Figure 23**).

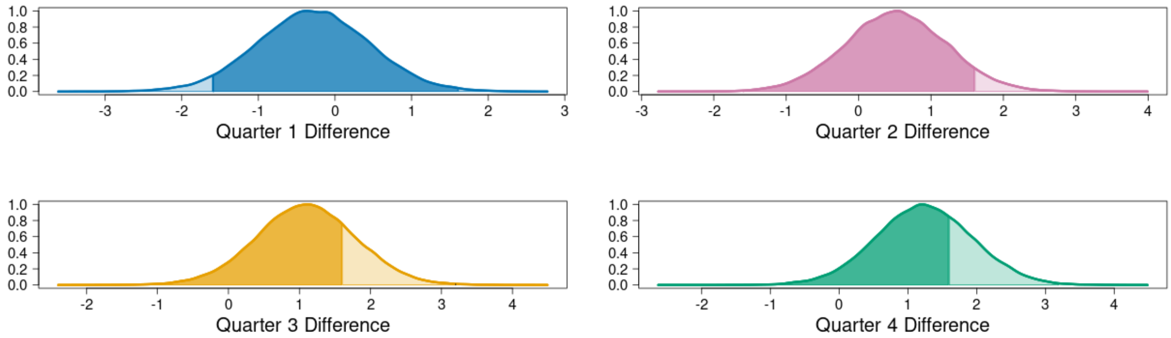

Figure 20. Fitted Posterior Distributions of DXA device predicting CT Bone % for each quarter of the dataset. Difference is reported as the CT result minus the DXA estimate.

A scatter plot depicting the relationship between CT Bone% and DXA predicted Bone% is shown in **Figure 24**. CT Bone % was predicted by DXA with an RMSEP of 0.73%, and an R^2=0.30. The slope was 0.56 and had a bias of 0.97 CT Bone %.

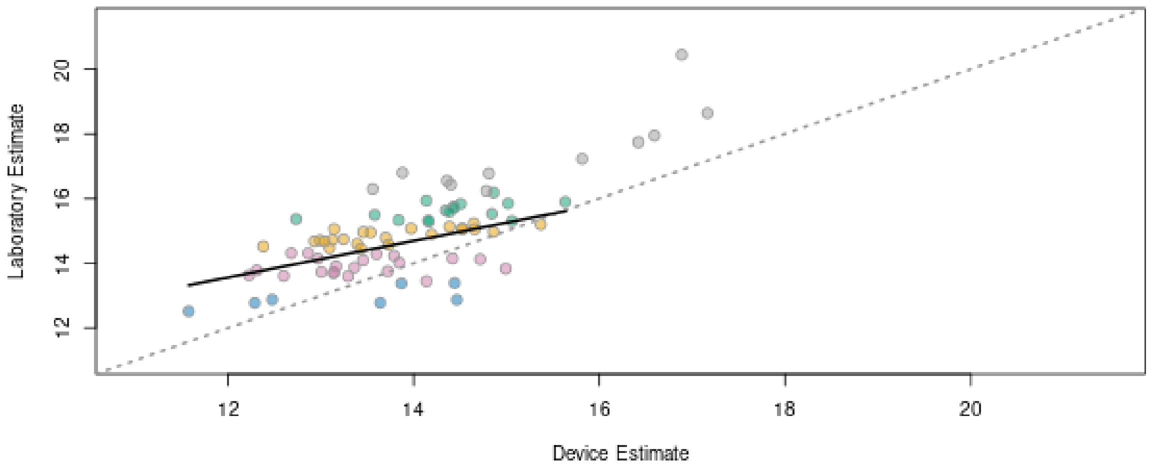

Figure 21. Relationship between CT Bone % (laboratory estimate) and DXA bone % (device estimate). The solid line represents the line of best fit, icons represent individual data points colour coded to fit the quarter to which they are assigned. The dashed line represents a 1:1 relationship.

5. Conclusion

The above findings have been submitted and accepted by AUS-MEAT and AMILSC, resulting in a successful re-accreditation of the LEAP DXA as a method of predicting sheep meat composition.

5.1 Key findings

The new accredited range for the LEAP DXA device is as follows:

HCWT category	Tissue Type		
	Carcase Fat%	Carcase Lean%	Carcase Bone%
<22kg	13.9% - 31.8%	52.6% - 64.5%	14.3% - 21.4%
22-28kg	16.4% - 35.2%	50.0% - 64.7%	13.7% - 19.3%
>28kg	22.0% - 40.0%	48.9% - 62.4%	12.5% - 16.2%

5.2 Benefits to industry

The acceptance of the re-accreditation report by AMILSC allows the sheep meat industry to use the LEAP DXA system as a means of trading upon sheep carcase composition through this objective carcase measurement tool. The use of this device proves to be far superior to HCWT and GR measures as a means of predicting carcase composition.

6. Future research and recommendations

The ongoing and future research for the lamb DXA devices includes, but are not limited to:

- Using the DXA bone values as a method of predicting consumer eating quality scores
- Predicting the objective composition of three distinct sections of the carcass through virtual dissection by DXA
- Predicting cut weights that would be obtained based on HCWT and DXA section composition predictions

These projects are currently underway or are in the final stages of procuring funding.

7. References

Connaughton, S. L., A. Williams, F. Anderson, K. R. Kelman, J. Peterse and G. E. Gardner (2020). "Dual energy X-ray absorptiometry predicts lamb carcass composition at abattoir chain speed with high repeatability across varying processing factors." Meat Science: 108413.