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Report Title: Ability of live microwave scanning in sheep to predict whole body fat composition as determined by live DEXA scanning

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Abstract

This experiment evaluated the ability of a portable microwave system (MiS) coupled with Vivaldi Patch antenna used in mature ewes (n=835) to predict whole body fatness as determined by dual energy x-ray absorptiometry (DEXA). MiS scanning was performed at the C-site (45 mm from spine midline over the 12th rib), Point A3 (20 mm cranial to C-site), the GR-site (110 mm from spine midline over the 12th rib), and a combination of 8 points across the right thorax. Precision of prediction was greatest at the 8 combined points with an average R2 of 0.51 and RMSEP of 1.85 mm, however there was negligible difference in prediction when scanning at only the GR-site with an average R2 of 0.49 and RMSEP of 1.84 mm.

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Executive Summary

- MiS scanning of mature ewes can predict whole body fatness composition as determined by DEXA
- MiS scanning at the GR-site demonstrated the same precision and accuracy of prediction as scanning at 8 multiple sites across the thorax

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Contents

This project is supported by funding from the Australian Government Department of Agriculture, Fisheries and Forestry as part of its Rural R&D for Profit programme in partnership with Research & Development Corporations, Commercial Companies, State Departments & Universities.

1 Project objectives

The overall objective of this work is the testing and validation of a low-cost, portable, prototype microwave (MiS) scanning device to predict whole body fat composition in live sheep.

2 Methods

2.1 Experiential design and live animal measurements

This study utilised a subset of mature ewes (n=835) enrolled in a GPEP project from the Australian Wool Innovation. The ewes were located at the Department of Primary Industries and Regional Development Katanning research farm. The aim of the GPEP project was to evaluate various methods for determining whole body fat composition in ewes. Ewes were housed in a feeding shed in single pens and fed at the recommended rate for liveweight maintenance. Ewes were scanned for estimation of whole body fat% using Dual Energy X-ray absorptiometry (DEXA) at 7 different time points across two years (*Table 1*).

To enable DEXA scanning, ewes were individually sedated with a combination of acepromazine and ketamine administered intravenously via a catheter placed in the cephalic vein. The sedated ewes placed in sternal recumbency on the DEXA table with hind legs extended and front legs tucked next to the thorax. A rectangular patch of wool was clipped across the right thorax (20cm wide x 15cm long), extending from the spine down, and behind the shoulder to caudal to the last rib. Microwave (MiS) scanning on the clipped site was performed using a prototype ultrawide band microwave device coupled with a Vivaldi Patch antenna. The microwave system design and signal analysis are detailed in (Marimuthu, Loudon, & Gardner, 2020).The centre of the antenna was placed in direct contact with the clipped skin, at 8 different points as depicted in Figure 1. Measurement point ‘A2’ corresponded to the C-site, located at 45 mm from spine midline over the 12th rib. Measurement point ‘B’ corresponded to the GR site, located at 110 mm from midline of the spine over the 12th rib. The other points scanned were in relation to the distance from either the C-site or GR site. A1 was 2cm caudal to the Point A2 (C-site), A3 was 2cm cranial and A4 4cm cranial. In relation to Point B (GR site), Point C was 2cm cranial, Point D 4 cm cranial and Point E 12cm cranial.

DEXA scanning commenced after the completion of MiS scanning. DEXA scanning and image analysis was performed according to protocols described by (Hunter, Suster, Dunshea, Cummins, Egan, & Leury, 2011).

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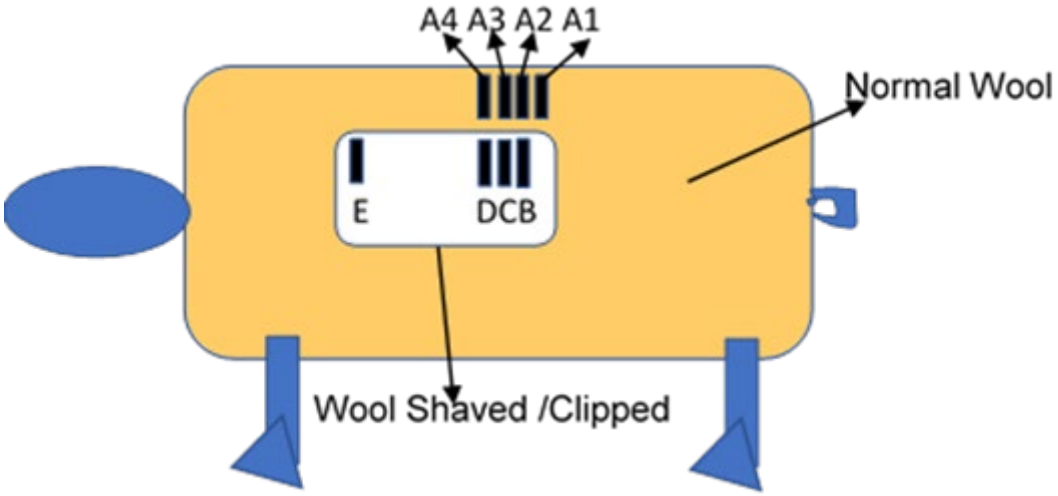

Figure 1 The measurement sites for microwave scanning. A2 corresponds to the C-site, B corresponds to the GR site

2.2 Statistical analysis

The microwave signal prediction equations were constructed using a machine learning ensemble stacking method in WEKA® 3.9.4 (The University of Waikato, Hamilton, New Zealand) and detailed in Marimuthu et al., (2020; Marimuthu, Loudon, & Gardner, 2021). In brief, the stacking method consisted of layering two prediction models to create a meta-algorithm (Elshazly, Elkorany, Hassanien, & Azar, 2013; Ribeiro & dos Santos Coelho, 2020). Layer one was composed from Support Vector Machine and Random Forest, and layer two used a Partial Least Squares Regression two component model.

Multiple analysis were run to determine the ability of MiS scanning at different sites to predict DEXA whole body fatness (DEXA Fat%). Firstly the data from all ewes (n=835) were pooled and divided into 5 groups balanced for DEXA Fat%. The first analysis was to determine the ability of MiS scanning performed at the C-site (Fig.1, point A2) to predict DEXA Fat%. To estimate the performance, a 5-fold cross validation technique was performed on the pooled and balanced data. The prediction equations were trained in 4 of these groups, and validated in the 5th group, with this process repeated until models had been validated in all 5 groups. The models predicting DEXA Fat% were run with and without liveweight (kg) included in the model.

The second analysis used GR site (Fig 1, point B) to predict DEXA Fat%. Again a 5-fold cross validation procedure was used, where groups were balanced for DEXA Fat%.

The third analysis was to combine the MiS scanning predictions at all 8 sites (Fig 1) to predict DEXA Fat%, using the 5 fold cross validation technique with groups balanced for DEXA Fat%.

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3 Results

Descriptive statistics are provided in *Table 1*, demonstrating the range in liveweight and DEXA Fat% for each of the groups scanned.

Table 1 Descriptive statistics including animal numbers (n), experiment feeding day, scanning date, mean ± standard deviation, minimum and maximum for liveweight and DEXA Fat%

Group	Scanning Date	n	Live Weight	DEXA Fat%
1	4-8 Feb 2019	62	61.51 ± 5.45 (47.50 - 72.50)	19.27 ± 2.93 (13.82 - 27.12)
2	24-28 June 2019	155	60.84 ± 6.22 (43.50 - 76.50)	17.98 ± 2.94 (12.90 - 27.86)
3	29 Jul – 2 Aug 2019	120	63.48 ± 9.40 (41.50 - 93.00)	18.12 ± 2.78 (12.96 - 25.80)
4	3 – 7 Feb 2020	135	53.78 ± 5.52 (39.50 - 69.00)	14.99 ± 1.75 (11.71 - 21.02)
5	16 – 20 March 2020	119	51.25 ± 5.02 (36.50 - 61.50)	15.28 ± 1.78 (11.58 - 21.27)
6	22 – 26 April 2020	156	53.30 ± 8.05 (36.50 - 73.00)	15.79 ± 1.86 (12.62 - 23.53)
7	6 – 10 July 2020	88	58.23 ± 6.33 (44.50 - 72.50)	16.62 ± 2.29 (12.49 - 24.14)

Across all models there was a slight improvement in precision and accuracy indicators when liveweight was included in the model *Table 2*.

The precision and of prediction of DEXA Fat% was the greatest using the 8 combined MiS sites, with an R^2 of 0.51 without liveweight included in the model (*Table 2*). However there was minimal difference in the precision when scanning at only the GR site with an average R^2 of only 0.02 units lower than the 8-combined points (*Table 2*). There was negligible difference between the average RMSEP between GR-site and the 8 points of 0.01 mm (*Table 2*). The average bias of the 8 combined points at 0.047mm was less than twice that of the GR site, however there was only a 0.02 mm difference in the average slope deviation from 1.

There was negligible difference between the precision indicators of DEXA Fat% prediction when scanning at the C-site, or at Point A3, with identical R^2 values of 0.42 when liveweight was not included in the model (*Table 2*). The difference between the average RMSEP of C-site to A3 prediction was only 0.03 mm (*Table 2*). The average bias was almost three times less of 0.054 mm at the A3 site however there was only a 0.01 mm difference in the average slope between A3 and C-site (*Table 2*).

The association between actual and microwave predicted DEXA Fat% without liveweight included in the model is depicted in Figure 2.

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Table 2 Precision and accuracy estimates for 5-fold cross validation models of MiS Scanning at the (a) C-site (Point A2), (b) Point A3, (c) GR tissue depth (Point B) and (d) the combined 8 sites to predict DEXA Fat%. Precision estimates include R^2 and root mean square error of the predicted (RMSEP). Accuracy estimates include slope which is the difference between the actual and predicted slopes, expressed as a deviation from 1, and bias which represents the difference between the actual minus predicted value calculated at the mean of the predicted site.

				Liveweight not included				Liveweight included			
Validation Group	N	Liveweight (kg)	DEXA Fat%	R^2	RMSEP (mm)	Bias (mm)	Slope (mm)	R^2	RMSEP (mm)	Bias (mm)	Slope (mm)
(a) C-site (Point A2)											
1	167	57.15 ± 8.22 (36.5 – 81.5)	16.60 ± 2.63 (11.58 – 24.70)	0.47	1.93	-0.210	-0.08	0.51	1.86	-0.152	-0.08
2	167	56.50 ± 8.65 (40.0 – 93.0)	16.60 ± 2.63 (11.71 – 24.88)	0.44	1.98	-0.209	-0.02	0.46	1.95	-0.235	+0.02
3	167	56.96 ± 7.70 (40.5 – 74.5)	16.60 ± 2.63 (11.77 – 24.99)	0.41	2.04	+0.189	+0.01	0.44	1.99	+0.203	+0.02
4	167	57.64 ± 7.79 (36.5 – 76.5)	16.60 ± 2.64 (11.79 – 25.30)	0.37	2.11	+0.154	-0.01	0.36	2.11	+0.060	+0.03
5	167	57.05 ± 8.30 (37.0 – 81.0)	16.61 ± 2.64 (12.32 – 25.80)	0.39	2.06	+0.022	-0.02	0.42	2.01	+0.002	+0.00
			Average	**0.42**	**2.02**	**0.157***	**0.03***	**0.44**	**1.98**	**0.130***	**0.03***
(b) Point A3											
1	167	57.15 ± 8.22 (36.5 – 81.5)	16.60 ± 2.63 (11.58 – 24.70)	0.50	1.87	-0.098	-0.10	0.51	1.84	-0.063	-0.07
2	167	56.50 ± 8.65 (40.0 – 93.0)	16.60 ± 2.63 (11.71 – 24.88)	0.40	2.02	+0.019	+0.00	0.46	1.94	-0.005	+0.00
3	167	56.96 ± 7.70 (40.5 – 74.5)	16.60 ± 2.63 (11.77 – 24.99)	0.45	1.95	+0.062	-0.08	0.48	1.89	+0.010	-0.04
4	167	57.64 ± 7.79 (36.5 – 76.5)	16.60 ± 2.64 (11.79 – 25.30)	0.40	2.04	+0.089	-0.00	0.41	2.02	+0.117	+0.04
5	167	57.05 ± 8.30 (37.0 – 81.0)	16.61 ± 2.64 (12.32 – 25.80)	0.37	2.09	-0.002	+0.01	0.40	2.04	-0.036	-0.05
			Average	**0.42**	**1.99**	**0.054***	**0.04***	**0.45**	**1.95**	**0.046***	**0.04***
(b) GR-site (Point B)											
1	167	57.15 ± 8.22 (36.5 – 81.5)	16.60 ± 2.63 (11.58 – 24.70)	0.56	1.69	+0.174	-0.13	0.59	1.64	+0.137	-0.14
2	167	56.50 ± 8.65 (40.0 – 93.0)	16.60 ± 2.63 (11.71 – 24.88)	0.52	1.76	-0.151	+0.00	0.54	1.71	-0.155	+0.02
3	167	56.96 ± 7.70 (40.5 – 74.5)	16.60 ± 2.63 (11.77 – 24.99)	0.43	1.96	+0.118	-0.05	0.49	1.87	+0.106	-0.10
4	167	57.64 ± 7.79 (36.5 – 76.5)	16.60 ± 2.64 (11.79 – 25.30)	0.50	1.84	-0.107	+0.01	0.51	1.82	-0.046	-0.00
5	167	57.05 ± 8.30 (37.0 – 81.0)	16.61 ± 2.64 (12.32 – 25.80)	0.42	1.96	+0.022	+0.02	0.44	1.93	-0.021	+0.04
			Average	**0.49**	**1.84**	**0.114***	**0.04***	**0.51**	**1.79**	**0.093***	**0.06***
(d) combined 8 sites											
1	167	57.15 ± 8.22 (36.5 – 81.5)	16.60 ± 2.63 (11.58 – 24.70)	0.50	1.86	-0.084	-0.05	0.52	1.81	-0.061	+0.00
2	167	56.50 ± 8.65 (40.0 – 93.0)	16.60 ± 2.63 (11.71 – 24.88)	0.56	1.74	+0.027	-0.05	0.57	1.73	+0.087	-0.04
3	167	56.96 ± 7.70 (40.5 – 74.5)	16.60 ± 2.63 (11.77 – 24.99)	0.51	1.83	+0.069	-0.05	0.54	1.79	+0.070	-0.06
4	167	57.64 ± 7.79 (36.5 – 76.5)	16.60 ± 2.64 (11.79 – 25.30)	0.51	1.84	-0.020	-0.06	0.53	1.81	-0.126	-0.05
5	167	57.05 ± 8.30 (37.0 – 81.0)	16.61 ± 2.64 (12.32 – 25.80)	0.45	1.97	+0.033	+0.07	0.47	1.93	+0.063	+0.05
			Average	**0.51**	**1.85**	**0.047***	**0.06***	**0.53**	**1.81**	**0.081***	**0.04***

*mean of the absolute values

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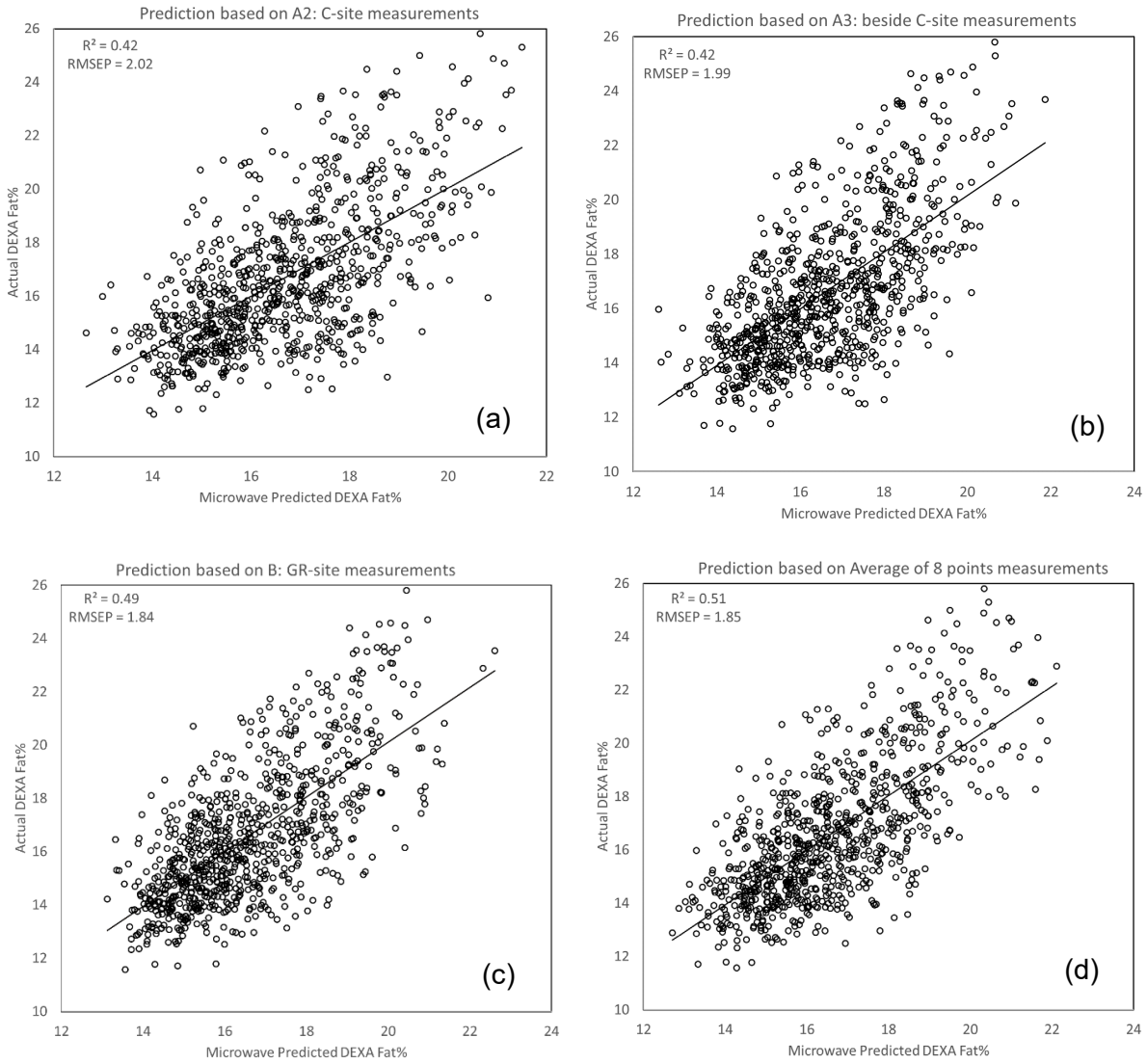

Figure 2 The association between actual DEXA Fat% and MiS scanning at (a) C-site (b) Point A3 (c) GR-site (d) combined 8 Points to predict DEXA Fat% with HCWT not included in the model. The predictions are derived from the validation tests detailed in Table 2. The actual tissue depths were regressed against the predictions. Solid line represents the relationship between predicted and actual measurements.

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4 Discussion

This experiment demonstrates the ability of a hand-held MiS scanning device to predict DEXA Fat% in mature sheep. The negligible difference in precision and accuracy of scanning once at the GR-site, compared to combining 8 points across the thorax was unexpected as fat distribution changes along a carcase (Anderson, Williams, Pannier, Pethick, & Gardner, 2015) thus a single-site tissue depth is not a particularly accurate measure of whole carcase composition (Williams, Anderson, Siddell, Pethick, Hocking Edwards, & Gardner, 2017). However for ease of commercial application into industry, scanning at just one site will be faster and easier, thus this demonstrates the GR-site may offer a promising solution.

The insignificant difference between the prediction of DEXA Fat% when MiS scanning at the C-site vs site A3 (2cm cranial to C-site) demonstrates that while correct anatomical location and placement of probe is important, a slight deviation will not affect the result. However future studies should investigate the difference in prediction in deviating from the GR-site, along both sagittal and transverse planes.

The ewes in this study were all clipped prior to MiS scanning allowing perfect MiS probe-skin contact. In the commercial environment clipping will not be practical thus future experiments needs to investigate the precision and accuracy of prediction in ewes with wool of varying lengths as wool can trap water and dust which can alter dielectric properties at microwave frequencies (Vijay, Jain, & Sharma, 2015; Wang, 1980).

5 Conclusion

This study demonstrated the capacity of MiS scanning to predict whole body fatness phenotype in mature sheep.

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