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Report Title: Report on the continued improvement of the operating system and algorithm development for the use of portable microwave system in abattoirs

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Abstract

Portable ultra-wide band microwave system coupled with an open-ended coaxial probe (OCP) or Antipodal Vivaldi Antenna (AVA) was tested as non-invasive objective measurement to predict beef carcase single site fat depth at commercial abattoirs. Hot carcase P8 was measured using an OCP (n=435) across two slaughter groups and by an AVA (n=241) across 4 groups. Cold carcase rib fat was measured using AVA (n=598) across 5 groups. A machine learning stacking ensemble technique was used to create the prediction equations. Datasets were grouped by prediction trait (P8 or ribfat) and probe/antenna then randomly divided into 5 groups based on tissue depth. The precision was greatest using the OCP to predict P8 site with an RMSEP of 2.47 mm and R^2 of 0.70. The VPA precision was greatest in the hot carcase on the P8 site with an RMSEP of 2.86 mm and R^2 of 0.58 compared to the cold carcase rib fat RMSEP of 2.60 mm and R^2 of 0.55.

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Executive Summary

A novel option for non-invasive, single site objective measurement is ultrawide-band (UWB) microwave system (MiS) (Hussain, 1998; Jafari, Liu, Hranilovic, & Deen, 2006; Jayaseelan Marimuthu, Bialkowski, & Abbosh, 2016). A prototype portable UWB MiS system using low power, non-ionizing electromagnetic waves has been developed at Murdoch University (Jayaseelan Marimuthu & Gardner, 2019; J Marimuthu, Hocking-Edwards, & Gardner, 2018). This technology takes advantage of the differing dielectric properties ($\varepsilon^* = \varepsilon' - j\sigma$, ε' = permittivity and σ = conductivity) of biological tissues where an antenna transmits pulses into the tissues, resulting in a frequency-dependent diversion and scattering at the interfaces between differing tissue (Hussain, 1998; Jafari et al., 2006; Jayaseelan Marimuthu et al., 2016). The backscattered array is collected by the same antenna and the signal analysed allowing measurement of the tissue layers (Jafari et al., 2006; Jayaseelan Marimuthu et al., 2016). The low power frequencies of UWB MiS is non-destructive thus poses no health risks to living or dead tissues (Zastrow, Davis, & Hagness, 2007). The measurement is instantaneous and requires no specific training of the operator apart from accurate placement of the antennae on the desired site of measurement. UWB MiS for use in human medical imaging has been an active area of research over the last few decades, with numerous published reviews (Bolomey & Jofre, 2010; Chen, Liang, Wang, Wang, & Parini, 2008; Hussain, 1998; Jafari et al., 2006; Klemm, Craddock, Leendertz, Preece, & Benjamin, 2008). The research and application of microwave generated electromagnetic waves for the prediction of meat quality is limited (Damez & Clerjon, 2013). Microwave sensing in the meat industry has been used in the laboratory to evaluate muscle structure changes during beef aging (Sylvie Clerjon & Damez, 2009; S Clerjon & Damez, 2007) and muscle moisture content in broiler meat (Jilani, Wen, Cheong, & Ur Rehman, 2016; Jilani, Wen, Rehman, Khan, & Cheong, 2016). To the authors knowledge this experiment is the first time UWB MiS has been used to predict fat depth on the whole carcass in a commercial setting.

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1 Introduction

Subcutaneous fat depth is a key component of beef carcass composition trading in Australia. Consumers are driven towards purchasing beef cuts with reduced visible subcutaneous fat (Steenkamp & van Trijp, 1996) thus beef carcass value is based on the proportion of saleable lean meat yield along with the eating quality of the cuts (Polkinghorne, Philpott, Gee, Doljanin, & Innes, 2008). Fat depth is negatively correlated to carcass value (Polkinghorne et al., 2008), predominately due to increasing fatness decreasing lean meat yield, and increased trimming costs to meet market specifications. Additionally, fatter carcasses have been associated with a slower rate of chiller cooling, which can affect glycolytic rates and pH decline (Daly, 2005). Polkinghorne *et al.* (2008) estimated that a 1 mm increase in rib fat reduced carcass value by AUD$0.018/kg. As such, Australian processors set narrow price grids based on hot carcass weight and subcutaneous fat depth specifications and producers are paid on a per carcass basis based on these measurements. Accurate objective measurements of carcass fatness is essential for carcass trading both in feedforward information to optimising boning rooms for market specifications, and feedback to beef producers to improve on farm production and reduced wastage of nutrition in unwanted fat.

Single site fat depth measurement of the Australian beef carcase is currently taken via an invasive technique, where a cut knife or probe is inserted at the P8 site, or rib fat depth taken from the cut surface of the quartering site, 75% along the rib eye muscle (AUSMEAT, 2005). Personnel performing cut measurements operate under AUSMEAT accreditation and audit scheme, however these measurements can be imprecise and prone to operator error (Williams et al., 2017). Non-invasive measurements which use electromagnetic or mechanical energies are rapidly becoming the preferred technique of assessing carcass composition (Scholz, Bünger, Kongsro, Baulain, & Mitchell, 2015). The advantages lie in improved precision and accuracy of the predictions, no destruction of the tissues, and enhanced producer confidence by removing the human element of the measurement. Any new carcass composition measurement must be able to operate at industry chain speeds while being safe, precise and accurate (Scholz et al., 2015).

Preliminary work has demonstrated the capacity of the prototype UWB MiS to predict carcass single site fat depth in beef (Jayaseelan Marimuthu & Gardner, 2019) and lamb (J Marimuthu et al., 2018). The precision for predicting hot carcass P8 fat depth had a root mean square error (RMSEP) varying from 1.63 – 3.78 mm and R-square (R^2) from 0.53 to 0.69 (Jayaseelan Marimuthu & Gardner, 2019). Building on the findings of the preliminary research, this study details the calibration and validation of the prototype UWB MiS on a larger sample size of beef cattle with diverse genotypic and phenotypic traits, to assess the precision of to predict single site carcass fatness in beef carcasses. We hypothesised that UWB MiS can provide adequate precision and accuracy for predicting P8 and rib fat depth in beef carcasses.

2 Methods

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2.1 Experimental design, slaughter protocol and carcass measurements

This study utilised 6 slaughter groups of Australian commercial beef cattle (n = 676). Groups 1-4 & 6 utilised slaughter cattle from the Beef Information Nucleus (BIN) project. Group 5 utilised commercial slaughter cattle not part of the BIN project. The rationale of the BIN project has been described in detail previously (Banks, 2011). Briefly, the BIN project is a collaboration between Meat Livestock Australia (MLA) and the major beef breed societies of Australia with the aim to improve genotypic and phenotypic data capture to accelerate genetic progress (Banks, 2011). Group 5 cattle were Bos indicus Droughtmaster-Brahmin cross, whilst all other groups were Bos Taurus, of Angus, Hereford-Angus cross, or Hereford breed (*Table 1*). Slaughter group 1 were grass-fed whereas slaughter group 2 – 6 were 100 – 105 days grain-fed. Cattle were processed at Meat Standards Australia (MSA) accredited commercial abattoirs, one located in Tasmania, one in New South Wales (NSW) and two in Queensland.

In line with Meat Standards Australia (MSA) protocols, all cattle were consigned direct from farmgate to slaughter and processed within 48 hours from leaving farmgate with no more than 12 hours in lairage prior to slaughter (MSA, 2016). Four MSA accredited abattoirs were used; one located in Tasmania, one in New South Wales and two in Queensland. Each slaughter group was processed on a different kill day, with the breakdown of groups, kill date and abattoir location listed in Table 1. Cattle were processed under standard commercial operating systems, identified with a carcass ticket and electrical stimulation and trimming performed to AUSMEAT standards (AUSMEAT, 2016). Within one hour of slaughter, hot standard carcass weight was recorded, and manual measurement of the fat depth at the P8 site on the hot carcass was measured using the cut-and-measure technique. The P8 was measured with a metal ruler at the point defined by AUSMEAT (2016) “the point of intersection of a line from the dorsal tuberosity of the tripartitie tuber ischia parallel with the chine, and a line at 90^{o} to the sawn chine centred on the crest of the spinous process of the third sacral vertebrae”.

The UWB MiS scanning of the hot carcass P8 site commenced at 40 min post slaughter. Group 1 and 5 hot carcass P8 was measured using the prototype MiS coupled with an open-ended coaxial (OCP) probe and Groups 2 – 4 & 6 were coupled with an Antipodal Vivaldi Antenna (AVA) (Table 1).

Carcass sides were chilled overnight and the following morning prior to MSA grading cold carcass subcutaneous rib fat depth was measured using the prototype UWB MiS coupled with an AVA antennae for slaughter groups 1, 2, and 4 - 6. The antenna was placed on the left side of the carcass at the $12^{th}/13^{th}$ rib, 75% along the rib eye muscle (Anonymous, 2005).

Individual carcass grading was performed according to AUSMEAT chiller assessment measurements by MSA and AUSMEAT accredited graders (Anonymous, 2005). The left carcass was quartered at the $12/13^{th}$ rib, cutting straight across the eye muscle. The depth of subcutaneous fat over the rib was measured using a metal ruler on the exposed cut surface (Anonymous, 2005). Other carcass measurements included marbling, ossification, eye muscle area, ultimate pH and temperature of *m. longissiumus thoracis* (loin) (Anonymous, 2005).

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2.2 Description of microwave hardware and signal analysis

The portable UWB MiS was designed as a single-port vector network analyser with built in computer modules, operating system and automated python-based program utilising a R54 vector refractometer from Copper Mountain Technologies (Copper Mountain Technologies, Indianapolis, USA). The design and fabrication of UWB MiS, OCP and AVA was conducted at Murdoch University, Western Australia.

For this experiment an antipodal UWB vivaldi patch antenna (AVA) was designed using a dual-elliptically tapered antipodal slot. AVA has a planar structure and was designed and fabricated on RO3010™ (Rogers Cooperation (Advanced Connectivity Solutions USA)) laminates of dielectric constant 10.2, dissipation factor 0.0022, thickness of 1.27 mm and copper cladding of 17μm top and bottom. The antennae is 95 mm in height, 110 mm in length, and 1.27 mm in width, embedded in a 4 mm Teflon casing, creating an overall dimension of 5.27 mm width and 99 mm height contact point with the carcase. The narrow width of the AVA within Teflon creates good contract points on hot and cold carcases. The final design AVA has operating frequency from 300 MHz – 6.5 GHz with gain of 9.31dBi, directivity of 9.41dBi with main lobe direction at 90° of angular width (3dB) 65.9° at 3 GHz. (De Oliveira, Perotoni, Kofuji, & Justo, 2015; Fei, Jiao, Hu, & Zhang, 2011; Mohammed, Abbosh, Mustafa, & Ireland, 2013).

An OCP probe is a waveguide formed by two coaxial conducting cylinders (internal and external) (La Gioia, Porter, et al., 2018; La Gioia, Salahuddin, O'Halloran, & Porter, 2018; Meaney, Gregory, Seppälä, & Lahtinen, 2016). The cylinders were constructed from aluminium with a conductivity of 3.77 x 107 S/m. The interior cylinder is the solid core of the probe with a 10 mm diameter while the hollow external probe has a 32 mm diameter. The space between the two cylinders is filled with Teflon, a dielectric material acting as an insulator. At the end of the waveguide, a flat disc (75 mm diameter, 3 mm thickness) around the fringe ensures minimal field diffraction. The designed probe has a 50 Ω characteristic impedance and operates at frequencies between 100 - 6 GHz. To connect the probe to the MiS, a SubMiniature version A (SMA) adapter was used. For adequate surface contact the OCP probe requires a semisolid surface with homogenous properties hence it was used only on the hot carcase while the fat was in a semisolid state.

The UWB MiS coupled with either OCP or AVA was set to transmit electromagnetic waves with 100 MHz to 5.4 GHz of microwave frequency at a power output of -10 dBm. The wave propagation is determined by the reflection coefficient (S11). The collection of reflected microwave signal *S11(f)* (*f* indicating frequency domain signals) were recorded at 10 MHz intervals from 100 MHz to 5.4 GHz, resulting in 531 separate readings. With R indicating the raw signal, each collected $S11(f)_{jR}$ signal is composed of two components of data points: real ($x(f)_{jR}$) and imaginary ($y(f)_{jR}$) with the following equation

$$S11(f)_{jR} = x(f)_{jR} + iy(f)_{jR} \quad j = 1, 2, \ldots .256$$

MiS calibration was performed at chiller temperatures using a "short, open and load" technique. With 'A' indicating chiller ambient signals, the chiller ambient reflection coefficient

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$S11(f)_{jA}$ was recorded at 10 MHz intervals (100 MHz to 5.4 GHz -10 dBm) using the MiS coupled with probe/antennae in free space.

$$S11(f)_{jA} = x(f)_{jA} + iy(f)_{jA} \quad j = 1, 2, \ldots.., 256$$

Processing of signals was performed whereby the chiller signal $S11(f)_{jA}$ was subtracted from the carcase signal in Matlab (R2019b)® (The Math Works Inc., Natick, MA, USA). Statistics and analysis was performed in WEKA® 3.9.4 (The University of Waikato, Hamilton, New Zealand).

$$S11(f)_j = S11(f)_{jR} - \ S11(f)_{jA}$$

$$S11(f)_j = (x(f)_{jR} - x(f)_{jA}) + \ i(y(f)_{jR} - \ y(f)_{jR})$$

$$S11(f)_j = x(f)_j + \ iy(f)_j \quad j = \ 1, 2, \ldots \ldots, 256$$

The prediction of P8 or rib fat depth was obtained by calculating the magnitude of the feature dataset from the real ($x(f)_j$) and imaginary ($y(f)_j$) of $S11(f)_j$ processed frequency domain using the following equation

$$Mag\left(S11(f)_j\right) = \left|S11(f)_j\right| = \sqrt{x(f)_j^{\,2} + y(f)_j^{\,2}}$$

2.3 Microwave analysis

The estimation of P8 or rib fat depth was derived by calculating the magnitude of the calibrated and processed frequency domain signals ($|S11(f)_j|_k$ (j = 1,2, ……, 256) where $_k$ represents the individual carcase). The statistical method for constructing the prediction equations was by a machine learning ensemble technique in WEKA® 3.9.4 (The University of Waikato, Hamilton, New Zealand). A stacked generalisation approach was used, where two different prediction models were layered to create a meta-algorithm (Elshazly, Elkorany, Hassanien, & Azar, 2013; Ribeiro & dos Santos Coelho, 2020). The first prediction model layer was composed of algorithms derived from Support Vector Machine and Random Forest. The second layer used Partial Least Squares Regression to construct a two-component model.

For the P8 site, OCP (group 1 and 5) and AVA (groups 2-4 and 6) estimations were analysed separately. Slaughter group datasets for each probe/antenna were pooled then randomly divided into 5 groups balanced for P8 fat depth. A leave-one-out cross-validation methodology was used, where training was performed on 80% of the data (4 groups) and validated on the remaining 20% (the 5th group) resulting in a total of 5 validation groups. The validation predictions using OCP are reported in Table 2 and using AVA are reported in Table 3.

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The same validation procedures were applied to the rib fat datasets (groups 1,2 and 4-6). All data was pooled and randomly divided into 5 groups balanced for rib fat depth prior to performing the leave-one-out cross validation ensemble machine learning technique (Table 4)

The precision between actual and MiS predicted values is expressed as R-square (R^2) and root mean square error of the prediction (RMSEP) while accuracy is expressed via bias and slope. The bias was calculated by taking the difference between the predicted and actual values at the median of the dataset. The average slope represents the mean of the deviation of each slope estimate from 1.

3 Results

Descriptive statistics are provided in Table 1, demonstrating the range in HCWT, P8 fat depth and rib fat depth from the 6 slaughter groups.

The precision of prediction of hot carcase P8 fat depth was greater with the MiS coupled to the OCP (Table 2 and 3). The OCP RMSEP averaged 2.47 mm, with a range of 2.34 to 2.61 mm and an R^2 average describing 70% of the variation with a range from 67 to 73%. The association between actual and predicted P8 fat depth for the OCP is depicted in Figure 1. The VPA RMSEP averaged 2.86 mm with a range of 2.5 to 3.17 mm and an average R^2 describing 58% of the variation with a range from 46 to 71%. The association between actual and predicted P8 fat depth for the VPA is depicted in Figure 2. The OCP average bias was 0.13 mm with an average slope deviating 0.03 mm from 1. The VPA bias was slightly lower at 0.09 mm though with a slightly greater average slope deviating 0.07 mm from 1.

The precision of VPA probe to predict cold carcase rib fat was close to P8 prediction. The RMSEP values averaged for rib fat values averaged 2.60 mm with a range from 2.39 to 2.71 mm. However the rib fat depth VPA R^2 average was slightly lower, described 55% of the variation ranging from 50 to 59%. The association between actual and predicted rib fat depth for cold carcase VPA is depicted in Figure 3.

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Table 1 Descriptive statistics including animal numbers (n), and mean ± standard deviation, minimum and maximum for hot standard carcass weight, P8 site and Rib fat depth

Kill Date	Slaughter group	Abattoir	Breed	n	Sex	Antennae hot carcass measurement	Antennae cold carcass measurement	Hot standard carcass weight (kg)	Hot P8 Fat depth (mm)	Cold Rib Fat depth (mm)
19 Jul 2018	1	JBS Longford, Tasmania	Hereford-Angus Cross	156	Steers	OCP	VPA	306.6 ± 28.7	8.13 ± 2.98	6.82 ± 2.55
17 Dec 2018	2	NH Foods Wingham, NSW	Hereford	45	Heifer	VPA	VPA	253.0 ± 20.6	17.0± 3.42	7.45 ± 2.27
06 Feb 2019	3	NH foods Wingham, NSW	Hereford	78	Steers	VPA	-	352.1 ± 25.9	20.6 ± 4.20	11.1 ± 3.60
01 Apr 2019	4	John Dee Warwick, Queensland	Angus	48	Steers	VPA	VPA	288.8 ± 28.7	13.7 ± 3.70	9.13 ± 3.27
16 Apr 2019	5	ACC, Brisbane, Queensland	Droughtmaster-Brahmin Cross	279	Mixed	OCP	VPA	257.8 ± 18.4	13.3 ± 4.15	7.25 ± 3.25
05 Jun 2019	6	NH foods Wingham, NSW	Herefords	70	Steers	VPA	VPA	351.3 ± 37.5	21.1 ± 4.51	14.0 ± 5.46

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Table 2 Precision and accuracy estimates for leave-one-out cross validation of models predicting hot carcass P8 fat depth using an open-coaxial probe (slaughter group 1 and 5). Precision estimates include R^2 and root mean square error of the predicted (RMSEP). Accuracy estimates include slope of the relationship between actual versus predicted (slope) and bias, which represents the difference between the actual minus predicted value calculated at the mean of P8 fat depth.

Validation Group	N in validation	N in training	R^2	RMSEP (mm)	Bias (mm)	Slope
Groups balanced for hot carcass P8 fat depth						
1	87	348	0.72	2.45	-0.06	1.00
2	87	348	0.72	2.42	+0.02	1.01
3	87	348	0.73	2.34	+0.16	1.01
4	87	348	0.68	2.53	+0.18	1.03
5	87	348	0.67	2.61	-0.23	0.91
		Average	**0.70**	**2.47**	**0.13**	**0.03**

Table 3 Precision and accuracy estimates for leave-one-out cross validation of models predicting hot carcass P8 fat depth using a Antipodal Vivaldi Antenna (slaughter group 2, 3, 4 and 6). Precision estimates include R^2 and root mean square error of the predicted (RMSEP). Accuracy estimates include slope of the relationship between actual versus predicted (slope) and bias, which represents the difference between the actual minus predicted value calculated at the mean of P8 fat depth.

Validation Group	N in validation	N in training	R^2	RMSEP (mm)	Bias (mm)	Slope
Groups balanced for hot carcass P8 fat depth						
1	49	192	0.61	2.85	+0.06	1.10
2	48	191	0.47	3.12	-0.01	0.91
3	48	191	0.46	3.17	+0.03	0.92
4	48	191	0.71	2.50	+0.19	1.09
5	48	191	0.64	2.64	-0.14	1.00
		Average	**0.58**	**2.86**	**0.09**	**0.07**

Table 4 Precision and accuracy estimates for leave-one-out cross validation of models predicting cold carcass rib fat depth using a Antipodal Vivaldi Antenna (slaughter groups 1, 2, 4 - 6). Precision estimates include R^2 and root mean square error of the predicted (RMSEP). Accuracy estimates include slope of the relationship between actual versus predicted (slope) and bias, which represents the difference between the actual minus predicted value calculated at the mean of rib fat depth.

Validation Group	N in validation	N in training	R^2	RMSEP (mm)	Bias (mm)	Slope
Groups balanced for hot carcass P8 fat depth						
1	120	478	0.55	2.66	-0.12	1.03
2	120	478	0.56	2.62	+0.06	0.99
3	120	478	0.55	2.60	+0.10	0.96
4	119	479	0.50	2.71	+0.12	1.00
5	119	479	0.59	2.39	-0.08	1.07
		Average	**0.55**	**2.60**	**0.10**	**0.03**

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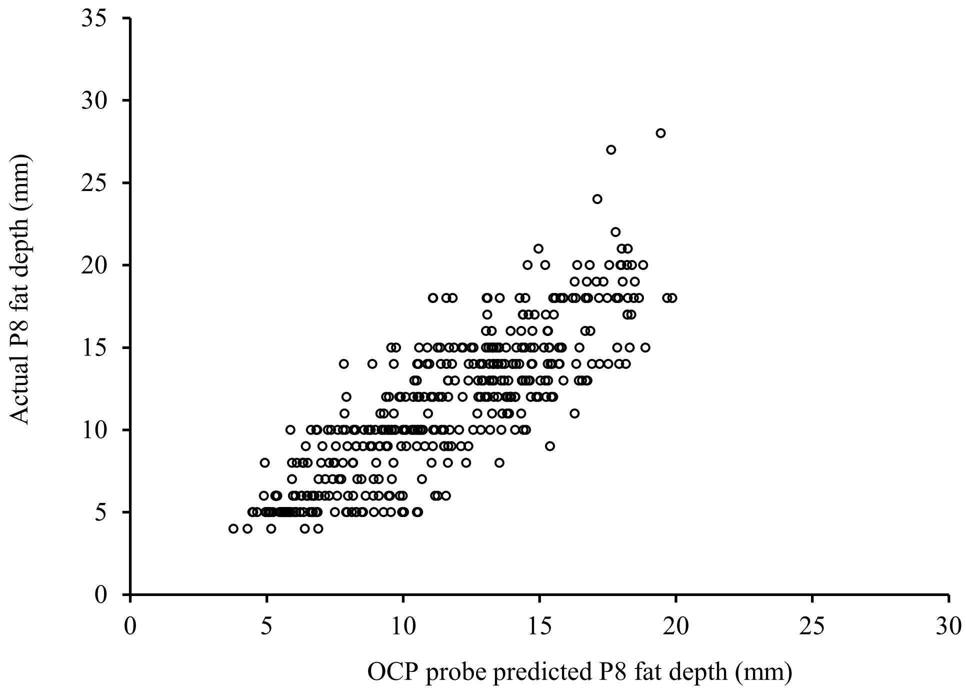

Figure 1 The association between actual and microwave predicted hot carcase P8 fat depth (mm) using a OCP probe. Symbols denote actual versus predicted means for groups balanced for P8 fat depth

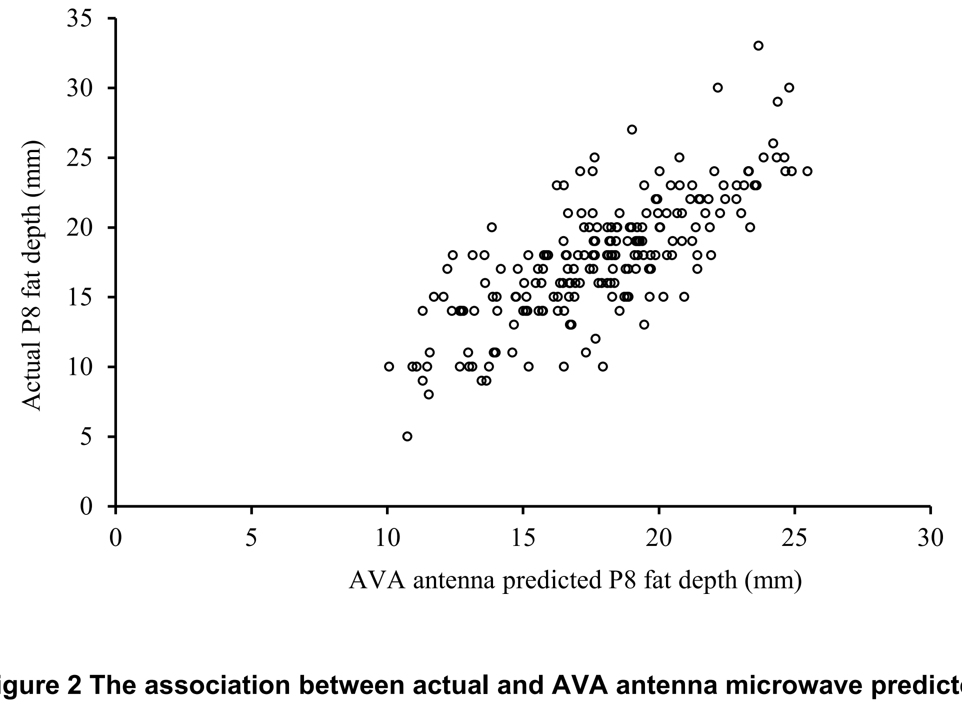

Figure 2 The association between actual and AVA antenna microwave predicted hot carcase P8 fat depth (mm). Symbols denote actual versus predicted means for groups balanced for P8 fat depth.

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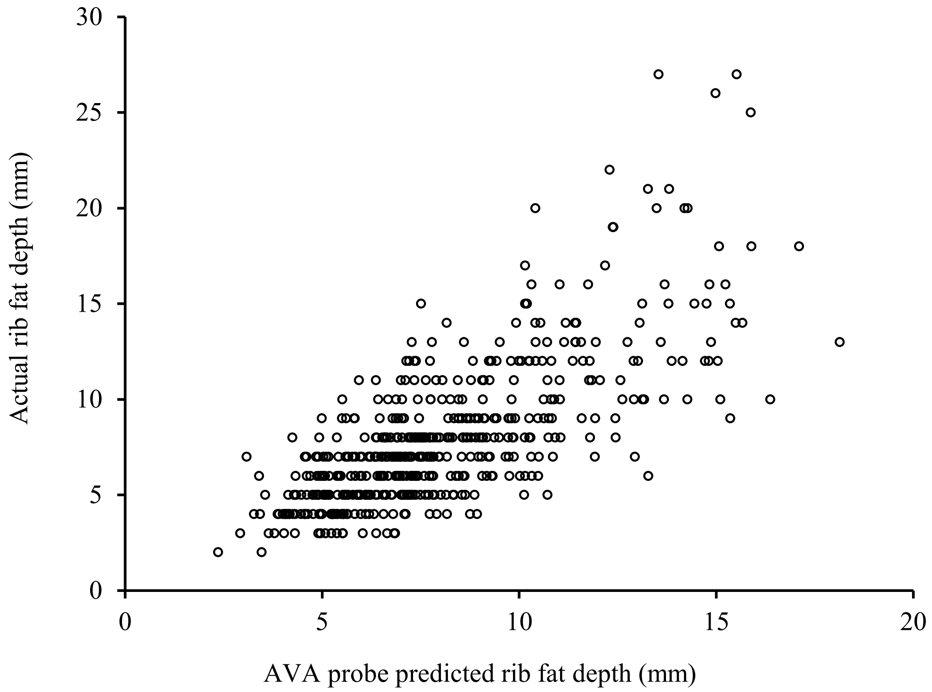

Figure 3 The association between actual and AVA antenna microwave predicted cold carcase rib fat depth (mm). Symbols denote actual versus predicted means for groups balanced for rib fat depth.

4 Discussion

Confirming our hypothesis, the prototype UWB MiS had good precision and accuracy in predicting beef carcase single site fat depth. The precision was greatest overall for the UWB MiS coupled with OCP to predict hot carcase P8. There was some loss of precision in the AVA probe, particularly to predict cold carcase rib fat. This increased precision of the OCP in part is likely due to the larger area of electromagnetic wave/field interaction in comparison to the AVA. A major challenge in deploying dielectric probes/antennas is maintaining good surface contact between the device and material under test. The cylindrical design of OCP allows for excellent contact on a semi-solid surface while the probe remains at a perpendicular angle. The planar design of the AVA with a 5.27 mm wide contact point may have not always be perfectly perpendicular to the tissue surface thus distorting the field measured. On a cold carcase, subcutaneous fat hardening into an irregular shape can impede perfect contact between antennae and fat surface. This can result in an air-fat interface, refracting the electromagnetic wave/field away from the antenna and carcase thus impacting precision. Chiller factors may have further compounded the cold carcase results. Tight chiller carcase arrangement may have reduced operator ability to obtain perfect antenna placement and the use of spray chilling resulting in a wet surface will reduce electromagnetic precision as water has its own dielectric properties thus will alter microwave transmission and reflection (Vijay, Jain, & Sharma, 2015).

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There was excellent accuracy from both OCP and AVA predictions with all slope values close to 1. All bias were under 0.24 mm demonstrating the ability of this system to accurately predict fat depth in the beef carcase. The precision estimates were similar to those reported previously by Marimuthu & Gardner (Jayaseelan Marimuthu & Gardner, 2019) where R^2 ranged from 0.53 to 0.71%. However the accuracy estimates in this experiment were markedly improved, as biases previously approached 2 mm, reflecting the improved MiS prototype used in this experiment.

The value in improved technology lies in its ability to be easily adopted into commercial industry (Toohey, van de Ven, & Hopkins, 2018). Barriers to commercial adoption include accuracy, cost, space, and ease of use (Toohey et al., 2018). Industry accredited beef carcase objective single site fat scoring technologies exist, such as the optical Hennessy Grading Probe™ (HGP) (Auckland, New Zealand). While HGP has been AUSMEAT accredited for decades, the commercial adoption of this portable device is low, with a 2015 survey of Australian processors finding 75% of processors were aware of HGP however only 32% implemented into their grading system (Toohey et al., 2018). Initial experiments demonstrated good precision of the HGP (Hopkins, 1989; Kirton et al., 1987; Phillips, Herrod, & Schafer, 1987), but accuracy was raised as one reason behind low processor adoption with a lack of repeat precision validation studies (Toohey et al., 2018). In its simplicity of use, UWB MiS may offer an attractive alternative to the invasive HGP technique. The measurement is instantaneous and training of staff will require only the correct placement of the smooth surfaced probe on the site to be measured. The authors predict that this non-invasive technology will have greatest benefit commercially at the P8 site as for rib fat a cut surface at the quartering site is required for other meat quality traits.

Subcutaneous fat depth underpins carcase boning and value-based trading thus technologies that improve the precision and accuracy of this measurement will greatly enhance beef industry productivity and profitability. MiS as a single site measurement will have reduced predictive power when compared to whole carcase composition technologies (Anderson, Williams, Pannier, Pethick, & Gardner, 2015; Williams et al., 2017). However, low power non-ionising electromagnetic waves are non-destructive thus completely safe for human operators without requiring shielding (Zastrow et al., 2007) making MiS technology a great prospect for ease of adoption in the commercial environment. Furthermore from a broader industry perspective, the low cost and portability of MiS offers the opportunity to establish an objective carcase measurement solution for smaller operators distinct from other technologies which are typically focused on large-scale enterprises.

5 Success in meeting milestone

This study demonstrates the capacity of a portable UWB MiS system to estimate P8 and rib fat depth in beef carcasses non-invasively. The results suggest that a range of different probe/antenna hardware can be used for hot and cold carcase measurement to predict fat depth within the carcass. Further validation and training across multiple devices is required to investigate the potential of this technology to be industry AUSMEAT accredited.

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