NON-INVASIVE TECHNIQUE USING LOW COST PORTABLE MICROWAVE SYSTEM ON CARCASE FOR FAT DEPTH MEASUREMENT

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INTRODUCTION

In the meat industries, overfat carcases cause significant economic loss due to the labour required for trimming fat, and the waste that it represents. Fat is the most variable component, both in its amount and distribution in the carcase, and on this basis the measurement of carcase fat depth is the cornerstone of most carcase classification schemes for beef, lamb and pork worldwide [1,2]. Fat depth is often measured manually, however this has the disadvantage of being destructive, subjective and time-consuming. The ability to estimate fat depth accurately via a non-invasive and non-destructive technique is therefore highly sought after [3]. One solution showing considerable promise for determining carcase fatness is a Microwave System (MiS) using low power non-ionizing electromagnetic waves [4]. Since biological tissues in animals, feature a high contrast in the dielectric properties (skin, fat, muscle and bone) at microwave frequencies [4], MiS can accurately evaluate the fat depth and body composition of carcases and live animals. As an illustration of tissue parameters, the range of contrast available in X-ray imagery within soft tissues is less than 2%; whereas within microwave electromagnetic fields the range in relative dielectric constant goes from a minimum of about 4 in fat to a maximum of about 70 in muscle [5]. Furthermore, the microwave devices required to produce and measure these fields are low cost and highly portable. Working within these constraints a low-cost portable Microwave System has been developed for measuring back fat depth in lamb carcases. This paper details early testing of this device, testing the hypothesis that it will provide a reliable estimate of back-fat depth in lamb carcases.

MATERIALS AND METHODS

Two groups of mixed sex lambs were slaughtered at a commercial abattoir on separate days. Kill 1 consisted of 110 lambs with carcase weights ranging between 17kg and 39kg and C-site fat depth (measured 5cm from the midline over the 12 rib using Vernier callipers) ranging between 0.6mm and 8.5mm. Kill 2 consisted of 90 lambs with carcase weights ranging between 18kg and 37kg and C-site fat depth ranging between 0.9mm and 10.7mm. Both kill groups were scanned at the C-site using a portable Microwave System (MiS) at 1, 2, and 4 hours post mortem, with kill group 2 also scanned at 24 hours. The prototype MiS operated at frequencies of 320 MHz to 6.5 GHz with output power ranging from -30 dBm to +10 dBm. This was coupled with two different prototype broadband antennas: (a) Vivaldi Patch Antenna (VPA) with operating frequency 0.6 GHz to 4.8 GHz and (b) Periodic Log Antenna (PLA) with operating frequency 0.3 GHz 5.6 GHz. The VPA antenna was used at all time points except for the 4 hour reading for kill group 2, where the PLA antenna was used. Measurements were recorded at 20 MHz intervals at frequencies ranging from 320 MHz to 6.5 GHz, with a power of -10 dBm. These calibrated and processed frequency domain microwave signals of 310 frequencies (between 320 MHz to 6.5 GHz) were then used to estimate the *C*-site fat depth via Partial Least Squares (PLS) Regression using leave-one-out cross validation (PLS procedure in SAS). R-square (R^2) and root mean square error are shown as indicators of precision. To further test transportability, the prediction equation for fat depth trained on the 2h post-mortem data in Kill 2 was used to estimate the C-site fat depth of lamb carcases from Kill 1 at 1, 2 and 4h after post-mortem and Kill 2 at 1, 4 and 24h after post-mortem. For the relationship between actual versus predicted *C*-site fat depth, R-square (R^2) of the prediction and root mean square error of the prediction (RMSEP) are shown as indicators of precision, and slope of the relationship and bias estimates are shown to represent accuracy. Bias represents the difference between the predicted and actual values at the mean of the dataset.

RESULTS AND DISCUSSION

Internal cross-validation within individual data sets demonstrated good precision for the prediction of C-site fat depth using the MiS (Table 1). This was evident within both kill groups and across all measurement times, with RMSE values ranging between 0.99mm to 1.34mm. Measurements taken using the PLA antenna (4h, Kill 1) showed similar precision to the VPA antenna at 1h and 2h in Kill 1 (Table 1). Within kill groups, the predicted fat depth values for the same carcases were highly correlated between time points. In kill group 1, these correlations ranged between 0.85 and 0.91, and in kill group 2 the correlations ranged between 0.91 and 0.98.

Table 1: Precision estimates for the prediction of C-site fat depth measured across 2 kill groups at a range of sampling times using a prototype microwave system. Values are R-square (R^2) and root mean square error (RMSE).

	Kill 1			Kill 2			
	1h	2h	4h	1h	2h	4h	24h
R^2	0.62	0.68	0.65	0.62	0.58	0.64	0.63
RMSE (mm)	1.08	0.99	1.04	1.22	1.34	1.18	1.19
Antenna Type	VPA	VPA	PLA	VPA	VPA	VPA	VPA

VPA = Vivaldi Patch Antenna; PLA = Periodic Log Antenna

Validation testing of the equation derived at 2h in Kill group 2 demonstrated good transportability across the remaining datasets (Table 2) where the VPA antenna was used. Precision estimates were only slightly reduced with RMSE values ranging from 1.17mm to 1.24mm, and slope values (all close to 1) and bias estimates (at worst 1.48mm) indicating good accuracy. The exception to this was for the Kill 1 data set at 4h where precision was reduced and accuracy was poor. However, this result is not surprising as these measurements were taken using a different antenna (PLA) to that which generated the training data in Kill 2 (VPA).

Table 2: Outcome based on Transported Trained Equation extracted from PM 2h Kill 2 on other, PM Measurement

	Kill 1			Kill 2		
	1h	2h	4h	1h	4h	24h
R^2	0.56	0.54	0.41	0.60	0.63	0.61
RMSE(mm)	1.17	1.19	1.35	1.24	1.19	1.22
Bias(mm)	0.61	0.79	-3.73	1.48	0.32	-0.18
Slope	0.98	0.83	0.98	0.90	1.04	1.00
Antenna Type	VPA	VPA	PLA	VPA	VPA	VPA

VPA = Vivaldi Patch Antenna; PLA = Periodic Log Antenna

CONCLUSIONS

These results demonstrate the capacity of a portable prototype MiS system to estimate fat depth at the *C*-site in lamb carcasses non-invasively. Results suggest that this measurement can be taken up to 24 h post-mortem with little loss in precision and accuracy, although equations derived for one antenna (VPA) cannot be seamlessly applied to an alternative antenna design (PLA). Future research will investigate the development of an antenna array for multi-site profiling of carcase and live animal back fat.

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