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Relationship between bioimpedance and muscle mass in chilled lamb carcasses

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ABSTRACT

The accuracy of multi-frequency bioimpedance analysis (MFBIA) as a predictor of carcass composition in lambs was assessed in a small study. Impedance and its' components of resistance (R) and reactance (X) were measured on 20 chilled carcasses from 8 month old second-cross Poll Dorset x (Border Leicester x Merino) cryptorchid lambs. Impedance values were transformed by allowing for path length in relation to frequency giving 2 indices E and F. Carcass weight, GR, C fat depth, and eye muscle area (EMA) were also measured. The right side of each carcass was dissected into fat (intermuscular and subcutaneous), muscle and bone. Carcass weight explained 68% of the variation in the weight of muscle (r.s.d. = 0.34 kg). This was significantly improved by addition of C fat depth to the model ($r^2 = 0.76$, r.s.d. = 0.31 kg) or EMA, but was not affected by addition of GR, E, F, R or X. The impedance derived value, E, was a significant predictor of the percentage of muscle and with carcass weight achieved similar accuracy to C fat depth alone. It is concluded from this study that impedance offers no significant improvement over standard carcass measures for estimating dissectible muscle mass or percentage. This may indicate that a refinement of methodology is required particularly for measurement of chilled carcasses.

Keywords: Lamb; impedance; muscle.

INTRODUCTION

There has been a continual search for methods of predicting carcass composition for both scientific and commercial applications and the focus on the latter has been intensified by the promotion of the value based marketing concept (Cross and Whittaker 1992). One of the more recent technologies to be studied is bioelectrical impedance analysis (BIA) which has shown potential for estimating the fat-free mass of lamb carcasses (Jenkins *et al.*, 1988). Impedance is recorded as the reduction of an electrical current as it passes through a carcass which is directly influenced by the amount of body water present (Cornish *et al.*, 1992). Various reports have indicated that BIA is useful for estimating carcass composition in both lambs (Cosgrove *et al.*, 1988; Berg and Marchello 1994) and pigs (Swantek *et al.*, 1992) where the common frequency which has been used is 50 kHz. A refinement of the BIA has been the use of multiple frequencies (MFBIA) (Cornish *et al.*, 1992) as a means of increasing the accuracy of total body water estimates and derivation of extracellular and intracellular water pools.

The object of this study was to compare the accuracy of MFBIA against standard carcass measures for the estimation of dissectible muscle mass in lamb carcasses.

MATERIALS AND METHODS

The study utilised twenty chilled carcasses from 8 month old second-cross Poll Dorset x (Border Leicester x Merino) cryptorchid lambs, three days post-mortem. Carcasses were suspended on rubber coated gambrels (to isolate the current) and measured for weight, temperature (mean = 3.6 °C), and length between electrodes (L) prior to measurement of impedance. A Model SFB2 (SEAC, Brisbane) multifrequency tetrapolar impedance meter was used for measuring impedance. Signal generating and receiving electrodes constructed from 18g needles held 5 cm apart in plastic jigs were pressed on the biceps femoris and neck simultaneously as current was applied with the needles penetrating 15 mm into the carcass. A range of frequencies from 33 to 1013 kHz were generated over approximately 1 minute with data being captured automatically. Each carcass was analysed twice in rapid succession. Impedance (Z), reactance (X) and resistance (R) were analysed by dedicated software (Johnson and Ward, 1992) with Cole Cole plots being fitted to the data to estimate the impedance at zero frequency (Z_o) and the characteristic frequency (Zc). Impedance values (Z_c) were transformed by allowing for path length giving 2 values E and F defined as;

E = length between electrodes^2 / impedance at 50 kHz

F = length between electrodes^2 / impedance at characteristic frequency

Cold carcass weight was measured at the time of measurement and then the carcasses held at 4°C until they were prepared into retail cuts as described by Hopkins *et al.*, (1994). GR which is defined as the depth of muscle and fat tissue from the surface of the carcass to the lateral surface of the 12th rib 110 mm from the midline was measured using a GR knife. Fat depth over the longissimus thoracis et lumborum (LD) (Fat C; Wood and MacFie 1980) was measured on the cut surface between the 12th and 13th ribs. At the same location the area of the LD was determined by using a grid of 1 cm squares (EMA).

All cuts and trimmed product from the right side were packed in heavy duty bags (100 µm thick) and stored at -24°C until dissected. Prior to dissection the carcass components were thawed at ambient temperature and then divided into fat (subcutaneous and intermuscular combined), muscle and bone. Each component was subsequently weighed. Fat and bone weights were subtracted from the cut weight before dissection and muscle weight adjusted to account for moisture loss.

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Muscle weight (MW) was doubled to give a whole carcass value and this value divided by the cold carcass weight to give the percentage of muscle (PM). The data were analysed using standard multiple linear regression techniques within SYSTAT (Wilkinson 1990). Both MW and PM were treated as dependent variables. Carcass weight, R, X, E, F, GR, Fat C and EMA were considered as independent variables. The amount of variation in the dependent variable that each independent variable explained, and the magnitude of the residual standard deviation were both used to assess the value of each independent variable.

RESULTS

The carcass characteristics of the lambs are shown in Table 1. Although the carcasses were heavy the range was similar to that observed in the general Australian lamb population. Only those models for which a significant relationship was found are reported and these are shown in Table 2. Carcass weight was the best single predictor of total muscle weight and up to 78% of the variation in this variable could be explained by a combination of carcass weight and EMA. Fat C was the best single predictor of the percentage of carcass muscle explaining 40% of the variance. In general the measurements from the impedance analyser were of minimal value for estimating either the weight or percentage of carcass muscle compared to readily available carcass measurements.

TABLE 1: Mean and range of carcass characteristics and impedance measurements for 20 cryptorchid chilled carcasses.

Variable	Mean	Range
Cold carcass weight (kg)	22.4	18.2 - 27.0
Cold GR (mm)	11.1	7.0 - 16.0
Fat C (mm)	2.4	1.0 - 5.0
EMA (cm^2)	13.9	11.0 - 17.0
R50 (ohms)	346	238 - 377
X50 (ohms)	106	75 - 128
E (cm^2/ohms)	2448	1931 - 3547
F (cm^2/ohms)	1732	1164 - 2283
Muscle Weight - MW (kg)	12.5	10.2 - 14.7
Percentage Muscle - PM (%)	56.0	48.3 - 62.9
Percentage Fat - (%)	27.0	9.4 - 35.8

TABLE 2: Estimation of the weight (WM) and percentage (PM) of muscle in cryptorchid carcasses using cold carcass weight (CW), measures of subcutaneous fat (GR, Fat C), eye muscle area (EMA), reactance (X), impedance at 50 kHz (E) and the impedance at characteristic frequency (F).

Intercept	Independent variables	R2	r.s.d.
WM			
4.47**	0.017 X*	0.22	0.54
4.27**	0.001 F*	0.36	0.49
1.76*	0.201 CW**	0.68	0.34
$0.96^{n.s.}$	0.254 CW** - 0.163 Fat C*	0.76	0.31
$1.24^{n.s}$	0.142 CW** + 0.133 EMA*	0.77	0.30
PM			
65.0**	-0.004 E*	0.21	3.09
72.2**	-0.721 CW*	0.27	2.98
63.7**	-0.687 GR*	0.33	2.86
60.0**	-1.666 Fat C*	0.40	2.70
77.0**	-0.616 CW* - 0.003 $E^{n.s.1}$	0.40	2.77

[1] The coefficient for E has a P=0.07.

DISCUSSION

The theory of impedance is based on the relationship between transmission of electrical current, the amount of body water and assumptions about the geometry of either an animal or carcass (Cornish *et al.*, 1992). Thus as fatness increases impedance to the flow of the electrical current increases due to a decrease in water content and conductivity. Initial research with impedance meters was conducted on humans where the impedance values were correlated to total body water but later research with animals has correlated these values to carcass composition determined by differing invasive methods. Jenkins *et al.*, (1988) found that estimation of the weight of carcass protein and water could be achieved with similar accuracy using either carcass weight and fat depth or carcass weight and the term L^2/R which is similar to the E value described in this paper. These workers reported that a further improvement could be made by use of carcass weight, fat depth and eye muscle area as demonstrated by Hopkins (1994) using standard carcass measures. Because of the high correlation between carcass weight and the weight of carcass tissues most of the variation in muscle weight is explained by carcass weight thus additional predictors only increase the explanation of variance by small amounts (Jenkins *et al.*, 1998;Hopkins 1994).

Both Cosgrove *et al.*, (1988) and Berg and Marchello (1994) also found that combinations of measurements from impedance meters were useful for estimating the amount and percentage of lean in a carcass, but only the latter report compared impedance values with carcass weight as a sole predictor and neither compared impedance values to standard carcass measures. When this was done (Slanger *et al.*, 1994) there were few instances in which the usefulness of impedance exceeded that of the 12th rib fat. Compared to our results using standard carcass measures the models based on impedance as presented by Berg and Marchello (1994) showed no significant increase in the variance explained and were less accurate.

Current at 50 kHz or the characteristic frequency is thought to pass through all body water (extracellular and intracellular) so it was expected E and F values would be useful predictors of carcass muscle, whereas in fact, none of the impedance meter measurements were of any significant value. One aspect of MFBIA that was unable to be evaluated was its ability to differentiate total body water into extracellular and intracellular water pools (Cornish *et al.*, 1992). Experiments to develop these correlations are still required. If this differentiation is possible in lambs it is anticipated that intracellular water may be more closely correlated with muscle protein mass than is total body water. While bioimpedance has been demonstrated to have potential as a non-invasive technique for estimating carcass composition in other experiments, there are aspects of methodology that require further study before it could be offered as an alternative to standard carcass measures. Refinement is still required in estimation of the electrical path length, siting of electrodes and methodology for accommodating for the geometry of the carcass. Since the carcass is the conductor of the electrical current and the volume of the conductor influences impedance, increasing the accuracy of volume estimates should increase the usefulness of E and F values. Compared to the work of Berg and Marchello (1994) the present study was conducted on carcasses covering a significantly smaller range for carcass fatness. Therefore calibration over a wider range of weight and fatness is likely to increase the correlation between carcass composition and impedance values.

CONCLUSIONS

Based on the results of this study it is concluded that impedance offers no significant improvement over standard carcass measures for estimating dissectible muscle mass or percentage. The methodology will require improvement before the technique would be advantageous in commercial situations.

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