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Calibration of an on-line dual energy X-ray absorptiometer for estimating carcase composition in lamb at abattoir chain-speed

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ABSTRACT

This experiment assessed the ability of an on-line dual energy x-ray absorptiometer (DEXA) installed at a commercial abattoir to determine carcase composition at abattoir chain-speed. 607 lamb carcases from 7 slaughter groups were DEXA scanned and then scanned using computed tomography to determine the proportions of fat (CT fat%), lean (CT lean%), and bone (CT bone%). Data between slaughter groups were standardised relative to a synthetic phantom consisting of Nylon-6. Models were then trained within each dataset using hot carcase weight and DEXA value to predict CT composition, and then validated in the remaining datasets. Results from across-dataset validation tests demonstrated excellent precision for predicting CT fat%, with RMSE and R^2 values of 1.32 and 0.89, compared to values of 1.69 and 0.69 for CT lean%, and 0.81 and 0.68 for CT bone% which had less precision. Accuracy across datasets was also robust, with average bias values of 0.66, 0.83, and 0.51 for CT fat%, lean%, and bone%.

1. Introduction

Saleable meat yield reflects the weight of saleable meat as a proportion of the weight of the carcass. Overfat carcases have lower saleable meat yield, and impose considerable cost on the supply chain, both to farmers through wasted nutrition and processors who are required to trim excess fat from carcasses to meet consumer expectations. For this reason saleable meat yield represents a key determinant of carcass value along the supply chain, and explains why most Australian processors offer price grids that take account of both carcass weight and fatness.

In the Australian lamb industry these price grids are largely based on carcase weight and a palpated "estimate" of GR tissue depth (110 mm from the spine over the 12th rib) which acts as an indicator of whole body fatness and saleable meat yield. This has been shown to be a highly imprecise estimate, partly due to the relatively poor association between palpated estimates of tissue depth and fat elsewhere in the carcase (Williams et al., 2017), and also because single point measures can introduce significant bias in genetically diverse populations, particularly where redistribution of fat and lean has occurred between carcase regions (Anderson, Williams, Pannier, Pethick, & Gardner, 2015, 2016). On this basis, new technologies are required that measure bone, muscle, and fat composition throughout the entire carcase, while also operating at abattoir chain-speed.

One option for whole-carcase tissue measurement is dual energy x-ray absorptiometry (DEXA). This approach captures x-ray images of the entire carcase at two separate energy levels. These images are matched and within each pixel the attenuation of the lower energy image is expressed as a ratio (R-value) to the attenuation observed at the higher energy (Peppler & Mazess, 1981). R-values align positively with atomic mass enabling differentiation of tissue types (Pietrobelli, Formica, Wang, & Heymsfield, 1996), hence carcases varying in their tissue proportions will have different R-values.

Off-the-shelf medical DEXA scanners have previously been used in research scenario's to determine carcase composition in sheep (Mercier et al., 2006; Pearce et al., 2009), pigs (Lukaski, Marchello, Hall, Schafer, & Siders, 1999; Mitchell, Scholz, & Conway, 1998; Suster et al., 2003) and cattle (López-Campos, Larsen, Prieto, Juárez, & Aalhus, 2015; Mitchell, Solomon, & Rumsey, 1997). Yet these medical systems cannot seamlessly be applied in a commercial environment, in part due to expense and the need for X-ray shielding, but also due to practical limitations associated with speed and carcass movement. Many of the modern medical devices require the scanned object to be held perfectly still to produce two matching high and low energy images (Pietrobelli

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et al., 1996), a significant limitation in abattoirs with rapid line-speeds. Alternatively, "sandwich" style detectors that combine two photodiodes separated by a copper filter can be used to acquire these images simultaneously. In this case a single emission from an X-ray tube passes through the scanned object, and then through the first photodiode that is more responsive to low energy photons, then through the copper filter which attenuates the low energy photons, and then through the second photodiode that is more responsive to high energy photons. Hence the high and low energy images are simultaneously acquired, overcoming the challenges associated with dual energy image acquisition in moving carcases. Recent work (Gardner, Glendenning, Brumby, Starling, & Williams, 2015) demonstrated the capacity of such a system to determine carcase composition at abattoir chain-speed, indicating levels of precision for determining CT fat%, CT lean%, and CT bone% within training datasets of 2.68, 2.45, and 1.02 (Gardner et al., 2015). However these datasets were relatively small and consisted of lambs selected randomly from the days kill with limited phenotypic and genetic variation, highlighting the need for further validation studies. This study details the early calibration of this prototype DEXA system, assessing the performance of this technology across flocks containing a diverse range of genotypes, weights and compositions, testing the transportability of the resulting prediction equations between these flocks. We tested the hypothesis that predictions of carcase composition made at abattoir chain speed would maintain their precision and accuracy when transported between flocks consisting of genetically and phenotypically diverse animals.

2. Materials and methods

2.1. Experimental design and slaughter details

For this study, 7 groups of lambs were used (see Table 1). Group 1 consisted of 48 lamb carcasses selected over a 45 min period across a broad range of fatness (5–27 mm GR tissue depth) and carcass weight (17–32 kg) immediately following slaughter at the commercial abattoir located near Bordertown, South Australia.

Groups 2–7 were all lambs from Meat and Livestock Australia's nucleus flock experiment, the design of which is detailed elsewhere (Fogarty, Banks, van der Werf, Ball, & Gibson, 2007; van der Werf, Kinghorn, & Banks, 2010). Briefly, about 600 lambs were produced from artificial insemination of Merino or Border Leicester-Merino dams at Kirby NSW, and born between 21 September and 16 October in 2014. The lambs (Merino, Maternal x Merino, Terminal x Merino and Terminal x Border Leicester-Merino) were the progeny of 163 industry sires, representing the major sheep breeds used in the Australian industry. The sires types included Terminal sires (Poll Dorset, Suffolk, Texel, White Suffolk), Maternal sires (Border Leicester, Coopworth, Dohne Merino), and Merino sires (Merino, Poll Merino). After weaning at 90 days of age the lambs were grazed under extensive pasture conditions until being re-located during April 2015 to a feedlot in South Australia, about 100 km from the commercial abattoir at Bordertown, SA. All male lambs were castrated.

Groups 2–7 were consigned to their slaughter group on the basis of live weight, with each group killed separately (kill groups) across a period of 4 months to enable a target carcass weight of 21.5 kg to be achieved, except for the final group which aimed for a target carcass weight of 28 kg. Within each group, we attempted to represent progeny from each sire, although due to limited numbers of progeny for some sires this was not always possible. Prior to each slaughter, lambs were yarded within 48 h before slaughter, maintained off-feed for at least 6 h, and then weighed to determine pre-slaughter live weight. They were then transported for 2 h via truck to JBS Bordertown abattoir, held in lairage at the abattoir for between 8 and 12 h, and then slaughtered.

2.2. Slaughter protocol and carcase measurements

All carcases were electrically stimulated and trimmed according to AUSMEAT standards (Anon, 1992), and hot standard carcase weight (HCWT) was then measured within 40 min of slaughter. All lambs were measured and sampled for a wide range of carcase, meat and growth traits including GR tissue depth, which was measured 12 cm from the midline over the 12th rib, and was taken as the total tissue depth above the surface of this rib. These carcases were then DEXA scanned at 24 h post-mortem, with the brisket oriented towards the X-ray source. Carcases were then transported at 2 °C to Murdoch University, WA, where they were scanned using computed tomography (CT) between 5 and 6 days post-mortem.

2.3. Computed tomography scanning

CT scanning of carcases was undertaken at Murdoch University using a Picker PQ 5000 spiral CT scanner to enable the estimation of percent lean (CT lean%), fat (CT fat%), and bone (CT bone%). Prior to scanning the carcasses were split into three primal components to enable more rapid post-scanning processing of the CT images such that future analyses of DEXA composition could be focused on the fore-section, saddle and hind section. The fore section was separated from the saddle by a cut between the fourth and fifth ribs. The hind section was separated from the saddle by a cut through the mid-length of the sixth lumbar vertebrae. In both cases the spiral abdomen protocol was selected with settings: pilot scan length of 512 mm, field of view set at 480 mm, Index 20, kV 110, mA 150, revs 40, pitch 1.5 and standard algorithm. The carcasses were scanned in 10 mm slice widths, with each slice taken 10 mm apart.

The analysis of images produced from the CT scan was the same as that used by Anderson et al. (2015). In summary these images were edited to remove non-carcass image artefacts and were partitioned into bone, muscle and fat components (Image J version 1.37v, National Institutes of Health, Bethesda, MD, USA, used in conjunction with Microsoft Excel). The discrimination point to identify the Hounsfield barriers for associating pixels with fat, muscle and bone were − 235 to 2.3 for fat, 2.4 to 164.3 for lean and > 164.3 for bone. An estimate of volume using Cavalieri's method (Gundersen, Bendtsen, Korbo, Marcussen, & Møller, 1988; Gundersen & Jensen, 1987) was calculated

Table 1
Descriptive statistics for lamb carcases from 7 slaughter groups that were scanned using computed tomography (CT) and on-line dual energy x-ray absorptiometry. Values are Mean ± standard deviation (minimum, maximum).

Slaughter Group (N)	Hot Carcase Weight (kg)	GR Tissue Depth (mm)	CT fat%	CT lean%	CT bone%
1 (48)	24.7 ± 4.4 (17.4, 32.2)	15.0 ± 5.0 (5.0, 27.0)	21.74 ± 3.99 (12.7, 33.8)	61.3 ± 3.1 (52.0, 67.8)	16.96 ± 1.48 (13.6, 21.4)
2 (74)	19.9 ± 3.1 (13.5, 29.0)	9.3 ± 3.5 (2, 17)	22.86 ± 3.33 (15.76, 31.77)	61.02 ± 2.66 (54.84, 66.80)	16.12 ± 1.35 (12.40, 21.04)
3 (95)	23.6 ± 4.8 (13.5, 35.0)	17.3 ± 5.6 (4, 30)	27.96 ± 3.91 (19.03, 37.17)	57.57 ± 3.09 (50.15, 64.39)	14.47 ± 1.39 (11.07, 18.63)
4 (98)	23.5 ± 4.6 (13.0, 34.2)	15.3 ± 5.1 (6, 28)	27.32 ± 3.52 (20.16, 34.56)	58.11 ± 2.78 (52.39, 64.31)	14.57 ± 1.21 (11.97, 17.18)
5 (98)	21.4 ± 4.9 (12.3, 33.5)	14.4 ± 5.5 (5, 30)	26.05 ± 3.98 (18.62, 36.55)	59.18 ± 3.14 (50.29, 65.60)	14.78 ± 1.33 (11.86, 17.86)
6 (100)	22.2 ± 5.4 (10.9, 37.1)	15.7 ± 6.0 (2, 36)	27.69 ± 4.20 (17.11, 36.47)	57.39 ± 3.16 (49.57, 65.91)	14.91 ± 1.70 (12.05, 20.91)
7 (94)	26.1 ± 6.1 (13.2, 39.3)	19.6 ± 7.5 (5, 44)	29.57 ± 4.54 (18.41, 39.53)	55.46 ± 3.33 (47.29, 62.19)	14.96 ± 1.64 (12.28, 20.17)