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Severiano Rocha Silva, Vitor Carvalho Pinheiro, Cristina Miranda Guedes, José Medeiros Mourão. Prediction of carcass and breast weights and yields in broiler chickens using breast volume determined in vivo by real-time ultrasonic measurement. *British Poultry Science*, 2007, 47 (06), pp.694-699. 10.1080/00071660601038776 . hal-00545304

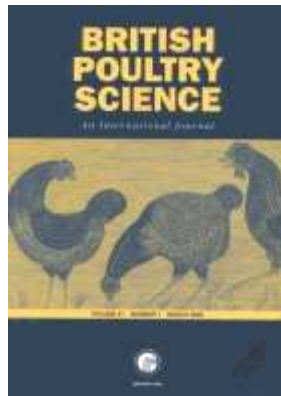
HAL Id: hal-00545304

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Submitted on 10 Dec 2010

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Journal:	<i>British Poultry Science</i>
Manuscript ID:	CBPS-2006-096.R1
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	08-Jun-2006
Complete List of Authors:	Silva, Severiano; CECAV-UTAD, Zootecnia Pinheiro, Vitor; CECAV-UTAD, Zootecnia Guedes, Cristina; CECAV-UTAD, Zootecnia Mourão, José; CECAV-UTAD, Zootecnia
Keywords:	Broilers, Breast, Ultrasound, Volume



Prediction of carcase and breast weights and yields in broiler chickens using breast volume determined *in vivo* by real-time ultrasonic measurement

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RUNNING TITLE: ULTRASONIC BREAST VOLUME MEASUREMENT

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Accepted for publication 11th August 2006

Abstract 1. The use of *in vivo* real-time ultrasonic (RTU) to predict breast and carcase weights and yields in 103 male broiler chickens was evaluated. Breast area (mm²), thickness (mm) and volume (cm³) were measured by RTU in three identified sites. After RTU measurements, the broiler chickens were weighed (live weight, LW, g) and slaughtered. Carcase and breast weights (g) and physical measures of breast area (mm²), and thickness (mm) corresponding to the 3 identified sites, and volume (cm³) were recorded.

2. The best simple correlation between RTU and carcase measurements was obtained for breast volume. Breast and carcase weights were well predicted by LW. Furthermore, breast volume measured in carcase or by RTU was better in predicting breast weight and breast and carcase yields.

3. Multiple regression equations were fitted using LW (g) and RTU measurement of breast volume to predict breast and carcase weights and yields. The coefficients of determination were 0.52 and 0.65 for breast and carcase yields, respectively, and 0.92 and 0.99 for breast and carcase weights, respectively.

INTRODUCTION

In animal nutrition, physiology and genetics studies, body composition or the carcase traits are usually determined by comparative slaughter followed by chemical analysis or dissecting and weighing the body tissues (McBride *et al.*, 1991). These procedures are expensive, laborious and destructive (*i.e.* an animal can be used only once) and are not desirable from economic or welfare points of view. There is an increasing need for the development of non-invasive methods capable of minimising animal slaughtering without any detriment to accuracy. Several techniques have

been evaluated in chickens. Among these techniques computed tomography (CT; Bentsen and Sehested, 1989; Svihus and Katle, 1993; Andrassy-Baka *et al.*, 2003) and magnetic resonance imaging (MRI; Mitchell *et al.*, 1991; Kover *et al.*, 1998; Scollan *et al.*, 1998) have been pointed out as very accurate. However, the high cost and immobility of the equipment severely limit their routine application in animal science. Real-time ultrasonic (RTU) has been used for several years in animal science studies (Greiner *et al.*, 2003; Stouffer, 2004; Silva *et al.*, 2005). In recent years, several attempts have been made to predict bird composition by using RTU (Bochno *et al.*, 2000; Dixon *et al.*, 2000; Melo *et al.*, 2003). Studies with broiler chickens focused mainly on abdominal fat content and breast weight (Grashorn, 1996; Dixon *et al.*, 2000; Melo *et al.*, 2003).

Studies using CT and MRI in pigs (Mitchell *et al.*, 2001) and in lambs (Jopson *et al.*, 1995) showed high correlation coefficients ($r > 0.99$) between volume measurements and carcass traits. The Nsoso *et al.* (2000) revision also indicated that volume measurements were good carcass traits predictors in sheep. These results are in agreement with those obtained in poultry by Mitchell *et al.* (1991) and Scollan *et al.* (1998) using MRI. Studies conducted by Scollan *et al.* (1998) showed a high correlation ($r^2 = 0.99$; $n = 12$) between breast weight and volume in broiler chickens. As far as we know, there are no studies using the RTU for volume measurements in broiler chickens.

The objectives of the present study have been to evaluate the use of the volume of breast muscles (*Pectoralis major*, *Pectoralis minor*) measured by RTU to predict carcass and breast weights and yields.

MATERIALS AND METHODS

Animals and management

This experiment took place in the experimental facilities of the University of Trás-os-Montes and Alto Douro (Department of Animal Science). A total of 103 male feather-sexed broiler chicks (Ross 350) were reared together to 35 d of age. The chicks were housed in pens on deep litter in an air-conditioned closed building. The birds were fed *ad libitum* on a standard two-phase programme and had free access to water. Temperature and light were provided to simulate normal light and temperature schedules in commercial conditions.

***In vivo* RTU measurements**

Prior to ultrasound measurements, all the birds (35 d of age) were laid on their backs and restrained. The measurements sites were identified and the images were taken from living feathered birds using a 7.5 MHz linear probe (UST-5512U-7.5, Tokyo, Japan) attached to an Aloka SSD 500V real time scanner (Tokyo, Japan). Medical ultrasound gel was used as a coupling medium. The images were taken from 3 sites on the right breast muscles. The measurement sites were:

Site 1: at a fixed point in a distance of 1.5 cm from the cranial end of sternum;

Site 2: at a point in the middle of sites 1 and 3;

Site 3: at a fixed point in a distance of 1.5 cm from the caudal end of sternum.

During the RTU measurements the probe was placed perpendicular to the breast muscles.

Once a satisfactory image had been obtained at each site, it was captured on a video printer (Aloka SSZ-303E, Tokyo, Japan) for image analysis.

Slaughter and carcase measurements

After RTU measurements, all the birds were fasted for 8 h and live weight (LW) was recorded.

Birds were slaughtered by cervical dislocation, scalded, plucked and eviscerated. The carcase

weight (CW) was recorded. The right and left breast muscles (*Pectoralis major* and *Pectoralis minor*) were removed by dissection and weighed (breast weight, BrW). The carcase yield (CW/LW) and the breast yield (BrW/CW) were calculated and expressed as percentages.

The right breast muscles were used to get carcase measurements equivalent to those taken by RTU. A digital camera (Nikon Coolpix 900, Tokyo, Japan) was used to capture an image of the planes on the 3 sites of the breast, previously described, for image analysis. To take these images a scale was used. Breast volume was determined by the Archimedes principle. The right breast muscles were submerged in water and the water displaced by this action was measured.

Image analysis

The printed images taken after RTU measurements were scanned. The area and the thickness of the breast at each site were measured after image analysis of the scanned images and of the images recorded with the digital camera. Images were amplified 1.5 times for area measurements. The area was determined by image analysis using the NIH software (version 1.57, National Institute of Health, <http://rsb.info.nih.gov/nih-image/>). The area was obtained by tracing the contour of breast muscles and by counting the number of pixels that represent breast muscles on each of the 3 sites studied. The number of pixels was then converted into area measurements corresponding to the image plane of the three mentioned sites. Three slice areas were obtained: A1, A2 and A3 for site 1, site 2 and site 3, respectively.

The volume of breast after RTU measurement was calculated by multiplying the slice areas by the slice lengths. The slice lengths were obtained after physical measurement, using calipers, of the total length of the breast muscle (between its cranial and caudal end), which was then divided by three. The following equation was used for breast volume calculation:

$$Volume = \sum_{i=1}^3 A_i d_i$$

Where: d is the slice length (cm), A is the slice area (cm) and i is the number of slices.

The breast thickness was recorded as the greatest depth of the breast muscles on each of the 3 sites studied. Three slice thicknesses were obtained: T1, T2 and T3 for site 1, site 2 and site 3, respectively.

All images were analysed by the same operator, who has large experience in image analysis.

Statistical analysis

Carcase and breast weights and yields were estimated by single regression equations using carcass and RTU measurements. Multiple equations using LW and breast volume measured by RTU were developed for predicting carcass and breast weights and yields. The regression equations were evaluated by the coefficients of determination (r^2) and standard error of estimation (S_y). All analyses were performed with SAS software (Version 8.2; SAS Institute Inc. Cary, NC, USA).

RESULTS AND DISCUSSION

Mean values, range of values, standard error (SE) and coefficient of variation (CV) for LW and carcass traits of broiler chickens are presented in Table 1. The CW variation observed in Table 1 reflects the LW variation, having similar values for CV. The variation observed for the BrW was higher than the variation observed for LW and CW. As expected, the variation of carcass and breast yields was lower than those observed for CW and BrW. Expressing carcass and breast

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weights as percentage removes some of its variation. This is in accordance with results presented by other authors (Grashorn, 1994; Konig et al. 1998). Using 108 male broilers, Konig et al. (1998) showed that the variation of carcass and breast yields (CV = 8.0% and CV = 6.5%, respectively) was lower than that observed for CW (CV = 12.5%) and BrW (C = 15.7%). A similar decrease in CV was also observed by Grashorn (1994) who reported values of 9.4 and 13.9% respectively, for CW and BW and values of 2.1 and 7.8% respectively, for carcass and breast yields.

Mean values, SE and CV for carcass and RTU measurements and the correlation coefficients (*r*) between RTU and carcass measurements are summarised in Table 2. The variation observed for all measurements presented on Table 2 is large, particularly for breast volume.

Tables 1 and 2 near here

The largest breast area was measured in site 2 and the smallest was observed in the caudal position (site 3). This was observed for both carcass and RTU measurements. For breast thickness, the lowest value was also observed on site 3. These effects of measuring sites are expected and depend on the anatomy of the bird.

Differences between RTU and carcass measurements of breast area, thickness and volume were also observed, the RTU measurements being lower than the carcass measurements. Similar findings have been reported previously (Hamby *et al.*, 1986; Robinson *et al.*, 1992; Greiner *et al.*, 2003) in cattle and lambs. Difficulties with image analysis, operator effect, and differences in muscles shape due to slaughter procedure are reasons commonly accepted for the underestimation of carcass measurements by RTU. In the present study it seems reasonable to

accept that the underestimation of carcase measurements observed can be explained by differences in muscles shape due to slaughter procedures.

Correlations between carcase and RTU measurements were high ($P < 0.001$). Previous studies using equipment similar to ours (Grashorn, 1996; Melo *et al.*, 2003) have also shown the ability of RTU to predict breast thickness and area. There is no information available using RTU for volume measurements in broiler chickens. However, studies conducted with broiler chickens (Mitchell *et al.*, 1991; Scollan *et al.*, 1998) and with other animals using CT (with lamb, Jopson *et al.*, 1995) and MRI (with swine, Mitchell *et al.*, 2001) have shown high correlations ($r > 0.9$) between volume measurements and carcase traits.

Our results indicate that breast volume measurements using RTU can accurately estimate breast volume in broiler chicken carcasses ($r = 0.866$, $P < 0.01$).

Estimations of carcase and breast weights and yields by simple regressions

Simple regressions were developed to estimate carcase and breast weights and yields from carcase and RTU measurements. The r^2 and S_y obtained are shown in Table 3. Carcase and RTU measurements provided reliable data to estimate breast and carcase weights of broiler chickens in the weight range studied (r^2 varied between 0.446 and 0.952; $P < 0.01$). These results are in agreement with those obtained in previous studies with broiler chickens (Grashorn, 1996; Konig *et al.*, 1998; Melo *et al.*, 2003) showing that breast measurements taken by RTU provided good breast weight and yield estimates. Determination coefficients presented in Table 3 are higher than those reported by Grashorn (1996) and by Melo *et al.* (2003). Using broiler chickens ($n = 96$), Melo *et al.* (2003) reported determination coefficients of 0.35 and 0.36 between RTU breast

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thickness and area respectively, and BrW. These results were in agreement with those previously reported by Grashorn (1996) between RTU breast thickness and BrW ($r^2 = 0.36$; $n = 108$). Using nearly the same measurement sites as those mentioned in the present study, König *et al.* (1998) predicted BrW of broiler chickens ($n = 150$) and reported determination coefficients varying from 0.39 to 0.51 for breast area and from 0.495 to 0.646 for breast thickness, which are quite similar to values presented in Table 3.

Table 3 near here

Breast and carcass weights were well predicted by LW ($r^2 = 0.850$ and $r^2 = 0.961$ for BrW and CW, respectively) as reported by Grashorn (1996) and König *et al.* (1998) in broiler chickens. The best carcass weight estimate was the LW. However, a poor fit of the data resulted when carcass and breast yields were regressed against LW, carcass or RTU measurements (r^2 lower than 0.567). These findings were also reported by others using RTU (Grashorn, 1996; König *et al.*, 1998) and MRI (Mitchell *et al.*, 1997) in broiler chickens. Grashorn (1996) and König *et al.* (1998) using LW or RTU breast measurements (area and thickness) also found lower correlation coefficients for breast yield prediction than for breast weight prediction.

The best estimates of carcass yield, breast weight and yield were obtained using the breast volume determined either in carcass or by RTU. However, as mentioned above for LW, breast area and thickness, the r^2 values were lower for carcass and breast yields estimation (r^2 0.439 to 0.569) than for CW and BrW estimation (r^2 0.879 to 0.952).

Using MRI and image analysis with broiler chickens, Scollan *et al.* (1998) also obtained a good relationship between *Pectoralis* muscle weight and volume ($r^2 = 0.99$; $n = 12$; $P < 0.01$).

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7 188 These authors also found that *Pectoralis* muscle weight was better correlated with its volume
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9 189 than with LW.
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11 The correlations between breast volume and carcass and breast weights and yields and the
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13 accurate estimate of breast volume by RTU mentioned above emphasise the usefulness of this
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16 192 ultrasound measurement to predict carcass and breast weights and yields in broiler chickens.
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18 193 **Estimations of carcass and breast muscles weight and yield by multiple regressions**

19 Several studies with broiler chickens (Konig *et al.*, 1998; Latshaw and Bishop, 2001; Melo *et al.*,
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21 194 2003) have shown that LW combined with RTU measurements is a potential predictor of carcass
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23 195 traits, with negligible cost. Since the practical utility of RTU measurements for carcass traits
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25 196 prediction is an important goal, multiple equations were developed to estimate carcass and breast
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27 197 weights and yields from breast volume determined after RTU measurements and LW (Table 4).
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Table 4 near here

33 199 As was shown in Table 3, breast volume calculated from RTU measurements accurately
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35 200 estimated breast and carcass weights ($r^2 = 0.879$ and $r^2 = 0.952$, respectively). The LW inclusion
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37 201 (Table 4) increased by 4.5 and 3.5 percentage points the ability to explain the variation in breast
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39 202 and carcass weights, respectively. The improving ability to estimate breast and carcass yields is
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41 203 meaningful, respectively increasing 8.1 and 8.3 points, with the inclusion of LW. The LW
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43 204 contribution to explaining variation in various carcass traits was also observed in previous studies
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45 205 with broiler chickens (Konig *et al.*, 1998; Latshaw and Bishop; 2001; Melo *et al.*, 2003) as well
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47 206 as other species (cattle, Greiner *et al.*, 2003; swine, Gresham *et al.*, 1992; lambs, Silva *et al.*,
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49 207 2005). With male broiler chickens ($n = 96$), Melo *et al.* (2003) found that including LW in the
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52 208 model for estimating BrW increased r^2 and decreased the S_y , regardless of the number of
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variables included in the model. Similarly, Grashorn (1996) observed a positive effect of LW inclusion on the BrW prediction of 108 male broiler chickens. However, LW had no improving effect in breast yield estimation (Grashorn, 1996). On the contrary, our results showed that the estimation of carcass and breast yields was increased by the inclusion of LW in the models.

Breast weight is predicted well by LW. However, the breast yield (*i.e.* the percentage of breast in carcass) is not easy to predict. Using LW combined with breast volume measured by RTU explained more than 50% of the observed variation for the breast yield and 65% of the observed variation for the carcass yield.

Our results show that the estimation of carcass and breast weights using RTU volume does not indicate any gain in accuracy compared with area measurements (A1, A2 or A3). However, regressions using breast volume alone or combined with LW clearly improve the ability to estimate carcass and breast yields compared with area measurements.

From a practical point of view the RTU scanning of one bird at the 3 sites examined in this study takes about one minute, and is quicker than the time taken for CT (10-15 minutes for three birds; Andrassy-Baka *et al.*, 2003) or MRI (15 minutes, for both left and right *Pectoralis* muscle; Scollan *et al.*, 1998). König *et al.* (1998) reported an average rate of 76 birds per h for RTU scanning at 3 sites similar to those used in our study. Furthermore, RTU is harmless for the chicken and requires only manual restraint. Using RTU scanning for breast muscle volume determination significantly reduces the costs of *in vivo* studies, without a decrease in robustness in predicting carcass and breast yields, when compared with the techniques mentioned above. Besides, RTU itself is quite simple to perform. The major disadvantage is the laborious manual procedure employed to trace the muscle from RTU images to the image analysis program.

Presently, CT and MRI techniques provide superior quality images and an excellent soft tissue contrast. However, for volume determination the use of image analysis and manual tracing is necessary and still the most appropriate approach for isolating a specific muscle in an image (Scollan *et al.*, 1998). It is necessary to find new automated image analysis systems in order to determine breast volume easily using RTU.

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Table 1. Mean values, range of values, standard error (SE) and coefficient of variation (CV %) for live weight, carcass and breast weights and yields of broiler chickens ($n = 103$)

	Mean	Range	SE	CV
Live weight (g)	1478	973 - 1951	20.5	14.1
Carcass weight (g)	1031	662 - 1391	16.1	15.8
Breast weight (g)	206	107 - 308	4.4	21.8
Carcass yield (%)	69.6	61.4 – 75.5	2.0	3.4
Breast yield (%)	19.9	14.3 – 24.6	0.19	9.6

Table 2. Mean values, SE and CV (%) for RTU and carcase measurements of broiler chickens ($n = 103$) and the correlation coefficients (r) between RTU and carcase measurements

	Carcase measurements			RTU measurements			<i>r</i>
	Mean	SE	CV	Mean	SE	CV	
Area (mm ²)							
A1	561.3	9.90	17.9	506.9	9.00	18.0	0.902**
A2	586.5	10.40	18.0	533.8	9.47	18.0	0.677**
A3	432.3	8.65	20.3	398.,4	8.01	20.4	0.687**
Thickness (mm)							
T1	24.9	0.387	15.8	17.1	0.336	20.0	0.770**
T2	21.1	0.408	19.6	20.4	0.365	18.2	0.773**
T3	15.7	0.369	23.8	15.6	0.321	20.9	0.838**
Volume (cm ³)	97.9	3.4	35.1	86.1	2.0	23.2	0.866**

** $P < 0.01$.

Table 3. Coefficients of determination (r^2) and standard error of estimation (S_y) of the regression equations for the estimation of breast and carcase weights and yields in broiler chickens ($n = 103$)

	Breast weight (g)		Carcase weight (g)		Breast yield (%)		Carcase yield (%)	
	r^2	S_y	r^2	S_y	r^2	S_y	r^2	S_y
Live weight (g)	0.850**	8.73	0.961**	32.3	0.262**	1.65	0.166 ^{ns}	0.02
Carcase measurements								
Area (mm ²)								
A1	0.571**	29.6	0.695**	90.4	0.126 ^{ns}	1.79	0.238*	2.12
A2	0.563**	29.8	0.675**	93.3	0.117 ^{ns}	1.80	0.213*	2.13
A3	0.531**	31.0	0.623**	100.5	0.141 ^{ns}	1.78	0.186 ^{ns}	2.14
Thickness (mm)								
T1	0.678**	25.6	0.884**	55.9	0.597**	1.22	0.294**	2.02
T2	0.738**	23.2	0.791**	74.4	0.196 ^{ns}	1.72	0.242*	2.11
T3	0.789**	20.8	0.852**	62.9	0.203*	1.71	0.308**	2.02
Volume (cm ³)	0.882**	16.4	0.892**	55.3	0.549**	1.22	0.546**	1.64
RTU measurements								
Area (mm ²)								
A1	0.578**	29.4	0.694**	90.6	0.137 ^{ns}	1.78	0.256**	2.02
A2	0.617**	28.0	0.683**	92.1	0.188 ^{ns}	1.73	0.259**	2.02
A3;	0.446**	33.6	0.584**	105.6	0.063 ^{ns}	1.86	0.174 ^{ns}	2.13
Thickness (mm)								
T1	0.699**	24.8	0.870**	59.1	0.255**	1.66	0.292**	2.04
T2	0.623**	27.8	0.772**	78.1	0.222*	1.69	0.264**	2.05
T3	0.742**	23.0	0.710**	88.2	0.188 ^{ns}	1.73	0.321**	1.92
Volume (cm ³)	0.879**	8.7	0.952**	48.7	0.439**	1.37	0.567**	1.44

** $P < 0.01$; * $P < 0.05$; ns $P > 0.05$.

Table 4. Multiple regression equations for estimation of carcase and breast weights and yields in broiler chickens (*n* = 103)

Equation	r^2	S_y
Breast weight (g) = 0.164 X_1 + 0.386 X_2 - 69.66	0.924**	17.31
Carcase weight (g) = 0.543 X_1 + 2.503 X_2 + 11.88	0.987**	26.38
Breast yield (%) = 0.007 X_1 - 0.024 X_2 + 11.87	0.520**	1.65
Carcase yield (%) = -0.009609 X_1 + 0.2 X_2 + 70.1	0.650**	1.80

X_1 is LW (g); X_2 is breast volume measured by RTU (cm³).

** *P* < 0.01.