In vivo measurement of body composition of chickens using quantitative magnetic resonance[1]

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ABSTRACT Quantitative magnetic resonance (QMR) is a nuclear magnetic resonance-based method for measuring the fat, lean, and water content of the total body of the live animal. The purpose of this study was to evaluate the use of QMR for measuring the body composition of chickens while comparing QMR results to those obtained by dual x-ray absorptiometry (DXA) and chemical analysis (CA). A total of 191 birds were scanned live (nonanesthetized) by QMR, killed, and then scanned by DXA. The birds were Ross 708 broiler chickens and ranged in weight from 786 to 3,130 g. In addition, 48 of the carcasses were chemically analyzed for total body lipid, water, and ash content. Compared with CA, QMR underestimated the percentage of total body fat by 34% whereas DXA overestimated the percentage of fat by 50% (10.35 ± 3.35 by CA vs. 6.73 ± 3.90 by QMR and 15.55 ± 4.01 by DXA; $P < 0.05$). Both QMR and DXA measurements of percentage total body fat were highly correlated with the CA measurement ($R^2 = 0.94$ and 0.68, respectively). Both QMR and DXA estimates of total body water were close to the CA measurement (1,166 ± 277 g by CA vs. 1,214 ± 279 g by QMR and 1,217 ± 255 g by DXA; $P > 0.05$), with R^2 values of 0.90 and 0.91, respectively. Based on regression analysis, when prediction equations were applied to the entire group of birds, the QMR and DXA measurements of total body water and total body lean mass were in good agreement, with no significant difference (1,125 ± 244 g vs. 1,135 ± 246 g and 1,377 ± 311 g vs. 1,403 ± 309 g, respectively; $P > 0.05$) and highly correlated ($R^2 = 0.97$ for both). Likewise, the QMR measurement of total body fat agreed closely with that measured by DXA (164 ± 48 g and 167 ± 47 g, respectively) and was highly correlated ($R^2 = 0.72$). The results of this study demonstrate that with proper calibration, both QMR and DXA can provide accurate measurements of the body composition of chickens. The major advantage of the QMR method is that no anesthesia is required, thus facilitating the ease of measurement and repeated measurements.

Key words: chicken, body composition, quantitative magnetic resonance, dual energy x-ray absorptiometry

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INTRODUCTION

During studies of the growth of broiler chickens it is important to be able to accurately assess changes in body composition (Dänicke et al., 1997). Body composition analysis results can be used to monitor and evaluate growth patterns, genetic improvement, dietary treatments, progression of chronic disease, and efficacy of medical interventions.

A variety of techniques have been evaluated for the in vivo body composition measurement of chickens. Ultrasound, although commonly used throughout the livestock industry for measuring body composition, has been used relatively little for body composition measurement in the poultry industry (Farhat and Chavez, 2001; Gaya et al., 2006; Oviedo-Rondón et al., 2007). Total body electrical conductivity (**TOBEC**) has been evaluated for the measurement of body composition of chickens (Roby, 1991; Staudinger et al., 1995); however, its accuracy for measuring fat content remains questionable (Dänicke et al., 1997). Magnetic resonance imaging (**MRI**) and magnetic resonance spectroscopy (**MRS**) techniques have been tested with poultry (Mitchell et al., 1991; Lirette et al., 1993; Kövér et al., 1998) and although either MRI or MRS can provide valid and useful information, both applications are of limited use. Likewise, computerized tomography provides useful imaging measurements (Bentsen and Sehested, 1989; Szakáll et al., 1998) but has thus far proved to be of limited use. The instruments needed for MRI, MRS, and computerized tomography are very expensive, measurement of live animals requires anesthesia,

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and both the measurement and analysis are time consuming. Dual energy x-ray absorptiometry (**DXA**) has been tested for measuring body composition in chickens (Mitchell et al., 1997; Swennen et al., 2004) and has been used to a small extent for that purpose (Jensen et al., 2005; Rosebrough and Mitchell, 2007). The DXA has been used mainly to measure bone density in chickens in both genetic (Kim et al., 2004; Zhou et al., 2005) and dietary (Angel et al., 2006; Shahnazari et al., 2007) studies.

Quantitative magnetic resonance (**QMR**) is a new method used to measure total body fat, lean tissue mass, free water mass, and total body water (Taicher et al., 2003). Success in using QMR in small animals of different sizes (flies, mice, rats, birds, dogs, and pigs) has been reported (Tinsley et al., 2004). Quantitative magnetic resonance is a very precise, accurate, fast, and easy-to-use method for determining fat and lean mass of mice, rats, and humans without the need for sedation or anesthesia (Napolitano et al., 2008). The ability of QMR to detect longitudinal differences and precisely monitor changes in body composition is most valuable (Mitchell et al., 2010).

The QMR method is a branch of nuclear magnetic resonance used for whole-body measurement of fat, lean tissues, free water (not bound in various tissues), and total body water (water contained in all the liquids and in tissues) of live animals, including humans. The QMR method differs from MRI in that the processed signal is obtained from the entire body at once (without spatial encoding) and it differs from MRS in that the time domain signal (rather than spectrum) is processed directly. Quantitative magnetic resonance devices stand out in that they are fast and very easy to use, require no sedation or anesthesia, are free of radiation, and are capable of unsurpassed precision and high accuracy. Typical scan times range from less than 1 min to less than 4 min in different specific devices and applications, and less than 30 min of training is sufficient for a typical user. Background information regarding the QMR approach to body composition analysis has been described previously (Taicher et al., 2003; Tinsley et al., 2004; Kovner et al., 2010). The purpose of this study was to use QMR to measure changes in the body composition of chickens ranging in weight from 786 to 3,130 g and to compare the QMR results with those obtained by DXA and chemical analysis (**CA**).

MATERIALS AND METHODS

Subjects

The birds used in this study were Ross 708 broiler chickens and ranged in weight from 786 to 3,130 g. A total of 191 birds were scanned by QMR and then scanned by DXA. A description of the birds and dietary treatments used in this study is given in Table 1. In addition, 48 of the carcasses (16 from each of groups 1, 2, and 5; see Table 1) were chemically analyzed for total body lipid, water, and ash content. Within those groups, the birds for carcass analysis were evenly distributed among age and dietary treatments but were otherwise selected randomly. The CA was chosen as a reference method for calibrating both instruments. The number used for CA was based on a similar number (50) used in a calibration–validation study of the same instrument with piglets (Kovner et al., 2010). Experimental animal protocols used in this study were approved by the Beltsville Area Institutional Animal Care and Use Committee.

Diets

From 1 to 7 d of age all birds were fed a standard (21% CP) starter diet. Starting at 7 d of age a variety of diets (12 to 30% CP; see Table 1) were fed to achieve differences in growth rate and body composition. Except for protein levels, all diets were formulated to meet or exceed NRC (1994) requirements. Composition of the basal diet is described by Rosebrough et al. (2011).

Body Composition Analysis Methods

All birds were scanned live by QMR (nonanesthetized), killed by pentobarbital injection (390 mg, intraperitoneally administered while restrained by hand), and then scanned by DXA. The bodies were individually identified by taped leg bands, placed in plastic bags, and then frozen and stored at −20°C until processed for CA.

The QMR device (EchoMRI-Infants, Echo Medical Systems, Houston, TX) based on a permanent magnet with constant field of approximately 0.021 T (Larmor frequency of approximately 880 kHz) was designed for live subjects in a mass ranging from 1 to 4 kg. The bird

Table 1. Description of the birds and dietary treatments used in this study

Group	Birds, n	Diet[1]	Age, d	Average weight, g	Weight range, g
1	48	A	37, 42, 48, 52	1,730	866–3,130
2	32	B	48	1,768	1,436–2,230
3	31	B	34	1,598	1,090–1,914
4	32	C	34	1,664	1,246–2,086
5	48	D	34	1,491	786–1,968

[1]A: 21% CP (hatch to 6 d), 15 or 18% CP (7 d to kill). B: 21% CP (hatch to 6 d), 30% CP (7 to 21 d), 18% CP (22 to 34 or 48 d). C: 21% CP (hatch to 21 d), 18% CP (22 to 34 d). D: 21% CP (hatch to 6 d); 12 or 30% CP (7 to 21 d or 22 to 34 d; see Table 4; Rosebrough et al., 2010).

was placed in a dark cloth sleeve inside a 20-cm diameter cylindrical holder, which was then inserted into the QMR instrument. The positioning was centered to ensure that the subject was within the homogeneity of the magnetic field of the instrument. The device was provisionally calibrated on traditional phantoms representing fat, lean, and free water, namely canola oil, pork loins with a known fat content (measured on smaller samples in a different but previously validated EchoMRI device), and tap water, respectively. Prior to this study, a final calibration was performed using piglets (live, anesthetized, and dead) and is described elsewhere (Kovner et al., 2010). The quantities measured by QMR are fat, lean, free water, and total water.

The DXA device (Lunar Prodigy, GE Lunar, GE Healthcare, Waukesha, WI) was tested as supplied by the manufacturer. Details of chicken measurement by DXA are described elsewhere (Mitchell et al., 1997). Scans were performed and analyzed using the small animal mode (version 8.10). The quantities measured by DXA are fat, fat free mass, and bone mineral content.

Carcass Preparation. Because feathers are not detected by either QMR or DXA and would interfere with the homogenization, the feathers were removed before the carcasses were processed. Otherwise, the carcasses remained intact (including head, feet, and internal organs plus contents). The carcasses were allowed to partially thaw (1 h at room temperature) and then the feathers were removed by hand. The defeathered carcasses were autoclaved for 1 h at 121°C, cooled to 3°C, and then homogenized for 1 min (30 s on low followed by 30 s on high) using a food processor (Robot Coupe, model R10; Robot Coupe USA Inc., Jackson, MS). Samples were stored at −20°C before analysis.

Water Analysis. A single sample from each bird was weighed (sample size was approximately 400 g), frozen, and then lyophilized in a freeze dryer (model 100 SRC-6, Virtis, Gardiner, NY) for 14 d. The samples were weighed again immediately after removing from the freeze dryer and the difference between the 2 weights was assumed to be attributed to water loss.

Lipid Analysis. Quadruplicate samples (3–5 g) of the wet homogenate were extracted for lipid analysis by the method of chloroform–methanol extraction (Folch et al., 1957). Each sample was extracted for 24 h in a 125-mL separatory funnel containing 60 mL of chloroform:methanol (2:1, vol/vol). After 24 h, 12 mL of 0.88% potassium chloride in water was added and then mixed by shaking for 10 s. The sample was allowed to set for another 24 h to permit phase separation. The lower phase was then drained into preweighed vials and the solvent was evaporated off at 70°C under a stream of nitrogen in a sample concentrator (Sybron SC248 Sample Concentrator, Brinkmann Instruments Canada Ltd., Mississauga, Ontario, Canada). The vials were allowed to cool and then were reweighed to determine the amount of lipid extracted.

Ash Analysis. Triplicate aliquots (approximately 2 g each) of the freeze-dried sample were weighed into tare weighed vials then placed into a muffle furnace. The samples were allowed to combust for 10 h at 520°C. The cooled vial was reweighed to determine ash content. Chemical lean was calculated as BW (feathers removed) minus the weight of chemical fat and ash: chemical lean = BW − (CA fat + CA ash).

Statistical Analysis

Statistical analysis was performed using Statgraphics Plus 5.1 (Statistical Graphics Corp., Warrenton, VA). Regression coefficients and prediction equations were generated by linear regression analysis. Differences in the mean values for body composition components, as measured by different techniques (QMR, DXA, and CA) or as a result of differences in age or dietary treatment, were evaluated by the GLM procedure of Statgraphics Plus 5.1 followed by a multiple range test that uses the Fisher's least significant difference procedure to discriminate among the means at the 5% level.

RESULTS

The results comparing the QMR and DXA measurements with CA are shown in Table 2. Compared with CA, QMR underestimated the percentage of total body fat by 34% whereas DXA overestimated the percentage of fat by 50%. Both QMR and DXA measurements of percentage total body fat were highly correlated with the CA measurement ($R^2 = 0.94$ and 0.68, respectively). Both QMR and DXA estimates of total body water were close to the CA measurement (both being approximately 4% larger), with $R^2 \geq 0.90$.

Using the results of the linear regression analysis comparing QMR and DXA measurements with CA, prediction equations were developed for the fat, lean, and water measurements of chickens for both instruments. The equations for prediction of total body lipid were

$$\text{total body lipid (g)} = 72.57 + 0.908 \times \text{QMR fat (g)}$$
$$(R^2 = 0.91;\ \text{SEE} = 26.2\ \text{g}) \text{ and}$$

$$\text{total body lipid (g)} = 18.74 + 0.607 \times \text{DXA fat (g)}$$
$$(R^2 = 0.73;\ \text{SEE} = 29.9\ \text{g}),$$

where SEE is SE of the estimate. The equations for prediction of total body water were

$$H_2O\ \text{(g)} = 24.67 + 0.940 \times \text{QMR } H_2O\ \text{(g)}$$
$$(R^2 = 0.90;\ \text{SEE} = 89.2\ \text{g}), \text{ and}$$

$$H_2O\ \text{(g)} = 7.31 + 0.850 \times \text{DXA lean (g)}$$
$$(R^2 = 0.91;\ \text{SEE} = 83.9\ \text{g}).$$

The equations for prediction of total body lean mass were

Table 2. Quantitative magnetic resonance (QMR) and dual x-ray absorptiometry (DXA) measurements of the body composition of broiler birds[1] compared with chemical analysis (CA) of the same birds

Item	Chemical[2]	QMR	R^2 (QMR vs. CA)	DXA	R^2 (DXA vs. CA)	SEM
Fat, g	169[b]	107[a]	0.79	249[c]	0.73	5.4
Fat, %	10.4[b]	6.7[a]	0.94	15.5[c]	0.68	0.31
Water, g	1,166[a]	1,214[a]	0.90	1,218[a]	0.91	22.6
Lean, g	1,508[a]	1,492[a]	0.89	1,362[a]	0.91	28.3
Ash/BMC,[3] g	51.2[b]	NA	NA	29.7[a]	0.70	1.4

[a–c]Means within a row followed by different superscripts are significantly different ($P < 0.05$).

[1]Sixteen birds from each of groups 1, 2, and 5 (see Table 1); n = 48.

[2]Chemical lean = BW − (CA fat + CA ash).

[3]BMC = bone mineral content.

$$\text{lean (g)} = 40.1 + 1.191 \times \text{QMR } H_2O \text{ (g)}$$
$$(R^2 = 0.90; \text{SEE} = 113.8 \text{ g}), \text{ and}$$

$$\text{lean (g)} = \text{DXA soft tissue (g)} - \text{DXA fat (g)}$$
$$(R^2 = 0.91; \text{SEE} = 107.3).$$

Figure 1 compares the initial fat measurements for both QMR and DXA with the predicted results (using the prediction equation shown above for total body lipid) and the results that would be expected from CA (the line of identity). Although the slopes for the regression lines for the QMR and DXA predicted values were similar, both were less than that of line of identity (0.79 and 0.73, respectively).

When prediction equations were applied to the entire group of birds (Table 3), the QMR and DXA measurements of total body water and total body lean mass were in good agreement and highly correlated, with no significant difference. Likewise, the QMR measurement of total body fat agreed closely with that measured by DXA and was highly correlated. Both QMR and DXA measurements revealed a low correlation between BW and fat content (Figure 2) but a high correlation between BW and lean mass (Figure 3). In agreement, using the CA of 48 birds, the correlation (R^2) between BW and chemical fat was 0.19 and between BW and chemical water or lean was 0.97.

A subset of 48 birds (group 5; see Table 1) included in this study was fed various combinations of high (30%

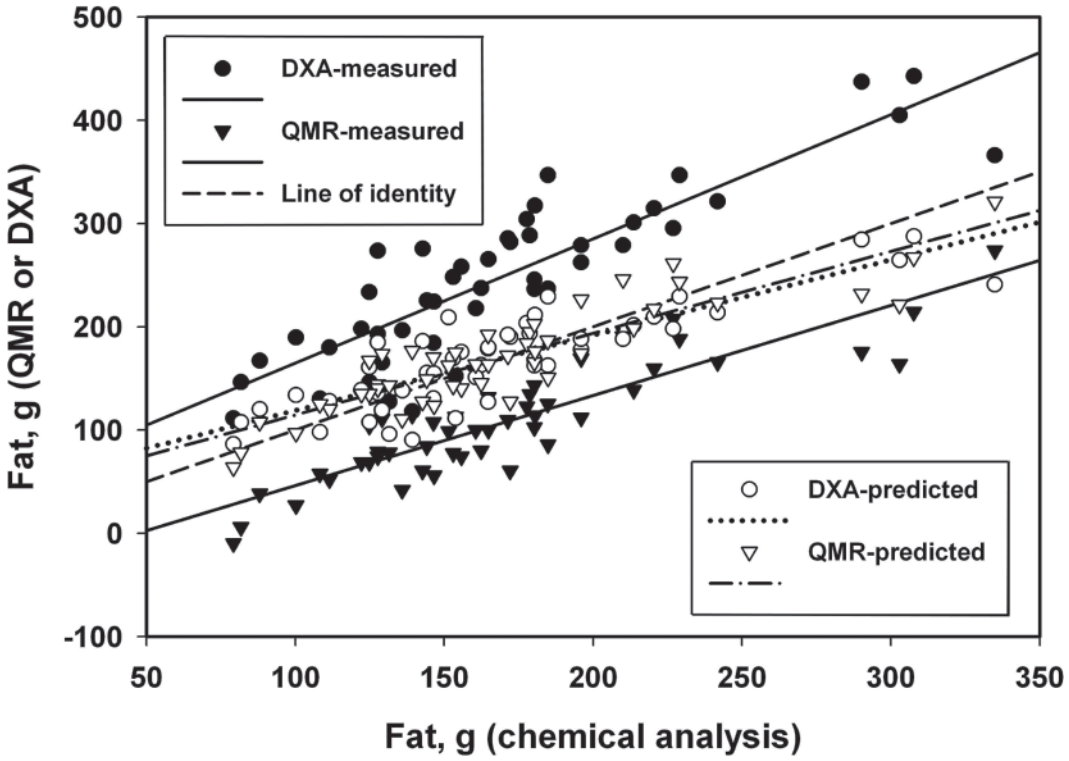

Figure 1. Relationship between quantitative magnetic resonance (QMR) and dual x-ray absorptiometry (DXA) measurements of total body fat and the amount measured by chemical analysis (16 from each of groups 1, 2, and 5 of Table 1; n = 48). Both QMR and DXA values are shown as measured and as predicted based on linear regression analysis [for QMR, total body lipid (g) = 72.57 + 0.908 × QMR fat (g); for DXA, total body lipid (g) = 18.74 + 0.607 × DXA fat (g)].

Table 3. A comparison of quantitative magnetic resonance (QMR) and dual x-ray absorptiometry (DXA) measurements of the body composition of broiler birds (n = 191) following calibration of both instruments based on chemical analysis of a subset of 48 birds[1,2]

Component	QMR	DXA	R^2	SEM
Fat, g	164 (75–375)	167 (71–332)	0.72	2.4
Fat, %	10.2 (4.2–19.3)	10.2 (4.9–16.7)	0.63	0.13
Lean, g	1,376 (585–2,513)	1,403 (637–2,620)	0.97	15.9
Water, g	1,125 (504–2,015)	1,135 (513–2,079)	0.97	12.5

[1]Subset of 48 birds described in Table 2.

[2]Range given in parentheses.

CP) and low (12% CP) protein diets between 7 and 34 d of age. The results of QMR and DXA measurements of body composition of these birds are shown in Table 4. In general good agreement was found between the QMR and DXA results, the exception being the fat measurements for the birds that were on the low protein diet throughout the experimental feeding period (12–12 group), in which case the QMR fat measurements of the percentage and amount of total body fat were significantly higher ($P < 0.05$) than the DXA measurements.

Another subset of 48 birds (group 1; see Table 1) was measured at different ages, thus representing different body sizes as well as composition; these results are shown in Table 5. Although the QMR fat measurements tended to be higher than the DXA fat measurements in the younger (lighter weight) birds, the only significant difference was for the percentage of fat in 48-d-old birds. Good agreement was found between the QMR and DXA measurements of both total body lean and water at all ages.

DISCUSSION

The growth composition of the broiler chicken is of interest mainly because of potential effect on the efficiency of growth and quality of the final product. Most studies have relied on the comparative slaughter technique based on CA of the carcass to measure composition (fat and lean) of the chicken; thus, the effect of early observations on subsequent composition can only be inferred because it assumed that the slaughter group is representative of the whole. It is difficult to accurately measure body composition of the live chicken. Whereas many methods have been developed for measuring body composition, most have serious deficiencies for use in longitudinal studies. Several criteria (e.g., cost, speed, ease of use, noninvasiveness) must be considered

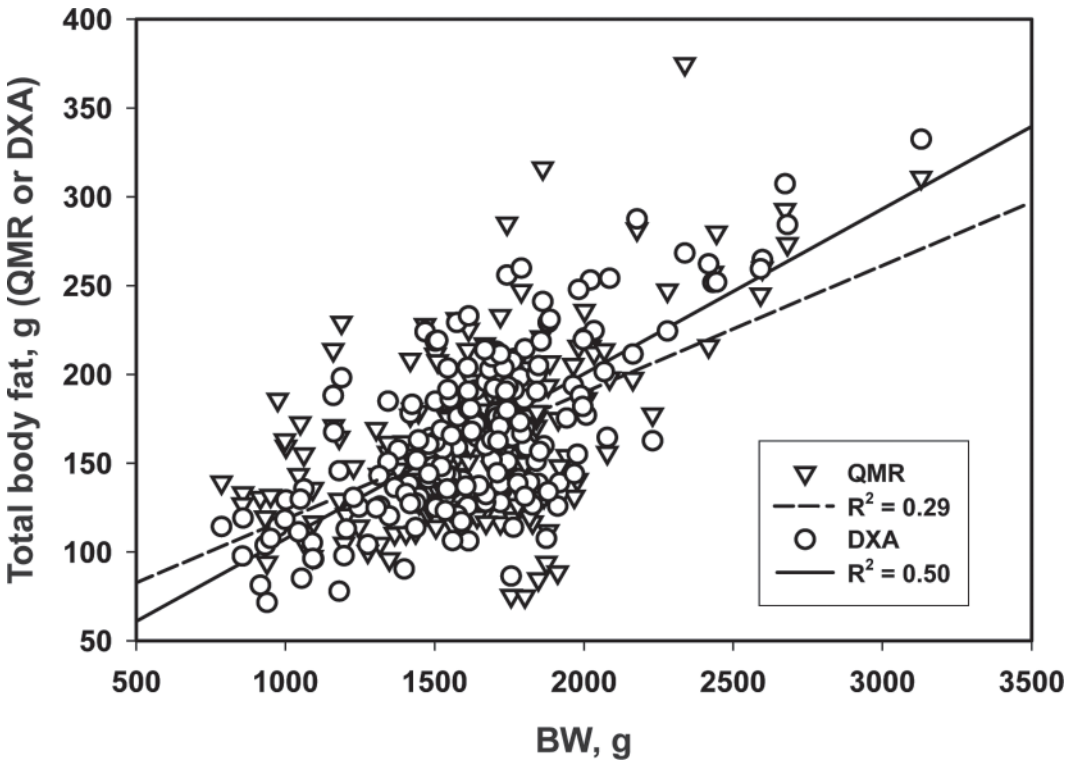

Figure 2. Relationship between quantitative magnetic resonance (QMR) and dual x-ray absorptiometry (DXA) measurements of total body fat and BW of the birds (n = 191).

Table 4. Comparison of quantitative magnetic resonance (QMR) and dual x-ray absorptiometry (DXA) measurements (following calibration) of the body composition of broiler birds on different dietary treatments[1]

	12–12		30–30		12–30		30–12		
Measurement	QMR	DXA	QMR	DXA	QMR	DXA	QMR	DXA	SEM
Weight, g	1,022	1,022	1,847	1,847	1,558	1,558	1,539	1,539	
Fat, g	162^{c}	134^{b}	109^{ab}	130^{a}	135^{b}	145^{bc}	211^{d}	210^{d}	3.0
Fat, %	15.8^{d}	13.0^{c}	5.9^{a}	7.0^{a}	8.6^{b}	9.4^{b}	13.7^{c}	13.6^{c}	0.16
Lean, g	792^{a}	846^{a}	1,618^{d}	1,644^{d}	1,319^{c}	1,340^{c}	1,212^{b}	1,263^{bc}	10.0
H_2O, g	666^{a}	678^{a}	1,314^{d}	1,360^{d}	1,079^{c}	1,092^{c}	995^{b}	992^{b}	7.8

$^{a–d}$Means within a row followed by different superscripts are significantly different ($P < 0.05$).

[1]Group 5 of Table 1 (n = 12 birds/treatment). Dietary treatments: 21% CP (hatch to 6 d) and 12 or 30% CP (7 to 21 d–22 to 34 d).

when selecting the most suitable method for measuring the body composition of a particular group of subjects. In all cases, accuracy and precision are very important.

Others have attempted to measure the body composition of chickens based on the proton nuclear magnetic resonance properties of the soft tissues (Mitchell et al., 1991; Lirette et al., 1993; Kövér et al., 1998). These earlier approaches consisted of either MRI or MRS. Although either MRI or MRS can provide valid and useful information, both applications are of limited use because much time is required to acquire and process the data, the birds have to remain essentially motionless (anesthetized) during the measurement, and the cost of the equipment can be prohibitive. Previous results indicate that with calibration based on CA of the same species and an appropriate model, QMR can provide accurate measurements of the water and lipid content of piglets in the range of 2 to 4 kg of BW (Andres et al., 2010; Kovner et al., 2010). The output of the QMR instrument used in this study can be adjusted by incorporating the calibration data directly into the algorithms of the instrument.

The use of TOBEC to measure the body composition of chickens has been of interest because it too offers a quick and easy measurement that does not require the bird to be anesthetized. In a manner similar to QMR, the bird is placed with minimal restraint into a chamber and the measurement time is similar. In part, because of the close relationship between lean mass and BW (Figure 3), TOBEC can accurately predict the lean mass of chickens (Staudinger et al., 1995; Dänicke et al., 1997, 2001). However, as demonstrated previously with DXA (Mitchell et al., 1997) and TOBEC (Dänicke et al., 1997), and here with both DXA and QMR, a low

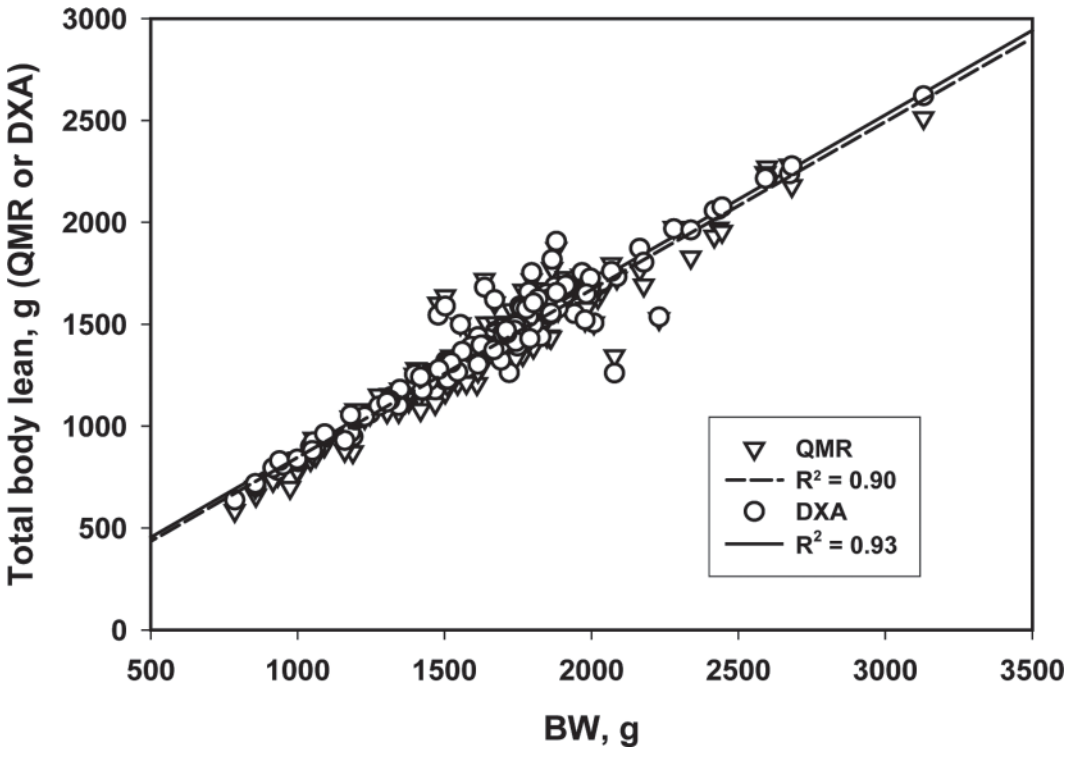

Figure 3. Relationship between quantitative magnetic resonance (QMR) and dual x-ray absorptiometry (DXA) measurements of total body lean and BW of the birds (n = 191).

Table 5. Comparison of quantitative magnetic resonance (QMR) and dual x-ray absorptiometry (DXA) measurements (following calibration) of the body composition of broiler birds at different ages (37, 42, 48, and 52 d)[1]

	37 d		42 d		48 d		52 d		
Measurement	QMR	DXA	QMR	DXA	QMR	DXA	QMR	DXA	SEM
Weight, g	1,230	1,230	1,554	1,554	2,010	2,010	2,166	2,166	
Fat, g	140^{ab}	125^{a}	174^{bc}	169^{abc}	234^{d}	202^{cd}	229^{d}	230^{d}	5.8
Fat, %	11.6^{b}	10.2^{ab}	11.2^{ab}	10.7^{ab}	11.7^{b}	9.8^{a}	10.8^{ab}	10.5^{ab}	0.2
Lean, g	1,069^{a}	1,054^{a}	1,304^{a}	1,313^{a}	1,715^{b}	1,718^{b}	1,742^{b}	1,838^{b}	37.8
H_2O, g	884^{a}	862^{a}	1,068^{a}	1,062^{a}	1,390^{b}	1,384^{b}	1,411^{b}	1,471^{b}	29.3

$^{a–d}$Means within a row followed by different superscripts are significantly different ($P < 0.05$).

[1]Group 1 of Table 1 (n = 12 birds/age group).

correlation often exists between BW and fat content, especially when different diets or breeds of chickens are included in the study. Consequently there exists a low correlation between lean mass and fat mass. Total body electrical conductivity provides only a measure of lean mass. The empirical character of the derived calibration curves may result in an inaccurate prediction of fat free mass and, to a greater extent, total body fat (Dänicke et al., 1997). Consequently, the TOBEC measurement is only conditionally useful for assessment of body chemical composition in live broiler chickens.

Because DXA is a widely used method for body composition measurement in both humans and animals, we chose to directly compare the QMR measurements of live chickens with ex vivo DXA measurements of the same birds. Validation studies have shown that DXA can be used to measure the body composition of chickens; however, calibration is needed, results can depend on the scan mode used, and anesthetization of live birds is difficult (Mitchell et al., 1997; Swennen et al., 2004). Because the output of the DXA cannot be modified, the data can be corrected only by the application of prediction equations. A calibration and validation study with piglets showed that regardless of whether the pigs were scanned awake, anesthetized, or dead by QMR or anesthetized or dead by DXA, little if any (comparable to the magnitude of random errors) effect was found on the precision or accuracy of the measurements of total body fat, lean, and water (Kovner et al., 2010).

When compared with CA (Table 2), QMR underestimated fat content whereas DXA overestimated the fat content. The CA was performed on the whole body (including viscera and contents), with only the feathers removed. Because the feathers do not contribute to either the QMR or DXA measurements of fat, water, or lean mass, the CA should have represented the same as measured by QMR and DXA. In an earlier study the same 2 instruments were evaluated for measuring the body composition of neonatal piglets weighing between 1,720 and 4,070 g (Kovner et al., 2010). In the piglet study substantial systematic errors were found in the provisionally calibrated DXA results for fat and QMR results for fat and total water relative to the results of CA. The results of that study indicated that with calibration based on CA of piglets of the same weight range, both DXA and QMR can provide similarly good accuracy and precision in measurements of fat and total water content of piglets in the range of 2,000 to 4,000 g of BW. As it appears from the validation with piglets, the precision is 2 to 4 times better in the case of QMR and the accuracy is 1.1 to 1.3 times better in the case of DXA. The results shown in Table 2 were obtained with DXA using the manufacturer's settings (provisional calibration); however, the QMR results were based on the calibration results obtained in the pig study. Thus, it appears that the calibration of the QMR based on pig measurements is not appropriate for chickens. This could be attributed to one or more physiological differences, such as body conformation, biological age (maturity), BW, fat distribution, or body temperature. It is known that temperature can affect QMR results (Dympna et al., 2010). The normal body temperature of pigs ranges from 36.8 to 40.4°C, with a mean of 38.7°C, whereas, the normal temperature of the adult chicken is between 40.6 and 41.7°C, with a mean of about 41°C.

Because both QMR and DXA fat measurements were highly correlated with chemical measurements, prediction equations based on linear regression analysis (using the prediction equation shown above for total body lipid) were applied as shown in Figure 1. When these prediction equations were applied to the entire group of birds the result was excellent agreement between QMR and DXA for the measurement of total body fat, lean, and water. Likewise, when subsets were examined that consisted of birds fed different levels of dietary protein or measured at different ages, good agreement was found between the QMR and DXA measurements. These subsets provided direct comparisons of QMR and DXA for measuring birds at different age, weight, and body composition (fat percentage). These results are in good agreement with previous studies where QMR and DXA were compared for measuring the body composition of pigs (Andres et al., 2010; Kovner et al., 2010).

In conclusion, QMR is a quick and convenient method for measuring body composition of broiler chickens. Without the use of anesthesia, the birds can be measured as frequently as needed without affecting growth. After both were calibrated against CA, good agreement was found between QMR and DXA for measuring fat, lean, and water content.

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