Development and Evaluation of a Regression Equation of Prediction for Fat-Free Soft Tissue in Heterogenous Populations of Cattle[1]

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ABSTRACT: Regression equations to predict kilograms of fat-free soft tissue (the sum of water and protein from chemical analyses) were developed from data collected on 526 steers and heifers. Straightbred animals representing Angus, Braunvieh, Charolais, Gelbvieh, Hereford, Limousin, Pinzgauer, Red Poll, and Simmental breeds of cattle contributed to the data set. Cattle ranged in slaughter weight and age from approximately 350 to 575 kg and from 13 to 23 mo, respectively. Diets (100% ground alfalfa, 67% ground alfalfa and 33% ground corn, or 33% ground alfalfa and 67% ground corn) were cross-classified with breed and sex. Estimative traits included in the equation were warm carcass weight, fat depth at the 12th rib, and body impedance. Carcass soft-tissue samples were taken for determination of chemical constituents. The prediction equation accounted for 94% of the variation in fat-free soft tissue of the carcass. Adjusting for breed-sex-diet contemporary groups increased the R^2 value by 2% units. The prediction model was evaluated using data collected on 65 steers sired by Charolais or Hereford bulls at the Ft. Keogh Livestock and Range Research Laboratory (Miles City, MT). Postweaning feeding strategies and slaughter ages varied among these animals. Carcass weight, back fat depth, and resistive impedance measures were recorded. Carcass soft-tissue samples were taken for determination of chemical constituents. Values of estimator variables recorded at Ft. Keogh were used in the regression equation to predict fat-free soft tissue for each animal. The values for kilogram of fat-free soft tissue determined from chemical analysis were regressed on predicted fat-free soft tissue. The results indicate that fat-free soft tissue of carcasses can be accurately predicted using estimative traits that do not diminish carcass value.

Key Words: Carcass Composition, Beef, Estimation, Impedance

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Introduction

Research to evaluate genetic, nutritional, or pharmacological effects on carcass composition requires determination of carcass constituents. Measurement protocols used in research include prediction equations developed from the part-whole relationships between chemical measures of individual or multiple carcass components and the total carcass, mass or linear carcass measurements, and fabrication of the total carcass and subsequent determination of chemical composition (Kempster et al., 1982). These authors observed that the least precise predictions of carcass composition were based on carcass dimensions and the most precise predictions were derived from sample joints, with the relative precision increasing as the number of joints sampled approached the entire carcass. But with increasing precision, cost of measurement increases, both in terms of labor expenditure and loss in product value. Recent efforts have focused on less-invasive means to determine carcass constituents. Technologies including ultrasound (Leymaster et al., 1985), magnetic resonance (Mitchell et al., 1991), and resistive impedance (Jenkins et al., 1988) have been evaluated. All three methods are noninvasive and are effective predictors of carcass constituents and thus reduce the loss in product value associated with the more traditional approaches. Resistive impedance may provide the least costly method to obtain an accurate measurement of carcass composition.

Our objective was to develop a regression equation to predict fat-free soft tissue using noninvasive measures (warm carcass weight, fat depth, and resistive impedance) and to evaluate the prediction model with an independently collected data set.

[1]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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Table 1. Number of observations by breed-sex-diet groups[a]

	Steers			Heifers		
Breed	Diet 10	Diet 20	Diet 30	Diet 10	Diet 20	Diet 30
Angus	10	9	10	9	9	10
Braunvieh	11	10	9	8	10	7
Charolais	11	10	12	8	7	9
Gelbvieh	9	13	10	6	8	6
Hereford	7	8	6	11	11	8
Limousin	11	12	13	8	10	9
Pinzgauer	10	11	9	9	8	11
Red Poll	10	14	11	11	12	11
Simmental	15	11	12	8	8	10

[a]Energy densities label (ME, Mcal/kg of DM): Diet 10 = 2.12, Diet 20 = 2.60, Diet 30 = 2.95).

Materials and Methods

Model Development. On the basis of results from Jenkins et al. (1988), estimators identified for inclusion in the prediction equation were warm carcass weight, a measure of fat depth, and body impedance. Biological impedance analysis has been used to predict total body water (Lukaski, 1986), a trait that is highly correlated with fat-free dry matter (Ferrell and Jenkins, 1984). Assumptions used in the application of biological impedance include the following: the body (carcass) is a circuit of known length that is shaped similar to a cylinder, has a relatively uniform cross-sectional area, and the volume of the conductor (carcass) is proportional to length squared relative to the resistance (Thomas et al, 1992). Tetrapolar electrode technique applies a constant current through two driver electrodes with the drop in voltage due to the conductor's (carcass) resistance measured by the remaining two electrodes.

Coefficients for the prediction model were estimated from data collected as part of a comprehensive study to evaluate life cycle production efficiency of nine breeds of beef cattle. Five hundred twenty-six steers and heifers from straightbred matings of Angus, Braunvieh, Charolais, Gelbvieh, Hereford, Limousin, Pinzgauer, Red Poll, and Simmental composed the data set. Calves were weaned at approximately 200 d. A more complete description of project protocol through weaning may be found in Jenkins and Ferrell (1994).

Shortly after weaning, calves of each breed-sex combination were randomly assigned to three diets and, within breed-sex combination, to one of three slaughter weights (with the exception of the Pinzgauer) as shown in Table 1. Composition of the three diets is presented in Table 2. Animals were individually fed their assigned diets on an ad libitum consumption basis from placement on test until they reached their assigned slaughter weight. Weights were recorded at 28-d intervals. Animals were assigned to one of five target slaughter weights (363, 408, 454, 500, and 544 kg). Target slaughter weights (unshrunk) were cross-classified with diet but partially confounded with breed and sex. Hereford, Angus, and Red Poll heifers were assigned target slaughter weights of 363, 408, and 454 kg, and the steer contemporaries were assigned to target slaughter weights of 408, 454, and 500 kg. Braunvieh, Charolais, Gelbvieh, Limousin, and Simmental heifers were assigned to target slaughter weights of 408, 454, and 500 kg, and the steer contemporaries assigned weights were 454, 500, and 544 kg. Pinzgauer steers were assigned to all steer target weights and Pinzgauer heifers were assigned to all heifer target weights. In total, the study consisted of 168 combinations of breed, sex, diet, and target slaughter weight.

Animals were slaughtered when their preshrunk weight was within 15 kg of the assigned slaughter weight. Before slaughter, animals were deprived of feed for 24 h. At time of slaughter, warm carcass side weights and a measure of carcass length and resistive impedance were recorded for each animal. Resistive impedance was recorded immediately after evisceration. Carcass length was defined as the distance from point of electrode insertion at the extensor carpe radialis of the forelimb to the point of electrode attachment at the tibialis anterior of the hindlimb. This placement of electrodes allows impedance to the flow of the current to be measured throughout the carcass. Resistive impedance was recorded by use of a

Table 2. Composition of diets (% DM)

	Diet[a,b]		
Ingredient	10	20	30
Ground alfalfa	84	42	5.9
Corn	0	48	84.1
Supplement	6	—	—
ME, Mcal/kg	2.12	2.60	2.95
CP%	15.70	15.70	15.70

[a]Energy density label (ME, Mcal/kg of DM): Diet 10 = 2.12, Diet 20 = 2.60, Diet 30 = 2.95).
[b]10% DM corn silage added to all diets.

tetrapolar impedance plethysmograph (model BIA-101, RJL Systems, Detroit, MI). A current of 880 μA at 50 kHz was applied to each carcass.

Twenty-four hours after death, fat depth at the 12th rib (over the longissimus muscle) was recorded. One carcass side from each animal was fabricated into totally trimmed lean retail product, lean trim, bone trim, and fat trim. The two fractions of lean were ground three times and sampled for determination of water content, ether-extractable lipid (fat), protein (N $\times$ 6.25), and ash. Kidney and pelvic fat were included in the fat trim component. Trimmed bone was assumed to contain 64.2% DM and 17.9% fat, and the fat-free DM was assumed to contain 25% protein and 75% ash (Ferrell et al., 1976). Fat trim was assumed to be 82% DM, 87.8% of which was fat, and the fat-free DM was assumed to contain 98% protein and 2% ash (Berg and Butterfield, 1976). Fat-free soft tissue (kilograms) of the carcass was defined as the sum of calculated water and protein constituents of lean retail product, lean trim, fat trim, and bone trim.

Data for the evaluation were collected from Charolais- and Hereford-sired steers slaughtered as part of a study conducted at Miles City, MT (Short et al., 1994). Warm carcass weight, carcass length (as previously described), and resistive impedance measurements were recorded by personnel at a commercial slaughter facility. Fat depth over the muscle at the 12th rib was recorded approximately 48 h after slaughter. Fabrication and tissue sampling followed protocol described in the previous paragraph.

Statistical Procedure. Fat-free soft tissue (kilograms) was regressed on warm carcass weight, fat depth, and resistive impedance using the GLM procedure from SAS (1985). On the basis of previous findings (Jenkins et al., 1988), these were the only estimators considered. A second set of regression coefficients was estimated by fitting the same continuous variables and accounting for breed-sex-diet combinations (contemporary group).

Predictive value of the equations was evaluated by applying the equation to an independent data set. Using the information collected at Miles City, MT, measurements of fat-free soft tissue derived from chemical analyses were regressed on the values for fat-free soft tissue predicted from the equation fit within contemporary group. The merit of the prediction equation was evaluated by testing for an “ideal fit” (i.e., the estimates for the intercept and regression coefficients against expected values of 0 and 1, respectively).

Results and Discussion

Model Development. Jenkins et al. (1988), Cosgrove et al. (1988), Swantek et al. (1992), Berg and Marchello (1994), and Marchello and Slanger (1994) demonstrated that the inclusion of resistance impedance with the traditional predictor variables significantly reduces the amount of unexplained variation in carcass fat-free tissue. Application of the technology was demonstrated to be equally effective for sheep, swine, and cattle carcasses. Because of the relative low cost of data acquisition and the nondestructive procedure, the methodology has been suggested as an effective alternative for evaluating fat-free carcass tissue differences in either commercial or research environments. Before general acceptance and application, regression coefficients estimated from a data set structured to include a wide range within each of the predictor variables should be evaluated by applying the prediction equation to an independent data set.

The robustness of a prediction equation often is limited simply because the data set used to estimate the parameters was sampled from a narrow inference space. An example is the report by Jenkins et al. (1988). The objective of that study was to demonstrate the merit of adding resistive impedance measurements to traditional carcass measurements to improve the fit and precision of a regression equation for carcass fat-free soft tissue relative to equations including only traditional estimators. However, the inference space of the data was limited to prediction of carcass fat-free soft tissue from rams of a single breed, freely consuming only one diet, and slaughtered at a constant age. In this homogenous sample, including resistive impedance and a measure of fat depth explained an additional 52% of the remaining variation in carcass fat-free soft tissue after accounting for differences in warm carcass weight. Coefficients estimated from such a sample are not likely to be sufficiently robust for use in a heterogenous population. The structure of the current data set was created by sampling postweaning individuals from breeds of cattle that varied in genetic potential for lean and fat deposition, had consumed diets of different energetic density, and that were slaughtered at several live weights. Regression coefficients estimated from such a sample should be robust and therefore have a wide range of application. Inspection of the means, SE, and CV for age at slaughter, shrunk slaughter weight, carcass fat, and fat depth (Table 3) for target slaughter weight pooled over breed, sex, and diet provides information describing the scope of the inference space for the prediction model.

Univariate statistics for estimator variables and the components of the carcass that were used in the development of the prediction equation are reported in Table 4. Among the carcass components, the greatest CV was associated with carcass fat (28.9%); variation among the remaining components was similar. Among the estimator variables, the CV was greatest for fat depth at the 12th rib (74.5%), for resistance the CV was 10.5%, and the ratio of carcass length squared to

Table 3. Means, standard errors, and coefficients of variations for age at slaughter, shrunk slaughter weight, carcass fat,[a] and fat depth by target slaughter weight groups

Target weight		Age, d	Shrunk slaughter weight, kg	Carcass fat, kg	Fat depth, cm
363 kg	Means	440	348	53	.76
(n = 33)	SE	8.9	2.2	2.3	.07
	CV	11.6	3.6	24.4	54.6
408 kg	Means	465	388	54	.56
(n = 113)	SE	6.9	1.3	1.3	.04
	CV	15.7	3.6	24.7	67.8
454 kg	Means	489	430	59	.60
(n = 166)	SE	6.3	1.0	1.4	.04
	CV	16.4	3.1	30.5	84.4
500 kg	Means	523	473	66	.51
(n = 149)	SE	6.0	1.2	1.5	.04
	CV	14.1	3.0	28.3	60.3
544 kg	Means	536	514	67	.51
(n = 65)	SE	8.7	2.6	1.9	.01
	CV	13.2	4.0	23.2	60.3

[a]Ether-extractable lipid.

resistance was 16.4%. Simple correlations among the estimative traits were as follows: .88, .75, and .19 between warm carcass weight and fat-free soft tissue, resistive impedance, and fat depth, respectively; .88 and –.16 between fat-free carcass tissue and resistive impedance and fat depth, respectively; and –.17 between resistive impedance and fat depth.

Parameter estimates for the predictor variables warm carcass weight, fat thickness at the 12th rib, and the ratio of carcass length squared to resistance and R^2 values and the residual SD are reported in Table 5. Approximately 94% of the variation in carcass fat-free soft tissue mass was accounted for by these three predictors. The RSD was 6.8 kg. A plot of the residuals from fitting this equation suggested a bias remained. To determine whether variation attributable to known sources of variation remained, the residuals from the multiple regression were analyzed with a model that contained contemporary group (53 df) effects. Results of this analysis indicated significant variation attributable to contemporary group remained that could account for the possible bias in the residuals.

The data were reanalyzed with an analysis of covariance that estimated the coefficients within contemporary group. Results from this analysis are reported in Table 5 (Model 2). Fitting the equation within contemporary group resulted in a minor change in the coefficient for warm carcass. However, the change in the coefficients for impedance and fat thickness at the 12th rib was approximately 45 and 65%, respectively, relative to the coefficients from the multiple regression model. No noticeable bias was observed in the plot of residuals. Consequently, this regression equation was evaluated with an independent data set.

Table 4. Means, standard errors, and coefficients of variations for carcass components and predictors of carcass fat-free soft tissue

	Development (n = 526)					Evaluation (n = 65)		
Trait	Means	SE	CV	SE[a]	CV[a]	Means	SE	CV, %
Carcass component								
Fat-free soft tissue, kg	192	1.22	14.6	.813	9.7	203	5.72	22.4
Fat, kg	61	.765	28.9	.562	21.2	71	3.96	44.5
Ash, kg	16	.104	14.5	.063	8.7	11	.367	26.6
Predictors								
Carcass weight, kg	269	1.59	13.6	1.25	10.7	284	9.14	25.5
Fat depth, cm	.60	.019	74.5	.015	56.3	.70	.054	62.1
Carcass length, cm	189	.412	5.0	.329	4.0	186	1.85	7.9
Resistance, ohms	35.8	.164	10.5	.113	7.3	36.2	.469	10.3
Carcass length^2/resistance	1018	7.28	16.4	4.73	10.7	978	27.7	22.5

[a]SE and CV after removing effect of contemporary group.

Table 5. Coefficients of regression and of determination and residual standard deviations from equations for estimating carcass fat-free soft tissue (kg) from cattle[a,b]

Model	b_0	b_1	b_2	b_3	R^2, %	RSD, kg
1, across groups	2.81 ± 2.22	.528 ± .014	−15.24 ± .78	.055 ± .003	94.2	6.79
	($P > .20$)	($P < .10$)	($P < .001$)	($P < .001$)		
2, within groups	8.83 ± 3.42	.550 ± .013	−9.074 ± .835	.038 ± .003	96.6	5.45
	($P < .02$)	($P < .001$)	($P < .001$)	($P < .001$)		

[a] $H_{0i}: b_i = 0$.
[b] Model 1: $\hat{y}_i = B_0 + B_1X_1 + B_2X_2 + B_3X_3$; Model 2: $\hat{y}_i = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + G_{ij}$, where X_1 = warm carcass (kg), X_2 = fat thickness (cm), X_3 = impedance (cm^2/ohms), and G_{ij} = contemporary group.

Table 6. Coefficients of regression and of determination and residual standard deviation from the regression of observed carcass soft tissue on predictor carcass soft tissue[a,b]

Model	b_0	b_1	R^2, %	RSD, kg
1	12.1 ± 5.59	.97 ± .028	95.2	9.98
	($P < .05$)	($P > .90$)		
2, adjusting for contemporary group	−12.6 ± 11.13	1.01 ± .049	98.9	5.75
	($P > .75$)	($P > .95$)		

[a] $H_{01}: b_0 = 0$; $H_{02}: b_1 = 1$.
[b] Model 1 $\hat{y}_i = b_0 + B_1X_1$; Model 2 $\hat{y}_i = b_0 + B_1X_1 + G_{ij}$, where $\hat{y}_i$ = observed soft tissue, X_1 = predicted soft tissue, and G_{ij} = contemporary group.

Model Evaluation. Information from 65 Charolais- and Hereford-sired calves and yearlings that had been slaughtered as either calves or yearlings at eight different time-on-feed constant endpoints was used to evaluate the model. Univariate statistics for traits of interest are reported in Table 4. Means for carcass fat-free soft tissue, fat, carcass weight, and fat depth at the 12th rib tended to be greater in the evaluation data set relative to the means for the same traits in the developmental data set. The CV tended to be larger with the exception of fat depth at the 12th rib.

Results of the regression of observed carcass fat-free soft tissue on predicted fat-free soft tissue estimates from the prediction equation are reported in Table 6. Approximately 95% of the variation in observed carcass fat-free soft tissue was accounted for by the predicted values. The residual coefficient of variation was 4.9%. If the prediction equation is correct, estimates of the parameters will not deviate from 0 for the intercept and 1 for the regression coefficient. Estimates of the regression coefficient did not differ significantly from 1 ($P > .90$), but the estimate for the intercept differed from 0 ($P < .05$). The equation was evaluated a second time by regressing the observed values on the predicted with simultaneous adjustment for breed of sire of the calf and date of slaughter. Inclusion of these effects increased the amount of variation accounted for to approximately 99% and resulted in a reduction in the residual CV from 4.9% to 2.8%. The partial regression coefficient did not differ from 1 ($P > .95$), and the intercept value did not differ from 0 ($P > .75$). These results demonstrate the equation predicts carcass fat-free soft tissue with a high degree of accuracy.

Implications

Costs associated with determination or prediction of carcass fat-free soft tissue are becoming increasingly important. Researchers needing a measure of differences in carcass constituents due to treatments require an inexpensive method to continue their investigations. Previous research has demonstrated that inclusion of resistive impedance measures with more traditional measures such as carcass weight and a measure of fat depth in a multiple regression model significantly reduces the residual variation. These traits are easily measured at relatively low cost. Given the results of the present study, the prediction equation reported is highly appropriate to apply in the estimation of carcass fat-free soft tissue for steers and heifers ranging in slaughter weights from 350 to 525 kg and previously consuming diets varying in energy density from 2.12 to 2.95 Mcal of metabolizable energy/kg of dry matter.

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