Computer image analysis for prediction of carcass composition from cross-sections of Japanese Black steers[1]

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ABSTRACT: Carcasses from Japanese Black steers were used to obtain prediction equations for carcass composition from information derived by computer image analysis of carcass cross-section images. The total weights of lean, fat, and bone were obtained from the left sides of 55 carcasses (Data Set I) and 18 carcasses (Data Set II) by physical dissection. The information such as total lean, fat, and bone areas in the cross-sections; muscle area, muscle circumference, short and long radius axis lengths, and direction of long radius axis; and geometric distance between any two muscle centers of gravity was obtained by scanning and image analysis of pictures of the cross-sections of the beef side at the 6th/7th rib interface. The coefficients of determination of the multiple regression equations estimated from Data Set I for kilograms of lean, fat, and bone were 0.76, 0.82, and 0.69, respectively, whereas for the percentages of lean, fat, and bone they were 0.57, 0.66, and 0.42, respectively. The multiple regression equations from Data Set I was applied to Data Set II in order to test the applicability of the prediction equations obtained. The correlation coefficients between the value predicted by the multiple regression equation and the measurement obtained by physical dissection for kilograms of lean, fat, and bone were 0.71, 0.72, and 0.70, respectively, whereas those for the percentages of lean, fat, and bone were 0.63, 0.44, and 0.29, respectively. The results indicate that the information obtained from the carcass cross-sections by the computer image analysis method can be used to predict carcass composition in Japanese Black steers.

Key Words: Beef Cattle, Carcass, Composition, Computer Analysis, Image Analysis, Prediction

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Introduction

Prediction of carcass composition is important for progeny testing, carcass evaluation, and evaluation of feeding experiments. The dissection method for predicting carcass composition is highly labor-intensive, time-consuming, and costly. Therefore, an automatic and noninvasive method by which carcass composition can be easily and accurately predicted is needed. The cross-sectional area is composed of well-developed and defined muscle, fat, and bone and may contain useful information relating to carcass composition. Obtaining specific structural information from the carcass cross-sections is expected to provide a way to predict beef carcass composition.

Shackelford et al. (1998) indicated that the technology investigated could be used accurately to characterize beef for carcass cutability in combination with tenderness classification. Application of video image analysis (**VIA**) in the prediction of beef carcass in high-speed beef processing plants ($r^2 = 0.52$) by Wassenberg et al. (1986) and research on instrument assessment of composition ($r^2 = 0.55$) by Belk et al. (1996) have been less successful in facilitating value-based marketing. Because it is difficult on a high-speed grading line to consistently position a camera, it is problematic to record an image of the entire longissimus and its surrounding muscles and fat cover.

Although there are many researchers addressing the automation of carcass prediction, no technology has proven completely successful in predicting the composi-

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Table 1. Statistics of slaughtered animals and their side composition of Data Sets I and II of Japanese Black steers

	Data Set I (n = 55)				Data Set II (n = 18)			
Variable	Mean	Minimum	Maximum	SD	Mean	Minimum	Maximum	SD
Slaughter age, mo	27.9	19.6	39.9	3.6	31.0	27.1	38.3	4.1
Slaughter wt, kg	670.4	557.0	838.0	26.6	754.4	645.0	848.0	65.9
Side wt, kg[a]	210.6	173.1	253.0	19.7	241.6	204.8	271.2	21.6
Total lean, kg[a]	111.3	95.3	131.1	9.6	123.6	103.8	138.8	9.7
Total fat, kg[a]	66.7	43.2	94.9	13.6	88.0	71.4	114.9	12.9
Total bone, kg[a]	25.1	21.0	35.8	2.9	28.6	21.6	36.9	3.9
Total lean, %	52.8	47.2	56.9	2.3	51.2	46.5	54.9	2.5
Total fat, %	31.4	24.3	41.2	4.2	36.4	30.3	42.4	3.0
Total bone, %	12.2	9.8	16.6	1.2	11.8	9.9	14.6	1.2

[a]Left side of the carcass.

tion of beef carcasses. The technology may therefore require further modification and evaluation. There is also a need to investigate additional technology that is more practical, cost-effective, and accurate to predict carcass composition. The purpose of this study was to establish prediction equations for beef carcasses based on the information derived from the carcass cross-sections by the computer image analysis (**CIA**) method and investigate the applicability of the equations.

Materials and Methods

Animals. Carcass data used in this study (n = 73) were collected from Japanese Black steers fattened during 1992 to 1998 at the Chugoku National Agricultural Experiment Station, the Ministry of Agriculture, Forestry, and Fisheries, Japan. The ages of the steers at slaughter ranged from 27 to 40 mo. The data were divided into Set I (n = 55) and Set II (n = 18), which were collected from 1992 to 1996 and from 1997 to 1998, respectively. The basic statistics of the data are shown in Table 1. The actual weights of lean, fat, and bone were measured following the physical dissection of the left side of the carcass following the protocol of Butterfield (1963).

The weight of heart fat was not included in the total fat weight. In beef cattle grading standards (Japan Meat Grading Association, 1988), yield score determination and carcass measurements are carried out on the left side between the 6th and 7th rib sections of the carcass. Therefore, the equation for yield score in Japan is formulated based on these factors.

Prior to dissection, the left side of the cold carcass was precisely cut between the 6th and 7th ribs. The cut cross-section was exposed vertically on the table and an individual identification number and a measurement scale were assigned to each cross-section. Pictures of the cross-sections were taken with a photographic camera (Minolta-Alpha-700, Sony Corp., Tokyo, Japan) using color negative film. In order to provide maximum lighting for the photographs, the background was illuminated with two 200-W halogen bulbs (SFC, Fijitsu, Tokyo, Japan). The bulbs were placed and lighted on each of two opposing sides of the cross-sections.

CIA Procedure. The CIA procedure was conducted using a Power Macintosh computer (Apple Vision, 7100/180AV) with 64 M of RAM and a flatbed image scanner, (Nikon Scantouch). Each photo was scanned at 145 dots per inch (**dpi**), which was found to be optimal for the digitization and processing of the image. Two software packages, Adobe Photoshop (Version 3.0j; Adobe Systems, San Jose, CA) and MacScope (Version 2.00j; Mitani Corp., Tokyo, Japan) were used in the image analysis. The Adobe Photoshop software was used primarily for image processing after scanning, whereas the MacScope software was used for image analysis. The procedure for obtaining the information was described by Karnuah et al. (1994, 1996, 1999). The various muscles analyzed were identified using different color labels and stored as label images. Pixel values were automatically assigned to each muscle and other selected areas through the process of bound connectivity (Gonzalez and Wintz, 1987). Connectivity between pixels is an important concept used in establishing boundaries of the region in the image. Calibration values were selected using the scale measurement imposed at the lower region of each cross-section. After scanning, a distance of 10 cm was sampled three times at different points within the image and averaged. Each value measuring the number of pixels per every 10 cm of the image was used as a scale to convert the pixel values into true area. Each image has its own calibration value. The goal, then, was to transform the determined pixel area into numerical data. The calibration values ranged from 0.121 to 0.130.

Information Derived. The information derived was transformed from image data to numerical data as follows: 1) muscle area, 2) muscle circumference, 3) long and short radius axis lengths, 4) muscle direction of the long radius axis, 5) geometric distance between any two muscle centers of gravity, 6) total area of the cross-sections, 7) total lean area in the cross-section, 8) total fat area in the cross-section, and 9) total bone area in the cross-section.

The information, except for items 4 and 5, was obtained following the procedure of Ballard and Brown (1982). Muscle direction of the long radius axis measures the angle of long axis length to the horizontal axis of that muscle. This information was obtained following the protocol by Harder (1992). Geometric distance between any two muscle centers of gravity determines how far or near the muscles are to each other. This is important in estimating the amount of intermuscular fat between the two adjacent muscles, and as a shape factor it also gives additional information on the size of the muscles. The information was obtained following the procedure of Gonzalez and Wintz (1987).

The scientific names and the locations of the muscles analyzed from the cross-sections are shown in Figure 1. The muscles analyzed were as follows: latissimus thoracis (M2), pectoralis profundus (M3), serratus ventralis thoracis (M4), trapezius thoracis (M7), iliocostalis (M8), longissimus thoracis (M11), rhomboideus thoracis (M12), and spinalis thoracis and cervicis (M13).

Statistical Analysis. Twenty-seven animals were randomly sampled from Data Set I (n = 55) repeatedly using the random sampling technique with replacement (Efron, 1982). Twenty sample data sets were produced with 27 animals per sample. Multiple regression analysis was carried out on these 20 sample data sets. All the information obtained by the CIA was included in the multiple regression analysis as independent variables. Dependent variables were the total weight of lean, fat, and bone and their percentages obtained by physical dissection.

In the second phase of the analysis, multiple regression analysis was done using Data Set I to formulate the prediction equation for carcass composition. As independent variables, only the information in the 20 multiple regression equations of the randomly sampled data set adopted three times or more (frequency of 15% and higher) was used. Finally, the prediction equations derived from Data Set I in the second phase were applied to Data Set II, and the carcass composition of the animals included in Data Set II was predicted. The predicted values were compared with the values measured by physical dissection by the correlation coefficient to evaluate the applicability of the prediction equations obtained.

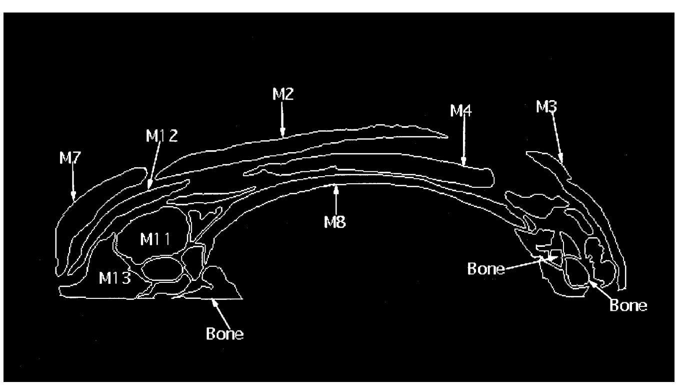

Figure 1. Scientific names of muscles and alpha-numeric designation used to identify them in a cross-section of a beef side at the 6th/7th rib interface. M2, latissimus thoracis; M3, pectoralis profundus; M4, serratus ventralis thoracis; M7, trapezius thoracis; M8, iliocostalis; M11, longissimus thoracis; M12, rhomboideus thoracis; M13, spinalis thoracis and cervicis.

Table 2. The coefficients of determination (R^2) for the multiple regression for predicting carcass composition based on all the information derived from the carcass cross-sections by computer image analysis method for the 20 randomly sampled data sets

Dependent variable	Coefficient of determination		
	Mean	Minimum	Maximum
Lean, kg	85.3	68.1	95.9
Fat, kg	90.5	74.3	98.7
Bone, kg	84.9	61.2	97.2
Lean, %	83.8	60.4	98.2
Fat, %	83.5	63.8	96.9
Bone, %	74.2	41.4	97.4

The stepwise procedure (SAS Inst. Inc., Cary, NC) of the maximum R^2 (coefficient of determination) improvement method (MAXR) was used for the multiple regression analysis. The maximum R^2 was preferred because for sets of prediction equations with constant numbers of independent variables, maximization of R^2 guarantees minimum residual variance. The inclusion of an increased number of variables in the prediction equation may not increase R^2 sufficiently to offset the reduction in residual degrees of freedom (n – p), in which the variance will be inflated (SAS Inst. Inc.). The R^2 was adjusted for the degree of freedom, and the significance level of the independent variables included in the prediction equations was set at 10 and 5% in the first and second phases of the analysis, respectively.

Results and Discussion

Statistics of the slaughtered animals and their carcass composition are shown in Table 1. The range of data was deemed to represent fattened steers with a high weight range, representing the carcass market in Japan. Studies of the production and marketing of high-quality beef in Japan have reported that the average live weight at slaughter for Japanese Black steers is 600 kg, which is greater than the 520 kg for US-produced beef (Longworth, 1983; Uri et al., 1993). Higher SD were observed for kilograms of fat among the steers as compared with lean in both Data Sets I and II.

The average and range values of R^2 obtained from the multiple regression analysis of the 20 randomly sampled data sets are shown in Table 2. The averages were high, ranging from 0.74 to 0.91, and even the minimum was not low except in the case of percentage of bone, suggesting that each randomly sampled data

Table 3. Equations predicting kilograms of carcass composition based on the selected information derived from the carcass cross-sections by computer image analysis

R^2	SE	Best equation[a]
0.76	1.2	Kilograms of lean Predicted = 2.5 + (1.1 × TMACS) + (−0.28 × short radius M12) + (−0.32 × area M4) + (0.16 × long radius M11) + (−0.29 × short radius M8) + (0.18 × MC M8) + (0.14 × short radius M7)
0.82	4.4	Kilograms of fat Predicted = −10.2 + (0.86 × TFACS) + (−0.21 × ratio[b] of area M12) + (0.22 × TBACS) + (0.16 × ratio[b] of area M3) + (0.33 × long radius M12) + (−0.14 × GGD M2–M7) + (0.08 × direction M8) + (−0.26 × direction M7) + (−0.33 × short radius M12)
0.69	1.8	Kilograms of bone Predicted = 0.58 + (0.69 × TMACS) + (−0.29 × short radius M7) + (−0.39 × MC M4) + (0.21 × long radius M11) + (0.33 × GGD M4–M11) + (0.25 × GGD M2–M3) + (−0.41 × short radius M12) + (0.33 × long radius M12)

[a]TMACS = total muscle area in the cross-sections; TBACS = total bone area in the cross-sections; MC = muscle circumference; TFACS = total fat area in the cross-sections; GGD = geometric gravity distance between two muscles. MXX is the symbol of a muscle, which was derived from the surface of the cross-sections.
[b]Ratio of the area of a variable to the total area in the cross-sections.

set yields different but useful information for predicting carcass composition. The more important information for prediction were included more frequently in the 20 multiple regression equations and were then selected as the independent variables to formulate the prediction equations.

The prediction equations derived from Data Set I by multiple regression analysis are presented in Tables 3 and 4. The best equation for predicting kilograms of lean had an R^2 of 0.76. This value is similar to that reported by Berg et al. (1994) using the electromagnetic scanning method. In this study, the best equation is referred to as that with the highest R^2 among the various equations produced for each carcass trait. Each variable included in the equation is in the order of importance that contributes to accounting for the overall variation in that carcass composition trait. For the variables measured on kilograms of lean, the sequential R^2 showed total muscle area in the cross-sections accounted for 62.6% of the variation in the total weight of lean. The best equation for predicting kilograms of fat had an R^2 of 0.82. This value is higher than that reported by Wassenberg et al. (1986) using VIA. Total fat area of the cross-sections was the most important predictor for kilograms of fat and accounted for 54.2% of the variation in the total weight of fat. For predicting kilograms of bone, the best equation had an R^2 of 0.69. The most important predictor was the total muscle area in the cross-sections, which accounted for 30% of the variation in the total weight of bone.

The R^2 for predicting the percentage of lean was 0.57. This figure is higher than that reported by Wassenberg et al. (1986) for estimating percentage of primal lean by VIA. Total fat area in the cross-sections accounted for 30% of the variation in the total percentage of lean. The best equation for predicting percentage of fat had

Table 4. Equations predicting percentages of carcass composition based on the selected information derived from the carcass cross-sections by computer image analysis

R^2	SE	Best equation[a]
0.57	1.4	Percentage lean Predicted = 29.5 + (1.0 × TFACS) + (2.0 × area M2) + (0.37 × MC M12) + (−0.1.3 × ratio[b] of M12)
0.66	5.6	Percentage of fat Predicted = −3.6 + (0.74 × TACS) + (−0.32 × area M12) + (−0.42 × direction M7) + (−0.46 × area M2) + (0.27 × short radius M2) + (0.22 × direction M12) + (0.15 × direction M8)
0.42	7.4	Percentage of bone Predicted = 22.2 + (−0.34 × GGD M11–M12) + (0.28 × long radius M11) + (−0.22 × GGD M7–M13) + (−0.24 × short radius M4) + (−0.29 × direction M8) + (0.29 × long radius M7) + (0.27 × ratio[b] of area M2)

[a]TFACS = total fat area in the cross-sections; MC = muscle circumference; TACS = total area of the cross-sections; GGD = geometric gravity distance between two muscles. MXX is the symbol of a muscle, which was derived from the surface of the cross-sections.
[b]Ratio of the area of a variable to the total area in the cross-sections.

Table 5. Correlation coefficients of carcass composition between the values predicted by the image analysis and actual measurements by the dissection method in Data Set II

	Correlation coefficient (r)	
Carcass composition	Approach used in this study	Alternative approach
Lean, kg	0.706**	0.584**
Fat, kg	0.725**	0.679**
Bone, kg	0.704**	0.603**
Lean, %	0.631**	0.613**
Fat, %	0.437*	0.201
Bone, %	0.289	–0.404

*$P < 0.05$.
**$P < 0.01$.

an R^2 of 0.66, with total area of the cross-sections accounting for 36.3% of the variation in the total percentage of fat. This value is higher than that reported by Horgan et al. (1995) using image analysis and lower than that reported by Berg et al. (1994). Shackelford et al. (1998) reported an R^2 of 0.86 for predicting percentage of retail product yield by image analysis. They also reported that the single image analysis variable accounting for the greatest variation in retail product yield was the percentage of lean. The equation for predicting the percentage of bone has an R^2 of 0.42, with the geometric gravity distance between M11 and M12 accounting for 11% of the variation in the total percentage of bone, followed by the long radius axis of M11 with 8%. The applicability of the prediction equations obtained from Data Set I (Tables 3 and 4) was tested by applying the equations to Data Set II. The correlation coefficients between the predicted values and the dissected measurements are shown in Table 5. The correlation coefficients were high ($P < 0.01$) for kilograms of lean, fat, and bone and percentage of lean and moderate for percentage of fat ($P < 0.05$), whereas that for the percentage of bone was low.

The alternative approach in obtaining prediction equations by multiple regression analysis is applying the analysis from Data Set I directly, considering all the information derived from the carcass cross-sections as independent variables. The R^2 for predicting kilograms of lean, fat, and bone by this approach were 0.74, 0.79, and 0.67 (not shown). These were lower than the results shown in Table 3 for the equations obtained by the previous approach, whereas those for the percentages were the same as those shown in Table 4. When the prediction equations obtained were applied to Data Set II as described above, all the correlation coefficients between the predicted values and the dissected measurements with the previous approach were higher than those with the alternative approach, except for the percentage of lean, which was the same (Table 5). There was a significant difference between the correlation coefficients for kilograms of lean (0.71 vs 0.58). These results indicate that the approach adopted in this study is effective in predicting carcass composition, especially when dealing with small data size and many independent variables.

Kempster (1979) and Abraham et al. (1980) reported that the accuracy of a prediction equation might be reduced when the equations are applied to predict the carcass composition in another population due to factors such as muscle deposition, sex, size, and genetic variation. In this study, the prediction equations derived from different populations were used to predict carcass composition in another population with the aim of testing the applicability of the prediction equations obtained. The results indicate that the prediction equations obtained in this study have great potential and can be used to predict the composition of carcasses from fattened Japanese Black steers.

It takes about 15 min to process each photo in order to obtain the necessary information from a carcass cross-section. Most of the processing time was spent on the separation of each muscle, however, so the CIA method will be applicable for practical use at the market by automating the process.

Implications

Equations using computer image analysis data can be used to predict composition of carcasses from Japanese Black steers. Different equations may be needed to predict composition of carcasses of different breeds, sex classes, or feeding regimens, but the principles involved and explored in this study using CIA for such prediction would apply.

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