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Mercedes M. Izquierdo
Iowa State University

Viren Amin
Iowa State University

Doyle E. Wilson
Iowa State University

Gene Rouse
Iowa State University

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Models to Predict Intramuscular Fat Percentage in Live Beef Animals Using Real-time Ultrasound and Image Parameters: Report on Data From 1991-1994

Abstract
Data from 710 yearling bulls and steers collected from 1991 to 1994 were used to predict the percentage of intramuscular fat (PIFAT) by using real-time ultrasound (RTU) and imageprocessing parameters. Image-processing parameters included histogram, texture, and Fourier transformation parameters. Additionally, ultrasound fat thickness (UFAT) was included. Two multiple regression models Model1 excluding UFAT and Model2 including UFAT,were developed by using 392 images and validated with 318 independent images. These models were used to assess the accuracy of image parameters in predicting PIFAT and to determine whether including UFAT as an additional covariate parameter increases accuracy. Results indicated that for actual PIFAT values ranging from .5% to 13%, RTU and image-processing parameters can consistently predict PIFAT with a root mean square error (RMSE) of 1.43 and 1.41 and a coefficient of determination (R-square) of .59 and .6 for Model1 and Model2, respectively. Both models were unbiased with intercepts of .47 and .51 ($p > 0.1$), respectively. RTU and image-processing parameters can accurately and without bias predict PIFAT without including UFAT in the prediction model.

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Models to Predict Intramuscular Fat Percentage in Live Beef Animals Using Real-time Ultrasound and Image Parameters: Report on Data From 1991-1994

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Mercedes M. Izquierdo, graduate student,
Viren Amin, associate scientist,
Doyle E. Wilson, professor of animal science
Gene Rouse, professor of meat science

Summary

Data from 710 yearling bulls and steers collected from 1991 to 1994 were used to predict the percentage of intramuscular fat (PIFAT) by using real-time ultrasound (RTU) and image-processing parameters. Image-processing parameters included histogram, texture, and Fourier transformation parameters. Additionally, ultrasound fat thickness (UFAT) was included. Two multiple regression models Model1 excluding UFAT and Model2 including UFAT,were developed by using 392 images and validated with 318 independent images. These models were used to assess the accuracy of image parameters in predicting PIFAT and to determine whether including UFAT as an additional covariate parameter increases accuracy. Results indicated that for actual PIFAT values ranging from .5% to 13%, RTU and image-processing parameters can consistently predict PIFAT with a root mean square error (RMSE) of 1.43 and 1.41 and a coefficient of determination (R-square) of .59 and .6 for Model1 and Model2, respectively. Both models were unbiased with intercepts of .47 and .51 (p > 0.1), respectively. RTU and image-processing parameters can accurately and without bias predict PIFAT without including UFAT in the prediction model.

Introduction

Because quality grade is such an important factor in determining beef carcass value, the beef industry needs an accurate and objective method of measuring the actual amount of intramuscular fat in beef carcasses. Additionally, seedstock breeders need a reliable tool to select young bulls for carcass quality merit. Ultrasound technology has shown promise because of the following properties: 1) it has the ability to reflect fatty-tissue, 2) it is completely non-invasive and easy to use on the live animal, and 3) the technology is relatively inexpensive. ISU has been working for several years to implement this technology to measure carcass attributes in the live animal. Several implementation changes have been adopted to increase the accuracy of prediction, either directly in the field as in direct image digitization or in the image laboratory developing new image-processing parameter algorithms. These parameters combined in a multiple regression model, are used to predict the percentage of intramuscular fat (PIFAT) or marbling in the live beef animal. The objectives of this research were to: 1) refine earlier models, 2) develop a more robust methodology to predict PIFAT in the live animal, and 3) include this predicted trait in beef breeding programs for improving carcass traits.

Materials and Methods

Description of the data

Seven-hundred-and-ten images of yearling bulls and steers from two research locations at ISU were serially scanned at 30-day intervals from 1991 to 1994. All cattle were born in the spring (March-April), weaned in the fall, and started on feed in November. After the feeding period (eight to nine months), the *Longissimus dorsi* (LD) muscles of all animals were scanned by using a Real Time Ultrasound machine. Animals were slaughtered at a commercial packing facility within five days after scanning with an average age of 440 days. After a 24-hour chilling period, marbling was scored by a USDA grader, and a rib facing across the LD muscle at the 12th rib was obtained from each carcass. This meat sample was used to determine the actualPIFAT by using n-hexane chemical extraction.

Equipment used

An ALOKA 500V machine (Corometrics Medical System, Inc., Wallingford, CT) equipped with a 3.5-Mhz, 17centimeter linear array transducer, developed specifically for animal applications, was used to collect these images (Figure 1).

Scanning procedure

The scanning site was determined by physical palpation of the 13th rib. Once the area across the 11th, 12th, and 13th ribs was located, the animal was clipped, oiled, and curried to remove foreign debris and then oiled again to obtain optimum image quality. Vegetable oil was used as the acoustic couplant.

A longitudinal scan was collected across the 11th, 12th, and 13th ribs approximately 15 centimeters from the animal midline (see Figure 2). In this image, different texture patterns are visible that relate to the amount of intramuscular fat deposited in the muscle. A second scan was collected between the 12th and 13th ribs using a Superflab (Nicks Radio-Nuclear Instruments, Inc., Bronx, N.Y) transducer guide that conforms to the general shape of curvature between the 12th and 13th ribs. This guide ensures proper contact between the ultrasound transducer and the animal without distortion of the LD anatomy. This image was used to measure the ultrasound fat thickness (UFAT) and ultrasound ribeye area.

Image analysis

First, images were preprocessed to score image quality subjectively and to select a square region of interest (ROI) from the image above the 12th and 13th ribs, free of undesired noise. Second, image-processing parameters were determined for the selected ROI. Image-processing parameters were calculated using techniques of histogram analysis, texture analysis, and Fourier transformation. Histogram parameters are computed from the frequency distribution of the pixel intensities; texture parameters provide information about the image patterns generated in part by ultrasound scattering, and spectral or Fourier parameters were calculated from two-dimensional Fourier transformations.

Statistical analysis

Image parameters and actual PIFAT were statistically analyzed to select a set of parameters for regression model development. Most of the analyses were done using SAS (SAS Institute Inc., Cary, N.C). Pearson correlations of all variables with PIFAT were calculated. The parameters showing significant correlation with PIFAT ($p >.05$) were selected for further analysis. The selection of mutually highly correlated parameters was avoided. Stepwise regression procedures were used for the final variable selection to determine the prediction model. The forward selection option of the regression analysis in SAS was based on three statistics: the coefficient of determination (R-square), the root mean square error (RMSE), and Cp Mallow statistic.

The 710 images were divided randomly into two groups. One group of 392 images was used to develop a linear multiple regression model to predict PIFAT. The other set of 318 images was used to validate and test the accuracy of the developed prediction model. In order to determine whether UFAT should be included in the prediction model with newer image-processing parameters, two models were developed, one including only image processing parameters, and the other also including UFAT.

Several statistics were used to compare the accuracy of the developed prediction models. From the developing set, the RMSE and R-square from the regression procedures were used. From the validation set, the intercept (INT) and the slope (SLOP) of the regression of actual on predicted PIFAT and the correlation (CORR) between the actual and the predicted PIFAT were used. In addition, the residuals were plotted against the predicted values to identify outliers and to confirm whether they were uncorrelated with a mean around zero.

In order to understand the nature of the outliers observed in the residual distribution, different categories of PIFAT were defined as the actual PIFAT less than 3%, between 3% and 6%, between 6% and 9%, and greater than 9%. Absolute residual means and standard deviations were computed for each class of PIFAT and for both models (with and without UFAT).

Results and Discussion

After stepwise regression selection procedures, final models included 14 parameters (all with $p < 0.05$). Not only parameters highly correlated with PIFAT but also some parameters that showed small correlation with PIFAT were included in the models because they had proved to increase R-square and decrease RMSE when combined with other parameters in the multiple regression model. The coefficient of the parameters included in the model and the correlations of these parameters with PIFAT are presented in Table 1.

The diagnostic statistics for Model1 and Model2 are summarized in Table 2. The RMSE and R-square diagnostic statistics were 1.43% and 0.59 for Model1 and 1.41% and 0.6 for Model2. The intercept and slope of regression between the actual and predicted PIFAT were 0.47 ($p > 0.1$) and 0.97 for Model1 and 0.51 ($p > 0.1$) and 0.98 for Model2. Neither intercept was significantly different from 0, indicating that the models are unbiased. Slopes were very close to 1, indicating a good model fit. Finally, correlation coefficients between actual and predicted PIFAT were 0.6 for both models. The diagnostic statistics indicated only small differences between Model1 and Model2, concluding that the addition of UFAT was not essential to predict PIFAT.accuratley

The residual distribution is one of the best statistic diagnostics. The plot of the residuals versus the predicted values is a good indicator of the fit of the model and allows visualization of the residual mean and the outliers. Any prediction model candidate needs to show uncorrelated residuals with a mean around 0, and the majority of the residuals need to be smaller than ±2%.

Residual means for animals with low (0% to 3%), medium (3% to 6%), high (6% to 9%), and very high (more than 9%) actual PIFAT are presented in Table 6. This table indicates that both models more accurately predict animals with medium PIFAT, average residual mean of 0.85%, and a maximum residual of 2.24% for Model1. Prediction models are also accurate for animals with low PIFAT values (average residual 0.92%); for animals with actual PIFAT values between 6% and 9%; the models can still be applied with an average residual of 1.67%. For animals with actual PIFAT values larger than 9%, however, predictions had large errors because there were few animals in this class.

Implications

Image-processing analysis can be used in predicting PIFAT from LD real-time ultrasound images obtained from live beef cattle. Prediction was accurate for most of the images; however, accuracy decreased when actual PIFAT increased. The newly implemented models will allow the beef industry to consistently and accurately measure PIFAT in the live animal and use the prediced values to calculate Expected progeny differences (EPDs) for young bulls for carcass quality traits.

Table 1. Regression coefficients and correlation between the parameters entering in both models and actual PIFAT.

PAR[a]	Parameter description	Coeff[b] for Model1	Coeff for Model2	Corr[c] with PIFAT
INT	Intercept	-106.9	-111.3	-
UFAT	Ultrasound fat thickness	-	1.7	.48
FR3	The average Fourier power at frequency 0	-1.9	-3.5	.28
FR10	The average Fourier power at frequencies from 0 to 5	106.2	112.6	.06
FR11	The average Fourier power at frequencies from 50 to 100	323	287	.17
FI1	Fourier power intensity mean	-410.7	-373.4	.07
FI2	Fourier power intensity standard deviation	140.7	238	.28
H2	Histogram standard deviation	.03	.06	.20
H3	Histogram skewness	.98	-	-.22
H7	Histogram coefficient of variation	-	-23.8	-.26
HI1	Histogram maximum value	.09	.08	.35
HP4	75th percentile of histogram	-	-.08	.31
C135_7	Texture sum average at angle 135	-.007	-	.22
C135_10	Texture entropy difference variance at angle 135	-.032	-	.11
C135_12	Texture correlation at angle 135	35.55	26.6	-.31
C090_7	Texture sum average at angle 90 degree	-	-.014	.28
C090_10	Texture entropy difference variance at angle 90	.60	.50	.25
C090_3	Texture contrast at angle 90	118.02	136.6	.20
R090_7-	Texture high gray-level run emphasis at angle 90	-.0009	-	-.05

[a] Image parameters.

[b] Regression coefficients for both models ($p < 0.05$ all parameters)

[c] Correlation coefficient.

Table 2. Diagnostic statistic results for percent intramuscular fat prediction and validation.

	Prediction		Validation		
	RMSE[b]	R-Square[c]	Intercept[d]	Slope[e]	Corr[f]
Model1(without UFAT[a)]	1.43	.587	.47	.97	.60
Model2 (with UFAT)	1.41	.60	.51	.98	.60

[a] Ultrasound fat thickness.
[b] Root mean squared error of prediction.
[c] Coefficient of determination.
[d] Intercept of the regression between actual and predicted PIFAT values.
[e] Slope of the regression between actual and predicted PIFAT values.
[f] Correlation between actual and predicted PIFAT values.

Figure 1. Absolute residual means for four classes of actual percent intramuscular fat.