Development and evaluation of empirical equations to interconvert between twelfth-rib fat and kidney, pelvic, and heart fat respective fat weights and to predict initial conditions of fat deposition models for beef cattle

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ABSTRACT: The Davis growth model (DGM) simulates growth and body composition of beef cattle and predicts development of 4 fat depots. Model development and evaluation require quantitative data on fat weights, but sometimes it is necessary to use carcass data that are more commonly reported. Regression equations were developed based on published data to interconvert between carcass characteristics and kilograms of fat in various depots and to predict the initial conditions for the DGM. Equations include those evaluating the relationship between the following: subcutaneous fat (SUB, kg) and 12th-rib fat thickness (mm); visceral fat (VIS, kg) and KPH (kg); DNA (g) in intramuscular, intramuscular, subcutaneous, and visceral fat depots and empty body weight; and contributions of fat (kg) in intramuscular (INTRA), SUB, and VIS fat depots and total body fat (kg). The intramuscular fat (INTER, kg) contribution was found by difference. The linear regression equations were as follows: SUB vs. 12th-rib fat thickness (n = 75; P < 0.01) with R² = 0.88 and SE = 10.00; VIS vs. KPH (kg; n = 78; P < 0.01) with R² = 0.95 and SE = 2.82; the DNA (g) equations for INTER, INTRA, SUB, and VIS fat depots vs. empty body weight (n = 6, 5, 6, and 6; P = 0.08, P < 0.01, P < 0.01, and P = 0.05) with R² = 0.57, 0.93, 0.93, and 0.66, and SE = 0.03, 0.003, 0.02, and 0.03, respectively; and initial contribution of INTRA, SUB, and VIS fat depots vs. total body fat (n = 23; P < 0.01) for each depot, with R² = 0.97, 0.99, and 0.97, and SE = 0.61, 0.93, and 1.41, respectively. All empirical equations except for DNA were challenged with independent data sets (n = 12 and 10 for SUB and VIS equations and n = 9 for the initial INTER, INTRA, SUB, and VIS fat depots). The mean biases were −2.21 (P = 0.12) and 2.11 (P < 0.01) kg for the SUB and VIS equations, respectively, and 0.05 (P = 0.97), −0.37 (P = 0.27), 1.82 (P = 0.08), and −1.50 (P = 0.06) kg for the initial contributions of INTER, INTRA, SUB, and VIS fat depots, respectively. The random components of the mean square error of prediction were 73 and 26% for the SUB and VIS equations, respectively, and similarly were 99, 85, 62, and 61% for the initial contributions of INTER, INTRA, SUB, and VIS fat depots, respectively. Both the SUB and VIS equations predicted accurately within the bounds of experimental error. The equations to predict initial fat contribution (kg) were considered adequate for initializing the fat depot differential equations for the DGM and other beef cattle simulation models.

Key words: beef cattle, carcass, deoxyribonucleic acid, fat, subcutaneous, visceral

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INTRODUCTION

Simulation of beef cattle growth is an essential tool for maintaining a profitable and sustainable beef industry. Several models have been developed to predict retained energy and growth rate (Lofgreen and Garrett, 1968; Fox et al., 1992; NRC, 1996). Several models are based on metabolic processes (France et al., 1987; Gill et al., 1989), and some include DNA accretion and protein-to-DNA ratios (Oltjen et al., 1986; Bywater et al., 1988; Di Marco and Baldwin, 1989).
The Davis growth model (DGM) is built on the dynamic steer growth model of Oltjen et al. (1986), which predicts accretion (in kg) of total body protein and total body fat (TBF). The DGM was updated (Sainz and Hasting, 2000) to partition TBF into 4 fat depots (intermuscular, INTER; intramuscular, INTRA; subcutaneous, SUB; and visceral, VIS). To produce industry-relevant outputs, 3 of the fat depots are converted to carcass characteristics: INTRA (kg) to intramuscular fat (%); SUB to 12th-rib fat thickness (FT, mm); and VIS to KPH (kg) and then to KPH (%). Conversely, data on fat depot weights are scarce; therefore, it is often necessary during the modeling process to convert from commonly reported carcass characteristics to fat depot weights.

The objectives of this study were to 1) replace the Sainz and Hasting (2000) equation for interconversion between FT and SUB, using a more extensive data set; 2) develop an equation for interconversion between KPH (kg) and VIS; 3) develop equations to predict the initial conditions of the differential equations for DNA and fat contribution in each of the fat depot models; and 4) challenge the accuracy and precision of the interconversion and initial condition equations using independent data sets.

**MATERIALS AND METHODS**

Animal Care and Use Committee approval was not obtained for this study because the data were obtained from existing publications.

The approach taken in this study was to assemble 2 data sets and then use one to develop empirical interconversion and initialization equations and then challenge those equations using the second data set. In some cases, the data that were reported had to be converted to more useful units, and variables (e.g., frame size) had to be computed based on available data and known relationships.

**Calculation of Frame Size**

Frame size is an important determinant of growth and body composition, and this is represented in the DGM. The frame size (FS) calculation (Eq. [1]) was based on the industry scale of 1 to 9 that corresponds to mature empty body weight (MEBW) of 550 to 950 kg (BIF, 2002), as follows:

\[
FS = [(\text{MEBW} - 750)/50] + 5. 
\]  

where the reference EBW (EBW_{ref}) was estimated from the inverse (Eq. [3]) of the TBF vs. EBW relationship of Simpfendorfer (1974), which was developed using chemical fat data from implanted steers, as follows:

\[
\text{EBW}_{\text{ref}}, \text{kg} = 0.0633 \times \text{TBF} + 40.96 \times \text{TBF}^{0.5} - 17.13. 
\]  

where the reference EBW (EBW_{ref}) was estimated from the inverse (Eq. [3]) of the TBF vs. EBW relationship of Simpfendorfer (1974), which was developed using chemical fat data from implanted steers, as follows:

\[
\text{EBW}_{\text{ref}}, \text{kg} = 0.0633 \times \text{TBF} + 40.96 \times \text{TBF}^{0.5} - 17.13. 
\]  

Mature empty body weight (MEBW) was calculated using the following relationship (Eq. [2]):

\[
\text{MEBW}, \text{kg} = \frac{\text{MEBW}_{\text{ref}} \times \text{EBW}}{\text{EBW}_{\text{ref}}}, 
\]  

where the reference EBW (EBW_{ref}) was estimated from the inverse (Eq. [3]) of the TBF vs. EBW relationship of Simpfendorfer (1974), which was developed using chemical fat data from implanted steers, as follows:

\[
\text{EBW}_{\text{ref}}, \text{kg} = 0.0633 \times \text{TBF} + 40.96 \times \text{TBF}^{0.5} - 17.13. 
\]  

Mature empty body reference (MEBW_{ref}) values were as follows: MEBW_{ref} = 600, 750, and 900 kg; for small-, medium-, and large-framed steers (BIF, 2002; frame scores 2, 5, and 8), respectively. At the same body composition, cattle implanted with an estrogenic implant have increased protein content of gain equivalent to a 35-kg change in the final shrunk BW at the expected final TBF (NRC, 1996). The development and challenge data (Charles and Johnson, 1976; Robelin, 1981; Cianzio et al., 1982; Perry and Arthur, 2000) for the interconversion equations were from nonimplanted steers, and therefore, observed weights were adjusted upward by 35 kg.

**Conversion of Carcass Characteristics to Fat Weights**

Data obtained by dissection of SUB fat and omental, mesenteric, pelvic (channel), and kidney fat from the carcass and viscera were used to develop equations for interconversion between commonly reported carcass characteristics [i.e., FT, KPH (%), marbling scores] and dissected fat in kilograms. The ratio (estimated coefficient/estimated coefficient) was used to assess the bias associated with measurement error (Robinson, 2005). The observed variance for FT, SUB, KPH (kg), and VIS was 200 mm², 828 kg², 27 kg², and 167 kg², respectively. The error variance assumption for FT, SUB, KPH (kg), and VIS was 1 mm², 20 kg², 1 kg², and 10 kg², respectively. The ratio for FT vs. SUB and SUB vs. FT was 0.01 and 0.02%, respectively, and the bias for KPH (kg) vs. VIS and VIS vs. KPH (kg) was 0.06 and 0.04%, respectively. The low ratios, based on the assumptions given, for FT vs. SUB and SUB vs. FT, and for KPH (kg) vs. VIS and VIS vs. KPH (kg), indicate that there was no bias between the slopes, and therefore, each equation can be interconverted. The variable for each relationship with the lowest observed variance was chosen as the independent variable [i.e., FT and KPH (kg)]. For the reverse calculations, the equations are simply inverted. This procedure was adopted rather than fitting the inverted regression to ensure a constant bidirectional relationship between the variables. The DGM predicts accretion of chemical fat; therefore, all dissected fat
values were converted to chemical fat by multiplying fat weights by 0.8, based on the report by Allen et al. (1976) that adipose tissue contains 80 to 90% extractable lipids.

For this study, VIS fat was assumed to comprise omental, mesenteric, kidney, pelvic, and heart fat. However, heart fat was not measured in the Perry and Arthur (2000), Charles and Johnson (1976), or Cianzio et al. (1982) studies and therefore was not included in development of the equations nor the independent challenge to the empirical equations. Because this is a minor component of VIS, the effect of its absence should be negligible. The VIS fat interconversion equation relates to KPH (kg), but because KPH (%) is the carcass characteristic that is commonly reported, this was multiplied by HCW to obtain KPH (kg).

Development of Subcutaneous and Visceral Fat Equations. The interconversion equations for both SUB and VIS fat were developed using data from Perry and Arthur (2000) that consisted of body composition data collected in a serial slaughter of 91 Angus steers to 2 yr of age. Perry and Arthur (2000) examined 3 selection lines after 12 yr of selection from birth to weaning; that is, high and low growth rate lines and an unselected control line. After slaughter, the noncarcass fat depots (omentum, mesenteric, kidney, pelvic, and testicular) were weighed separately, and SUB and INTRA along with muscle and bone were dissected from the right side of the carcass. Although not reported in their paper, FT was provided for this study (D. Perry, personal communication). The FT covering the LM was measured 4 cm medial to the lateral border of the muscle, and SUB fat was dissected from the right side of the carcass. Frame sizes of individual steers were calculated as described above. The average FS was then assigned to each selection line for each year. A summary of the development data, after removal of outliers (observations with residuals greater than 3 SD of the mean), is shown in Table 1. The interconversion equations were developed using the following fixed effect models: SUB (Eq. [4]) and VIS (Eq. [5]), where FT and FS were included in Eq. [4] and kidney + pelvic fat (kg), herein referred to as KPH (kg), and FS were included in Eq. [5], as follows:

\[
\text{SUB}, \text{kg} = \beta_0 + \beta_1 \text{FT} + \beta_2 \text{FS} + \beta_3 \text{(FT × FS)} + \varepsilon, \text{ and} [4]
\]

\[
\text{VIS}, \text{kg} = \beta_0 + \beta_1 \text{KPH} + \beta_2 \text{FS} + \beta_3 \text{(KPH × FS)} + \varepsilon. \text{ and} [5]
\]

Challenge of Subcutaneous Fat Equation.

The prediction equation for SUB predicted from FT and FS was challenged using data from the study of Charles and Johnson (1976) of breed differences among 10 Angus, 11 Hereford, 12 Friesian, and 10 Charolais (Charolais × Friesian, Charolais × Australian Short horn) steers in the amount and distribution of carcass dissectible fat. A summary of the challenge data for FT and SUB is also presented in Table 1.

Challenge of Visceral Fat Equation.

The equation for prediction of VIS from KPH was challenged using data from Cianzio et al. (1982), who reported the distribution and pattern of growth for adipose tissue depots in carcasses from 40 steers [Limousin, Maine Anjou, and crossbred cows (either 2-, or 3-way crosses among Angus, Hereford, Holstein, and Brown Swiss breeds)] representing 2 FS and slaughtered serially from 11 to 19 mo of age. Contributions of dissectible fat depots (%) vs. TBF of slaughtered steers were reported, and 5 values (omental, mesenteric, kidney, and pelvic) for large and small FS (i.e., n = 10) at 11 to 19 mo of age were interpolated from a graph (Cianzio et al., 1982). A summary of the challenge data for VIS and kidney and pelvic fat (kg) is also presented in Table 1. The data of Cianzio et al. (1982) could not be used to challenge the SUB interconversion equation, because FT was not reported.

Fat Depots

Initial Fat Depot DNA.

Equations to predict initial fat depot DNA for the initial conditions of the differential equations were developed using data from Robelin (1981) for INTER, SUB, and VIS fat depots and data from Cianzio et al. (1985) for the INTRA fat depot. The Robelin (1981) data comprised 25 Charolais and 25 Friesian bulls; bulls were slaughtered at 15, 25, 35, 45, 55, and 65% of the estimated mature BW, and the average number of cells in INTER, SUB, and VIS adipose tissue depots was determined. The Cianzio et al. (1985) data comprised 40 crossbred steers slaughtered at 11, 13, 15, 17, and 19 mo of age, and the total number of INTRA adipocytes was estimated. The DNA was estimated as the number of cells × 6.2 pg/cell (Baldwin and Black, 1979).

Equations were developed using EBW, adjusted to a reference value for the degree of maturity (Eq. [2]), as the independent variable. A summary of the initial DNA development data for INTER, INTRA, SUB, and VIS depots is shown in Table 2.

The initial DNA equations were developed using a simple linear regression model, with EBW as the predictor (Eq. [6]):

\[
\text{DNA}_i = \beta_0 + \beta_1 \text{EBW} + \varepsilon_i, \text{ and} [6]
\]

where i = 1, ..., 4 for each fat depot.

There were insufficient data available to challenge the DNA equations.

Initial Fat Depot Contributions.

Equations to predict the initial fat depots as initial conditions for the differential equations of the DGM were developed using the data of Johnson et al. (1972) that included the relative proportions (%) of 5 fat depots to the total carcass fat (kg). The relative contribution of kidney and pelvic (channel) fat, converted to kilograms, was used to cal-
culate VIS, which was then added to the total carcass fat to give TBF. A summary of TBF, INTER, INTRA, SUB, and VIS (kg) is shown in Table 3. The initial fat depot contributions for INTRA, SUB, and VIS \((i = 1 \ldots 3)\) were developed using a simple linear regression model, with TBF as the predictor (Eq. [7]).

\[
FAT_i, \text{kg} = \beta_{0i} + \beta_{1i} \times TBF + e_i, \quad [7]
\]

where \(i = 1, \ldots, 3\) for each depot. Intermuscular fat was found by difference.

Equations were challenged using initial slaughter carcass characteristics reported by Schoonmaker et al. (2002), Hersom et al. (2004), and Bruns et al. (2005). All carcass characteristics were converted to their respective kilograms of fat for each fat depot: intramuscular (%) to INTRA, FT (mm) to SUB (kg), KPH (%) to KPH (kg) and then to VIS (kg), and INTER fat by difference (Table 3).

**Statistical Analyses**

Empirical equations were developed using linear regression in S-Plus (version 7.0 for Windows, Insightful Corporation, Seattle, WA). All 2-way interactions were evaluated for the SUB and VIS interconversion equations. Quadratic terms were included to test for nonlinear trends. Terms in the models were evaluated at \(P < 0.05\) for the SUB and VIS interconversion equations and the fat depot equations and \(P < 0.1\) for the DNA equations. In developing the DNA equations, the \(P < 0.1\) level of significance was applied, because there was a limited amount of data. Evaluation of empirical equations was performed using the mean bias \([\Sigma(\text{observed value} - \text{predicted value})/n]\), the mean square error of prediction (MSEP), and the decomposition of the MSEP into bias, slope, and random components as proportions of MSEP (Tedeschi, 2006). The statistical significance of each mean bias was evaluated using a

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**Table 1.** Summary of development (Perry and Arthur, 2000; D. Perry, personal communication) and challenge data for frame size, 12th-rib fat thickness (FT), and subcutaneous (SUB), visceral (VIS), and KPH fat (Charles and Johnson, 1976; Cianzio et al., 1982)

<table>
<thead>
<tr>
<th>Item</th>
<th>Development data</th>
<th>Challenge data1</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Frame size1</td>
<td>FT, mm</td>
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<tr>
<td>n</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.20</td>
<td>0</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.40</td>
<td>53</td>
</tr>
<tr>
<td>Mean</td>
<td>4.13</td>
<td>19.62</td>
</tr>
<tr>
<td>SD</td>
<td>0.93</td>
<td>14.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>n</td>
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<tr>
<td>Minimum</td>
<td></td>
<td>2.80</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td>19.00</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>9.18</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>5.55</td>
</tr>
</tbody>
</table>

1Frame sizes are not presented for the challenge data, because they were excluded from the models.

---

**Table 2.** Summary of development data of empty body weight (EBW) and DNA contributions for intermuscular (INTER), subcutaneous (SUB), and visceral (VIS) fat depots (Robelin, 1981) and for intramuscular (INTRA) fat depots (Cianzio et al., 1985)

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td></td>
<td>DNA, g</td>
<td>DNA, g</td>
</tr>
<tr>
<td>EBW, kg</td>
<td>INTER</td>
<td>SUB</td>
</tr>
<tr>
<td>n</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Minimum</td>
<td>110</td>
<td>0.180</td>
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<tr>
<td>Maximum</td>
<td>511</td>
<td>0.304</td>
</tr>
<tr>
<td>Mean</td>
<td>312</td>
<td>0.228</td>
</tr>
<tr>
<td>SD</td>
<td>149</td>
<td>0.047</td>
</tr>
</tbody>
</table>
paired *t*-test of the mean of the difference between the observed and the model-predicted values. A plot of the residuals vs. fitted values was used to check for outliers and homogeneity of variance, and a normal QQplot of residuals was used to evaluate the assumption for linear regression that the data were normally distributed. Absolute values of residuals >3 × the SD were considered outliers. A robust regression procedure (lmRobMM) was used to test for bias associated with outliers and leverage points.

**RESULTS**

Data were diagnostically tested for outliers, homogeneity of variance, normal distribution, and leverage points. One outlier was removed from each data set for both the SUB and VIS interconversion equations based on the absolute residual being greater than 3 SD. The data were normally distributed and did not require transformation. There was no bias (*P* > 0.2) associated with outliers or leverage points in any of the models developed.

**Conversions of Carcass Characteristics to Fat Depot Weights**

**Subcutaneous Fat.** The final prediction equation for SUB (Eq. [4]) included FT (*P* < 0.01) but not FS (*P* = 0.52) in the model (Eq. [8]; Figure 1). The quadratic term for FT was not significant at *P* < 0.01. The relation-

![Figure 1](image)

**Figure 1.** Simple regression line of observed dissected subcutaneous fat vs. 12th-rib fat thickness at 2 frame sizes (small and medium).
ship between subcutaneous fat and 12th-rib fat shows a strong linear trend (Figure 1), and the 2 categories (small and medium FS; Figure 1) showed no significant differences between FS when predicting SUB fat.

\[
\text{SUB, kg} = 4.35 \pm 1.98 + 1.89 \pm 0.08 \times \text{FT} \\
(R^2 = 0.88, \text{SE} = 10.00). \quad [8]
\]

Results of the independent challenge to the SUB equation (Eq. [8]) are shown in Figure 2. Figure 2(a) illustrates the differences between observed and predicted values. There is a general spread of over- and underprediction over the range of observed values. Figure 2(b) illustrates the deviation of the difference between the predicted and observed values. The low mean bias for SUB was not different from zero \((P = 0.12; \text{Table 4})\). The MSEP quantifies the variation shown in Figure 2(b), and the decomposition of MSEP indicated that 73% of the error was attributed to random error [i.e., unexplained variance (Table 4)].

**Visceral Fat.** The regression equation for VIS (Eq. [5]) included KPH (kg) and FS \((P < 0.01)\) in the model (Eq. [9]; Figure 3). The quadratic term was not significant \((P = 0.75)\). The relationship between VIS fat and KPH (kg) shows a strong linear trend (Figure 3). The FS was subsequently excluded from the model for several reasons: inclusion of FS only increased \(R^2\) from 0.948 to 0.954 and reduced the SE from 2.96 to 2.82; reliable FS data are often unavailable; and bidirectional interconversion is more convenient without FS in the model. Therefore, the final prediction equation for VIS included only KPH (kg).

\[
\text{VIS, kg} = 2.32 \pm 0.62 + 2.42 \pm 0.06 \times \text{KPH, kg} \\
(R^2 = 0.95, \text{SE} = 2.82). \quad [9]
\]

Results of the independent challenge to the VIS fat equation (Eq. [9]) are shown in Figure 4. Figures 4 (a and b) and the positive mean bias (Table 4) illustrate that the model underpredicted most of the observed values. The mean bias for VIS was 2.11 kg \((P < 0.01)\). The MSEP for VIS and its decomposition indicated that only 26% of the error was attributed to random error and the majority (61%) to the bias, which is evident from Figure 4(b).

**Fat Depots**

**Initial Fat Depot DNA.** The final prediction equations for DNA included only the linear term EBW in the models for INTER \((\text{DNA}_{\text{inter}}; P = 0.08)\), INTRA \((\text{DNA}_{\text{intra}}; P < 0.01)\), SUB \((\text{DNA}_{\text{sub}}; P < 0.01)\), and VIS \((\text{DNA}_{\text{vis}}; P = 0.05)\) fat depots (Eq. [10] to [13]; Figure 5). None of the quadratic terms were significant \((P = 0.56, 0.80, 0.94, \text{and} 0.57 \text{for} \text{DNA}_{\text{inter}}, \text{DNA}_{\text{intra}}, \text{DNA}_{\text{sub}}, \text{and} \text{DNA}_{\text{vis}} \text{respectively})).

\[
\text{DNA}_{\text{inter}}, g = 0.1534 \pm 0.03 + 0.0002 \pm 0.0001 \times \text{EBW} \\
(R^2 = 0.57, \text{SE} = 0.03), \quad [10]
\]
Results of several challenges to the initial INTRA, SUB, and VIS fat depots (Eq. [14] to [16]) and by difference for INTER are shown in Figure 7 and Table 5. The mean biases for INTER, INTRA, SUB, and VIS were not significantly different from zero \((P > 0.05)\). The decomposition of the MSEP indicated that the majority of the error was attributed to the random component (i.e., unexplained variances were 99, 85, 62, and 61\% for the INTER, INTRA, SUB, and VIS fat depots, respectively).

**DISCUSSION**

The DGM (Oltjen et al. 1986; Sainz and Hastings 2000) and other models of cattle growth and composition have the potential to 1) assist the beef industry to meet market specifications by predicting final carcass characteristics at feedlot entry and 2) increase our understanding of the metabolic processes of converting feed to salable meat products. These models generally predict fat deposition in each of the depots in kilograms; therefore, they require empirical relationships that interconvert kilograms of fat and carcass characteristics. For dynamic models such as the DGM, additional equations are required to initialize the differential equations that represent fat deposition.

A limited number of published studies (Johnson et al., 1972; Charles and Johnson, 1976; Cianzio et al., 1982; Early et al., 1990; Perry and Arthur, 2000; Richardson et al., 2001) have reported data on dissected carcass (SUB and INTER) and noncarcass (omental, mesenteric, kidney, pelvic, and heart) fat depots of steers. The suitability of each study for model develop-
ment or evaluation depends on the data available and the methods used. For example, the Early et al. (1990) study was not used because there were only 2 treatments and no serial slaughters, and the Richardson et al. (2001) study was not used because 3 mm of fat trim was left on the meat cuts. Studies available for developing empirical equations are limited, because the separation of fat from the gastrointestinal tract after slaughter and dissection of carcasses is very laborious. Future studies using tomography (Thompson and Kinghorn, 1992) may provide the additional data to further develop the empirical relationships. The present study required judicious use of available data; additional data relating carcass observations to anatomical and physical measurements in cattle of different breeds, sexes, ages, weights, and compositions would certainly be useful.

Independent data sets were used in this study to first develop and then challenge and evaluate equations and identify weaknesses that require further research. In this context, the term challenge means that an independent data set has been used to determine the accuracy and precision of the equations developed. The graphical displays (Figures 2, 4, and 7) visually depict equation behavior, and the statistical analyses (Tables 4 and 5) quantify their adequacy. The mean bias is helpful in assessing whether the model is either over- or underpredicting, and the decomposition of the MSEP into bias, slope, and random components provides an indication of the adequacy of the model for prediction where the terms bias and slope are self-explanatory. Finding the majority of the error in the random component suggests that there is no systematic error of prediction [i.e., the model is adequate for prediction even though further improvements (for ex-

Figure 4. Plot of (a) observed vs. model predicted and (b) the residual (observed – model predicted) for visceral fat.

Figure 5. Simple regression lines of observed DNA in (a) intermuscular, (b) intramuscular, (c) subcutaneous, and (d) visceral fat depots vs. empty body weight (EBW).
ample, reduction in the MSEP) may be possible when additional data become available.

The Perry and Arthur (2000) data set of serially slaughtered steers from 0 (birth) to 47 mo of age has provided a solid platform to develop conversion equations from FT to SUB and from KPH (kg) to VIS. The descriptive statistics of Perry and Arthur (2000) for both the SUB and VIS equations covered a wide range, and the challenge data from Charles and Johnson (1976) and Cianzio et al. (1982) for SUB and VIS, respectively, were within the range of the development data (Table 1).

Figure 1 indicates a strong linear relationship between FT and SUB. The extensive study of Perry and Arthur (2000) provided additional data that has strengthened the relationship as opposed to the smaller data set of Charles and Johnson (1976) used by Sainz and Hasting (2000). Results of the SUB equation challenge (Table 4 and Figure 2) indicate that the equation predicts accurately and with precision within the bounds of experimental error; therefore, it was considered adequate for prediction. The SUB equation confirms the Cianzio et al. (1982) study that concluded that the FT was a good estimator of SUB fat content.

Figure 3 indicates a strong linear relationship between KPH and VIS. The VIS equation challenge (Table 4 and Figure 4) suggests that the equation, on average, underpredicts VIS by 2.11 kg. This was confirmed by the decomposition of the MSEP (61% bias and 13% slope). Only 26% of the MSEP for VIS was attributed to the random component. These results suggest that caution must be applied in the prediction of VIS using this equation. It is possible that the bias in the VIS equation is due to differences in the types of animals or experimental protocols between the development and challenge data sets. A ±6-kg deviation between 20 and 41 kg of observed VIS fat (kg) was considered within experimental error [Figure 4(b)], and hence, the equation was considered barely adequate. As additional data become available, further improvements can be made to this equation.

The initial fat depot DNA equations generally indicate a strong relationship between the variables (Figure 5). Unfortunately, there were no challenge data available for the DNA fat depot equations. Studies on the cellularity of bovine adipose tissues are scarce, and additional data are required to challenge and improve the prediction equations presented in this study. These empirical equations are the best that could be developed to initialize the DNA differential equations. Linear relationships were developed in this study but non-linear relationships between adipocyte volume and chemical fat weight in sheep have been shown by Broad et al. (1980), Thompson et al. (1988), and Thompson and Butterfield (1988). Truscott et al. (1983) showed a non-linear trend between age (200 to 600 d) and the number of fat cells in major fat depots in cattle. Hood and Thornton (1979) reported a linear relationship, similar to this study, between adipocyte fat weights in the carcass. Thompson et al. (1988) argued that the non-linear relationship may not have been apparent, because the data used to develop the relationship was over a small age range. Data used to develop the equations for DNA in INTER, SUB, and VIS fat depots in the current study ranged in EBW from 110 to 511 kg (Table 2) and may also have been too small a range. The nonsignificance of the quadratic term in these models indicated that there was no nonlinear trend. The linear regression equations for predicting the initial condition of DNA, in this current study, will adequately initialize
Figure 7. Plot of (a1, b1, c1, and d1) observed vs. model predicted and (a2, b2, c2, and d2) the residual (observed − model predicted) for (a) intermuscular, (b) intramuscular, (c) subcutaneous, and (d) visceral fat depots.
the logistic DNA fat deposition differential equations in the DGM.

The development (Johnson et al., 1972) and challenge (Schoonmaker et al., 2002; Hersom et al., 2004; Bruns et al., 2005) data for the initial fat depot contribution equations covered a wide range (Table 3). Results of the initial fat depot challenge (Table 5 and Figure 7) indicate that the models are adequate, because the random components of MSEP were high (99, 85, 62, and 61% for INTER, INTRA, SUB, and VIS, respectively). The initial fat depot equations for SUB and VIS had biases of 33 and 38%, respectively, but nonetheless, these models were the best that could be developed given the available data.

The empirical equations developed in the present study were developed to interconvert between FT and SUB and between KPH and VIS and also to provide initial conditions for both DNA and fat depot differential equations. All empirical equations with the exception of the DNA equations were challenged using independent data sets. The equations developed in this study will be incorporated into the fat deposition module of the DGM as part of an ongoing program for modeling beef cattle growth and carcass quality.

### LITERATURE CITED


