Genetic Parameter Estimates for Ultrasonic Meat Qualities in Hanwoo Cows

D. H. Lee*, V. Choudhary and G. H. Lee[1]
Department of Animal Life and Resources, Hankyong National University, Anseong city
Kyeonggi-Do, 456-749, Korea

ABSTRACT : Real time ultrasound data was generated on 10,596 live Hanwoo cows to study genetic variation on ultrasonic beef quality traits and to assess the best model to estimate genetic parameters on these traits. Pedigree stacking and data validation was done using the SAS statistical software and the genetic parameter estimates were obtained by EM-REML algorithm. Out of the five different multi-trait mixed animal models constructed, the optimal model included fixed effects of herd, year-season-appraisal, body condition score, linear and quadratic covariates for chest girth, the linear covariate effect of age and the random animal and residual effect of the five models studied. The heritability of longissimus muscle area (LMA), 12^{th} rib measurement of back fat thickness (BF) and marbling score (MS) was 0.11, 0.17 and 0.15, respectively. Genetic correlation of LMA vs. BF, LMA vs. MS and BF vs. MS was -0.15, 0.06 and 0.61, respectively. The results showed presence of genetic variation in these ultrasonic beef quality traits in Hanwoo cows and suggest that the selection of Hanwoo cows may be possible by performing ultrasonic scans on live animals, which will ultimately be helpful in reducing the generation interval and the cost of selection procedure. ***(Asian-Aust. J. Anim. Sci. 2006. Vol 19, No. 4 : 468-474)***

Key Words : Hanwoo Cows, Ultrasound, Beef Traits, Genetic Parameters

INTRODUCTION

Consumer's demand regarding animal food quality and safety is gaining importance in new millennium. This emphasis has led to an increased awareness among the breeders towards carcass merit and selection of breeding cattle for beef quality traits. Measurement of these traits on live breeding cows is feasible by using the real time ultrasound technology, which is being used to estimate the fat thickness and muscle development for the genetic improvement of the population and is considered as a cost-effective method (Wilson, 1992; Kemp et al., 2002). These real time ultrasonic carcass data on these traits helps in not only to evaluate a larger and more random sample of bulls within a population, but also to evaluate the genetic potential of females (Crews and Kemp, 2002). Several studies have shown that ultrasonic measurement of beef traits in yearling bulls and heifers have positive genetic correlations with corresponding carcass traits of progeny (Moser et al., 1998; Reverter et al., 2000; Bertrand, 2000; Lee and Kim, 2004).

Genetic evaluation of beef quality traits requires estimation of genetic parameters among the traits to be evaluated. Several authors have estimated genetic parameters for various carcass traits obtained by using ultrasound on live animals (Benyshek, 1981; Wilson et al., 1993; Robinson et al., 1993; Shepard et al., 1996). Study on ultrasonic beef traits on breeding cows is still lacking in the literature. Several studies by way of genetic aspects have been published on carcass traits measured on fatten Hanwoo cattle (Lee et al., 2001; Baik et al., 2002; Park et al., 2002; Lee, 2004), and few studies on ultrasonic beef quality traits on Hanwoo steers are also present in the literature (Lee and Kim, 2004). Marbling score which is mainly indicated for meat quality would be high heritable (Lee et al., 2001; Lee, 2004) in Korean cattle. Furthermore, beef farmers in Korea have a tendency to prefer Korean cattle rather than other breeds and rearing dual purpose of breed stock and fatten cattle. Therefore, many farmers are going to measure ultrasound meat quality for producing progenies even though the physiological differences between cow and bull/steers may affect the beef traits differently. So there is a need to study the variation on these ultrasonic beef traits on breeding cows. The present study was undertaken with the objectives to evaluate genetic variation on ultrasonic beef quality traits on live Hanwoo cows and to access the optimal model to estimate genetic parameters of these traits.

MATERIALS AND METHODS

Data

Ultrasonic measurements for various beef quality traits were recorded on a total of 10,596 live Hanwoo cows of South Korea. The observations were recorded during the period from 2001 to 2004. The real time ultrasound machine named as Medison-SV900 with 3.5 MHz frequency (Medison Co., Ltd) was used to capture images. Before scanning, the appropriate area was made free of dirt and debris and vegetable oil was then applied to ensure proper transducer-guide-animal contact. The technicians were trained to minimize error in recording of the ultrasonic

* Corresponding Author: D. H. Lee. Tel: +82-31-670-5091, Fax: +82-31-676-5091, E-mail: dhlee@hknu.ac.kr
[1] Korean Animal Improvement Association, Seoul 137-073, South Korea.
Received July 5, 2005; Accepted September 21, 2005

Table 1. General performances on meat quality traits in Hanwoo cows

	No. obs.	Mean±SD	Min.	Max.
No. progenies/sire	132	64.51±93.05	5.0	821.0
No. cows/ herd	629	13.54±17.86	3.0	247.0
Age (Mo)	8,515	38.33±14.74	16.0	100.0
Inbreeding coefficient (f)	236	0.038±0.04	0.002	0.125
Traits				
LMA (cm^2)	8,515	61.36±10.53	28.0	100.0
BF (mm)	8,515	5.54±3.39	0.3	41.5
MS (score)	8,515	6.51±3.35	1.0	21.0
BCS (score)	8,515	4.41±1.36	1.0	8.0
Chest girth (cm)	8,515	179.06±8.56	153.0	230.0

images. The traits studied by ultrasonic images were longissimus muscle area (LMA) at the 12^{th}-rib cross-section, measurements of 12^{th}-rib fat thickness (BF), and the marbling score (MS). The marbling score was assigned on seven points scale as per the existing standards for measurement at the start of the experiment in Korea and was then converted into 21 grade points based on a three way division of each of the seven marbling grades. The animals were also physically evaluated and were given Body Condition Score (BCS) with range of 1 to 8 scores. The chest girth was measured manually. The general performance of Hanwoo cows for beef quality traits and data statistics are presented in Table 1. The ultrasonically observed cows were the progenies of 132 sires and the cows belong to 629 herds of South Korea.

The data was grouped in four seasons namely spring (March-May), summer (June-August), autumn (September-November) and winter (December-February). The year-season effects were grouped as one interaction effect during analysis. Record on animals aging more than 100 months or less than 16 months were excluded from the genetic analysis. Records not having observations on both the chest girth and the body condition score were also deleted. The final data file after removing outliers was having 8,515 records.

The pedigree file containing all the Hanwoo animals of the country was available to find ancestors of animal with records and pedigree of each recorded animal was traced back up to five generations using SAS data step procedures (SAS-9.1, SAS Inst., Inc., Cary, NC). These steps tested the validity of the pedigree tree for each animal observed for the beef traits. At this step the pedigree file was having 18,782 records. Out of 18,782 animals in the final pedigree file, 236 animals were inbred with maximum inbreeding coefficient of 0.125. The average inbreeding coefficient among these 236 animals was 0.04.

Statistical analysis

The structured data and pedigree files were then analyzed to get genetic parameter estimates for LMA, BF and MS traits. Data were analyzed with a multivariate animal model using software that uses an EM-REML algorithm (Misztal, 2001) to obtain the (co)variance components estimates.

Models

Genetic parameters were estimated for LMA, BF and MS using multi-trait animal model. Before variance component analyses, the GLM procedure of SAS (SAS, Ver. 9.1, SAS Inst., Inc., Cary, NC) was used to test the significance of fixed effects of herd, year-season interaction, body condition score, linear and quadratic effect of age (covariate), and linear and quadratic effect of chest girth (covariate). The linear effect of chest girth was significant ($p<0.001$) for LMA and BF, so included in the genetic analyses. The quadratic effect of age was significant ($p<0.001$) for only MS but not for LMA and BF. The linear effect of age was closer to significance ($p<0.06$) for two of the traits i.e. BF and MS. A total of five models were run to access the best model to estimate the genetic parameters for the ultrasonic beef traits.

The Model 1 was:

$$Y_{ijkl} = \mu + Herd_i + YS_j + BCS_k + b_1Age_{ijkl} + b_2Age^2_{ijkl} + b_3CG^2_{ijkl} + a_l + e_{ijkl}$$

Where Y_{ijkl} = observation on lth cow belonging to ith herd recorded in jth class of year season with kth score for BCS; μ = overall mean; $Herd_i$ = fixed effect of ith herd; YS_j = fixed effect of jth class of year-season of observation on cow; BCS_k = fixed effect of kth score for BCS of the cow; Age_{ijkl} = fixed effect of age of cow considered as a covariate; Age^2_{ijkl} = fixed quadratic effect of age of the cow considered as a covariate; CG_{ijkl} = fixed effect of chest girth of the cow considered as a covariate; CG^2_{ijkl} = fixed quadratic effect of chest girth considered as a covariate; b_1, b_2 = regression coefficient of Y on age, linear and quadratic effects; b_3, b_4 = regression coefficient of Y on chest girth, linear and quadratic effects; a_l = random additive genetic effect of l^{th} animal with assumption of $a\sim N(0, A\sigma^2_a)$; and e_{ijkl} = random residual error with assumption of $e\sim N(0, I\sigma^2_a)$.

Other four models were modified from Model 1. The

Table 2. Genetic and environmental (co)variance component estimates for LMA, BF and MS on Model 2 in Hanwoo cows

	LMA	BF	MS
Residual			
LMA	42.040	5.254	5.130
BF	5.254	5.086	0.830
MS	5.130	0.830	6.246
Genetic			
LMA	5.092	-0.340	0.144
BF	-0.340	1.036	0.655
MS	0.144	0.655	1.116

LMA = 12th-rib longissimus muscle area, in cm^2.
BF = 12th-rib back fat thickness, in mm; MS = marbling score.

Table 3. Genetic parameter estimates for LMA, BF and MS on Model 2 in Hanwoo cows

	LMA	BF	MS
LMA	0.11	-0.15	0.06
BF	0.36	0.17	0.61
MS	0.32	0.15	0.15

Diagonal: heritability; upper diagonal: genetic correlation.
below diagonal: environmental correlation.

Model 1, 2 and 3 were three trait model with considering LMA, BF and MS as dependent variables. The Model 2 does not include quadratic effect of age as fixed effect on Model 1. The Model 3 does not include quadratic effect of both the age and the chest girth on Model 1. The Model 4 was a four trait model with LMA, BF, MS and chest girth as dependent variables and herd, year-season, BCS, linear and quadratic effect of age as independent variable, while, the Model 5 (five trait model) was constructed same as Model 4 except that the BCS was considered as a trait (dependent variable).

The general model for all the models discussed above can be expressed as

$$Y_i = X_i\beta_i + Z_ia_i + e_i$$

where, Y_i = vector of measurements for trait i

X_i = known incidence matrix that relates fixed effects to measurements for trait i

β_i = vector of unknown fixed effects for measures of trait i

Z_i = known incidence matrix that relates recorded animal to measurements for trait i

a_i = unknown random vector of animal effects for measures of trait i

e_i = unknown random vector of residual effects that affects measures of trait i.

The assumption is

Table 4. Comparison of residual variance of beef traits obtained by different models

	Model 1	Model 2	Model 3	Model 4	Model 5
LMA	42.04	42.04	42.18	43.40	56.28
BF	5.09	5.09	5.10	5.30	6.32
MS	6.27	6.25	6.26	6.41	6.89
BCS	-	-	-	-	1.076
Chest girth	-	-	-	0.00159	0.00416

Table 5. Comparison of heritability of beef traits obtained by different models

	Model 1	Model 2	Model 3	Model 4	Model 5
LMA	0.1083	0.1080	0.1078	0.1170	0.1228
BF	0.1689	0.1692	0.1707	0.1572	0.1919
MS	0.1459	0.1516	0.1503	0.1388	0.1420
BCS	-	-	-	-	0.0352
Chest girth	-	-	-	0.0414	0.0480

$$\text{Var}\begin{bmatrix} a \\ e \end{bmatrix} = \begin{bmatrix} G \otimes A & 0 \\ 0 & R \otimes I \end{bmatrix},$$

Where A is a matrix of additive genetic relationship among animals, ⊗ is a Kronecker product function, G and R is covariance matrices of the random coefficients for animal and residual effects, respectively, I is an identity matrix.

RESULTS AND DISCUSSION

Comparison between different models

Generally, ultrasonic measured carcass traits on over 20 month of age from Hanwoo steer would be highly correlated (over 0.90) to the direct measured carcass traits (Kim et al., 2003). However, there is no report for these accuracies on Hanwoo cows because of lack of information. Nevertheless, estimation of genetic parameters on cows would be valuable because of selecting cows for breeding. The heritability estimates for the beef traits estimated by all the five models are presented in Table 5. The estimates were almost same for LMA, BF and MS for all the models except in Model 5 where higher estimates were obtained for LMA and BF traits. The residual (co)variances of the beef traits estimated by all the five models constructed are given in Table 4. Model 1, 2 and 3 yielded almost similar residual estimates but the estimates from Model 2 were the least for all the three traits. When Model 2 was compared with Model 4 (four trait) and 5 (five trait) it was observed that the residual variances were much higher for Model 4 and 5. Hence, the Model 2 with three traits i.e. LMA, BF and MS and with herd, year-season, BCS, linear effect of age, and linear and quadratic effect of chest girth as fixed effects was considered as the optimal model for estimating genetic parameters and is further discussed in the text.

Heritabilities

The variance and covariance component estimates of LMA, BF and MS for Model 2 are summarized in Table 2. Heritability estimates for LMA, BF and MS were 0.11, 0.17 and 0.15, respectively (Table 3). All the five models that were constructed gave almost similar heritability estimates for all the three traits. The low heritability estimates for LMA indicates presence of small additive genetic effects on LMA. Lee and Kim (2004) reported heritability estimate of 0.17 and 0.20 respectively for age-adjusted and weight-adjusted ultrasound longissimus muscle area in Korean cattle. Lee (2003) also reported the heritability estimate of 0.17 for LMA using Monte Carlo Simulations in Korean cattle. The present result of low heritability estimate of LMA was in agreement with Shepard et al. (1996) who reported heritability of 0.11 for this trait on ultrasonically measured yearling Angus bulls and heifers. Turner et al. (1990) also reported almost similar findings with heritability estimate of 0.12 on yearling Hereford bulls. Arnold et al. (1991) reported heritabilities for the ultrasonically measured longissimus muscle area to be 0.25 for weight constant, and 0.28 for age constant estimates in Hereford cattle. Medium estimates of heritability for the ultrasonic longissimus muscle area are also present in the literature. Robinson et al. (1993) reported a range of heritability of 0.18 to 0.25 for the longissimus muscle area in Angus and Hereford breeding stock. Stelzleni et al. (2002) and Moser et al. (1998) reported heritability estimate of 0.31 and 0.29, respectively, for the LMA measured on yearling Brangus bulls and heifers. Reverter et al. (2000) reported heritability estimates of 0.37 and 0.41 in Angus and Hereford bulls, respectively. Heritability estimate of 0.40 in Brangus cattle (Johnson et al., 1993) and 0.50 in Red Angus cattle (Evans et al., 1995) for longissimus muscle area are much higher as compared to the present results. These differences in the estimates of present study with those of previous studies may be due to different breeds and different populations which have the varying additive genetic variance for this trait. Besides the large sample size and different model of (co)variance estimation, the present investigation also differs from previous studies with respect to the kind of animal studied. The present study was solely on breeding cows from a single breed. There is a much difference in the physiological status of cow as compared to steers and bulls that are reared on high concentrate diet which has direct effect on the traits studied.

The present result shows a very low heritability of the longissimus muscle area (0.11). The genetic variance was 5 and the total phenotypic variance was 47.1 (Table 2). The phenotypic standard deviation for LMA was 6.9 cm^2 and the genetic standard deviation was 2.2 cm^2. The heritability of a trait depends on the population studied that may differ in the amount of phenotypic variation. As the variation will be less there will be low improvement due to selection for the trait.

The result shows that the ultrasonic measurement of 12^{th}-rib back fat thickness is medium to low heritable (Table 3). In agreement to the present findings, Johnson et al. (1993) and Moser et al. (1998) both reported lower estimates of the heritability of 0.14 and 0.11, respectively, for ultrasonically measured back fat thickness in Brangus cattle. Robinson et al. (1993) reported a range of heritability from 0.15 to 0.42 for the ultrasonic rib fat thickness in Angus, Hereford and Polled Hereford breeds of cattle. Turner et al. (1990) reported very low heritability estimate of 0.04 for this trait on yearling Hereford bulls. Arnold et al. (1991) and Lamb et al. (1990) estimated heritability of ultrasound back fat thickness as 0.26 and 0.24, respectively, in Hereford steers. Stelzleni et al. (2002) reported heritability estimate of 0.26 on live yearling Brangus bulls and heifers.

Kemp et al. (2002) reported age-adjusted heritability of 0.39 for ultrasound back fat thickness in Angus steers. Shephard et al. (1996) and Evans et al. (1995) reported heritability estimate of 0.56 and 0.50, respectively, for the back fat thickness in Angus cattle, which is much higher than the present findings. Lee and Kim (2004) also reported age-adjusted and weight adjusted heritability estimate of 0.41 and 0.52, respectively, for the back fat thickness in Korean Hanwoo steers. The difference in the present estimates to that of heritability estimates reported by Lee and Kim (2004) may be due to small sample size in previous study and those were measured on steers in contrast to the present study on breeding cows. Cows are maintained for the purpose of reproduction and it differs in physiological conditions to that of steers or bulls which are maintained for fatten purpose. The feeding environment for a cow is directed towards reproductive characters, which differ totally with that of the feeding of animals kept for fatten beef. According that the beef traits are influenced much by the feeding system (i.e. genotype environmental interaction) it may be possible to get different estimates for the same trait in these two different categories of animals.

The heritability for the ultrasonic marbling score on live Hanwoo cows was low (Table 3). Similar to the present estimates, Stelzleni et al. (2002) reported heritability estimate of 0.16 for intramuscular fat on live Brangus yearling bulls and heifers. However, Lee and Kim (2004) reported heritability estimate of 0.55 for ultrasound marbling score in Korean Hanwoo steers. The heritability of marbling score in terms of RTU-predicted percentage ether extract was 0.51 as reported by Kemp et al. (2002). Reverter et al. (2000) reported heritability of 0.47 for marbling score in terms of intramuscular fat percent. However, Izquierdo et al. (1997) reported heritability estimates of 0.81 and 0.84, respectively, for the intramuscular fat on both an age and a weight constant basis, which is much higher than the estimates obtained in the present study. The marbling score tend to be the most important beef quality trait as per consumer's choice. The marbling depends on genetic and management methods.

The present study shows very low heritability for the three beef quality traits in Hanwoo cows. This is the first report on estimation of genetic parameters for the ultrasonic beef quality traits on mature breeding cows. The breeding cows were reared for producing the animals for beef purpose and so they are given emphasis on reproduction aspect. The physiological differences between cow and fatten beef affects the beef traits differently. The diet with low fat contents was fed to breeding cows as compared to steers and bulls that are kept for fatten purpose. Thus this environmental difference directly affects the beef traits measured on cows when compared with the fatten beef. Such environmental differences also add to the difference in performances of cows and fatten animals for beef traits and that may lead to different estimates of genetic parameters.

Genetic and environmental correlations

Genetic and environmental correlations between the beef quality traits (Model 2) are presented in Table 3. The results show antagonistic relationship between LMA and BF. The genetic correlation estimate of -0.09 between the two traits was reported by Stelzleni et al. (2002) which is almost similar to the present result. Further, in concurrence to the present findings, Lee and Kim (2004) reported genetic correlation of -0.09 and 0.04 respectively for age adjusted and weight adjusted data for these traits in Korean Hanwoo steers. All models estimated negative relationship between these two traits except in Model 5 where the correlation was observed as 0.14, which is comparable with Moser et al. (1998) and Johnson et al. (1993), who cited genetic correlation between the ultrasonic longissimus muscle area and back fat as 0.13 and 0.12, respectively. Robinson et al. (1993) reported very low estimates of genetic correlation (0.05) between the two traits. However, Kemp et al. (2002) reported higher estimates than the present findings with genetic correlation of 0.23 and 0.03, respectively for two different models, between ultrasonic longissimus muscle area and ultrasonically predicted back fat thickness in Angus steers. Arnold et al. (1991) reported genetic correlation of 0.39 for the two traits adjusted to a weight constant and 0.48 for the two traits adjusted to an age constant between ultrasonic longissimus muscle area and the ultrasonic back fat thickness. The difference in sign between the estimates of Model 2 of the present study and the estimates reported by earlier workers may be due to differences in model which included different traits and different fixed effects for obtaining these estimates of genetic correlation between LMA and BF. This is also evident from the estimates of present study obtained from Model 2 (-0.15; three trait model) and Model 5 (0.14; five trait model), where BCS and chest girth were considered as traits in Model 5 and as fixed effects in Model 2.

Many studies suggested that the longissimus muscle area and back fat thickness are negatively correlated characters but it depends on the population studied and also on the model of its estimation. In this study, in Model 2, we included BCS and chest girth as fixed effects and the relationship between the LMA and BF was negative. When BCS and chest girth were not included as fixed effects and were analyzed as a dependent variable in Model 5, the relationship between LMA and BF becomes positive. This suggests that BCS and chest girth are correlated with the two traits and have significant effect on them thus altering the relationship between them. So BCS and chest girth should be considered as effects and not as traits when LMA and BF are considered as dependent variable. This also supports Model 2 as the optimal model for the genetic analysis of these beef quality traits.

The correlation between LMA and MS was close to zero, which indicated that selection for one trait will have negligible effect on the other. Lee and Kim (2004) reported almost similar relationship (0.04) between the two traits in Hanwoo steers for the weight-adjusted data, but differs with the estimates (0.17) from age-adjusted data. The genetic correlation estimates for Model 5 of the present study was 0.17 and is in agreement to the corresponding estimates reported by Lee and Kim (2004) on age-adjusted data on Hanwoo steers. Kemp et al. (2002) reported genetic correlation of -0.02 between the ultrasonic longissimus muscle area and the ultrasonically predicted percentage ether extract (ultrasonic percent intramuscular fat). Stelzleni et al. (2002) reported negative relationship with medium magnitude (-0.25) between the two traits in Brangus bulls and heifers.

The result shows a higher positive genetic correlation between ultrasonic back fat thickness and ultrasonic marbling score. All the five models of the present study have estimated similar relationship between the two traits. Stelzleni et al. (2002) estimated genetic correlation of 0.36 between the ultrasonic back fat thickness and the intramuscular fat in Brangus bulls and heifers, which supports the present results. However, Kemp et al. (2002) estimated genetic correlation of 0.02 between ultrasonic rib fat thickness and the predicted percentage ether extract (ultrasonic marbling score). In contrast to the present results, Lee and Kim (2004) reported genetic relationship close to zero between the two traits in Korean Hanwoo steers. This contrast results may be due to physiological difference in cows and steers that may affect relationship between both the traits. Hammack (http://animalscience.tamu.edu/ansc/publications/beefpubs/E165-geneticselcarcassmerit.pdf) suggested that marbling declines as back fat is reduced by genetic selection. Thus results suggests that selection for MS may result in unwanted increase in back fat thickness of the progeny or, in the other way, selection for decreased back fat may also decrease marbling.

The environmental correlations between the beef quality traits are given in Table 3. Environmental correlation of LMA with BF and MS were moderate and positive, while, it was low and positive between BF and MS.

IMPLICATIONS

The traits analyzed in this study have variation and are considerate heritable suggesting possibility of genetic progress through selection. Measuring beef quality traits on live breeding cows has the advantage of avoiding the delay and expense of progeny testing and provides an opportunity to not only evaluate a larger and more random samples of bulls within a population, but also to evaluate the genetic potential of females, thus increasing the accuracy of selection. However, it is possible that beef traits measured on mature breeding cows may be different from those of yearling steers and heifers due to differences in their physiological conditions. Further study is emphasized to make selection of breeding cows on the basis of their own performance for these ultrasonically measured beef traits and to investigate the effect of selection on the performance of their progeny for these carcass traits.

ACKNOWLEDGEMENTS

This work is financially supported by Gyeong-gi Regional Research Center at Hankyong National University, Korea.

REFERENCES

Arnold, J. W., J. K. Bertrand, L. L. Benyshek and C. Ludwig. 1991. Estimates of genetic parameters for live animal ultrasound, actual carcass data, and growth traits in beef cattle. J. Anim. Sci. 69:985-992.

Baik, D. H., M. A. Hoque and H. S. Choe. 2002. Estimation of genetic and environmental parameters of carcass traits in Hanwoo (Korean Native cattle) populations. Asian-Aust. J. Anim. Sci. 15:1523-1526.

Benyshek, L. L. 1981. Heritabilities for growth and carcass traits estimated from data on Herefords under commercial conditions. J. Anim. Sci. 53:49-56.

Bertrand, J. K. 2000. Use of live animal ultrasound carcass measures in carcass evaluation of beef cattle. In Proc. 34th Beef Improv. Fed. Ann. Res. Symp. Annu. Mtg., Omaha, NE. pp. 128-134.

Crews, D. H., Jr. and R. A. Kemp. 2002. Genetic evaluation of carcass yield using ultrasound measures on young replacement beef cattle. J. Anim. Sci. 80:1809-1818.

Evans, J. L., B. L. Golden, D. R. C. Bailey, R. P. Gilbert and R. D. Green. 1995. Genetic parameter estimates of ultrasound measures of backfat thickness, loineye muscle area and gray shading score in Red Angus cattle. Proc. West. Sect. Am. Soc. Anim. Sci. 46:202.

Hammack, S. P. (http://animalscience.tamu.edu/ansc/publications/beefpubs/E165-geneticselcarcassmerit.pdf) accessed date May 12, 2005.

Izquierdo, M. M., D. E. Wilson and G. H. Rouse. 1997. Estimation of genetic parameters for fat composition traits measured in live beef animals. In: Proc. BIF Research Symposium, Dickinson, ND. pp. 99-101.

Jonhson, M. Z., R. R. Schalles, M. E. Dikeman and B. L. Golden. 1993. Genetic parameter estimates of ultrasound-measured longissimus muscle area and 12th rib fat thickness in Brangus cattle. J. Anim. Sci. 71:2623-2630.

Kemp, D. J., W. O. Herrings and C. J. Kaiser. 2002. Genetic and environmental parameters for steer ultrasound and carcass traits. J. Anim. Sci. 80:1489-1496.

Kim, H. C., D. H. Lee, S. B. Choi and G. J. Jeon. 2003. Relationship between ultrasonic and carcass measures for meat qualities in Hanwoo steers. J. Anim. Sci. Technol. (Kor.) 45:183-190.

Lamb, M. A., O. W. Robinson and M. W. Tess. 1990. Genetic parameters for carcass traits in Hereford bulls. J. Anim. Sci. 68:64-69.

Lee, D. H. and H. C. Kim. 2004. Genetic relationship between ultrasonic and carcass measurements for meat qualities in Korean steers. Asian-Aust. J. Anim. Sci. 17:6-12.

Lee, D. H. 2003. Monte Carlo simulations of selection responses for improving high meat qualities using real time ultrasound in Korean cattle. J. Anim. Sci. Technol. (Kor.) 45:343-354.

Lee, D. H. 2004. Methods of genetic parameter estimations of carcass weight, longissimus muscle area and marbling score in Korean cattle. J. Anim. Sci. Technol. (Kor.) 46:509-516.

Lee, D. H., I. Misztal and J. K. Bertrand. 2001. Bayesian analysis of carcass traits using multivariate threshold animal models and Gibbs sampling with missing records in Korean cattle. J. Anim. Sci. Technol. (Kor.) 43:9-22.

Misztal, I. 2001. Blupf90 family of programs. http:nce.ads.uga.edu/~ignacy/ newprograms.html. Accessed May 12, 2005.

Moser, D. W., J. K. Bertrand, I. Misztal, L. A. Kriese and L. L. Benyshek. 1998. Genetic Parameter Estimates for Carcass and Yearling Ultrasound Measurements in Brangus Cattle. J. Anim. Sci. 76:2542-2548.

Park, G. B., S. S. Moon, Y. D. Ko, J. K. Ha, J. G. Lee, H. H. Chang and S. T. Joo. 2002. Influence of slaughter weight and sex on yield and quality grades of Hanwoo (Korean native cattle) carcasses. J. Anim. Sci. 80:129-136.

Reverter, A., D. J. Johnston, H. -U. Graser, M. L. Wolcott and W. H. Upton. 2000. Genetic analysis of live-animal ultrasound and abattoir carcass traits in Australian Angus and Hereford cattle. J. Anim. Sci. 78:1786-1795.

Robinson, D. L., K. Hammond and C. A. McDonald. 1993. Live animal measurement of carcass traits: Estimation of genetic parameters for beef cattle. J. Anim. Sci. 71:1128-1135.

SAS, Ver. 9.1, SAS Inst., Inc., Cary, NC.

Shepard, H. H., R. D. Green, B. L. Golden, K. E. Hamlin, T. L. Perkins and J. B. Diles. 1996. Genetic parameter estimates of live animal ultrasonic measures of retail yield indicators in yearling breeding cattle. J. Anim. Sci. 74:761-768.

Stelzleni, A. M., T. L. Perkins, A. H. Brown, Jr., F. W. Pohlman, Z. B. Johnson and B. A. Sandelin. 2002. Genetic parameter estimates of yearling live animal ultrasonic measurements in Brangus cattle. J. Anim. Sci. 80:3150-3153.

Turner, J. W., L. S. Pelton and H. R. Cross. 1990. Using live animal ultrasound measures of ribeye area and fat thickness in yearling Hereford bulls. J. Anim. Sci. 68:3502-3506.

Wilson, D. E. 1992. Application of ultrasound for genetic improvement. J. Anim. Sci. 70:973-983.

Wilson, D. E., R. L. Willham, S. L. Northcutt and G. H. Rouse. 1993. Genetic parameters for carcass traits estimated from Angus field records. J. Anim. Sci. 71:2365-2370.