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PARTITIONING VARIATION IN MEASUREMENTS OF BEEF CARCASS TRAITS MADE USING ULTRASOUND

BY

BRADIE SCHMIDT

A thesis submitted in partial fulfillment of the requirements for the degree

Master of Science

Major in Animal Science

South Dakota State University

2020

THESIS ACCEPTANCE PAGE

Bradie Schmidt

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Michael Gonda
Advisor Date

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ACKNOWLEDGEMENTS

I would like to thank everyone who has helped me throughout my academic career. My teachers, professors, friends and classmates have all impacted my life and led me to where I am today. I cherish the memories and lifelong friendships I have made during my time at SDSU.

Thank you to my family for their continuous support throughout all of my endeavors. My mother Kathy especially, has been my main support system in life. She taught me through hard work and tenacity anything is possible. My mother has always pushed me to do more and always have a smile while doing it. I would not be where I am today without my mom. I would also like to give a special thank you to Jay Volk and his family. I know for a fact I would not be pursuing a master's degree if it were not for him. I remember the day Jay sat me down on a five-gallon bucket and taught me what an EPD was and first sparked my interest in genetics. I will be forever grateful for Jay and his family for hauling me around to shows and teaching the ins and outs of the beef cattle industry.

Dr. Michael Gonda has played an instrumental role in my academic career, from teaching my first formal genetics course as an undergrad to serving as my major advisor. Dr. Gonda sawn something in me that I didn't see for myself and is responsible for giving me the opportunity to further my academic career. He has pushed me to go outside my comfort zone and broaden my horizons on a multitude of occasions. Dr. Gonda was never short of insight or advice and was always more than willing to help with any situation. He stands as a leader in the Animal Science Department and the entire university and is

someone I look up to greatly. I would also like to acknowledge Dr. Gonda's lovely wife Tiffany for being always being supportive of Dr. Gonda and his students.

Dr. Michael MacNeil graciously served on my committee and headed many of the analyses in the project. Dr. MacNeil's years of expertise and experience really helped advance my genetics and data analytics knowledge. Dr. MacNeil resides in Montana but sacrificed many hours of windshield time to visit with Dr. Gonda and I in Brookings on multiple occasions. Dr. MacNeil and his wife even welcomed us into their home in order to jump-start the project. His dedication meant a lot to me and I never felt as if he were out of reach.

Finally, thank you to the American Angus Association, American Hereford Association and the American Simmental Association for providing the data used in this research project. And to the Ultrasound Guidelines Council, South Dakota Beef Industry Council and South Dakota State Agriculture Research Station for funding the research. It goes to show the commitment each of these entities has to improving the beef industry.

CONTENTS

ABBREVIATIONS

AAA	American Angus Association
AHA	American Hereford Association
ASA	American Simmental Association
EBV	estimated breeding value
ERT	economically relevant trait
IMF	percent intramuscular fat
LMA	longissimus muscle area
MARB	marbling score
MTDFREML	multiple trait derivative free restricted maximum likelihood
NCE	National Cattle Evaluation
RFD	rump fat depth
SFD	subcutaneous fat depth
UIMF	ultrasound percent intramuscular fat
ULMA	ultrasound longissimus muscle area
UGC	Ultrasound Guidelines Council
URFD	ultrasound rump fat depth
USFD	ultrasound subcutaneous fat depth

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ABSTRACT

PARTITIONING VARIATION IN MEASUREMENTS OF BEEF CARCASS TRAITS USING ULTRASOUND

BRADIE SCHMIDT

2020

Ultrasound technology provides cattle breeders a relatively quick, non-invasive, and economical way to gather carcass data on live animals. Ultrasound provides the means to accurately predict body composition and develop estimated breeding values; however, national cattle genetic evaluations assume homogenous additive genetic and residual variances. These assumptions may be violated when estimating genetic merit for carcass traits by ultrasound because of differences in variance due to scanning technician and image interpretation laboratory. The objective of this study was to partition the phenotypic variance of measurements of carcass traits that were made using ultrasound into components attributable to additive genetic effects, scanning technician, contemporary group, and residual effects. Data for longissimus muscle area (LMA), percent intramuscular fat (IMF), and subcutaneous fat depth (SFD) were provided by the American Angus Association (AAA; N=65953), American Hereford Association (AHA; N=43180), and American Simmental Association (ASA; N=48298) representing a sample of animals scanned between 2015 to 2017. Data provided by each association included ultrasound carcass measurements, contemporary group, technician ID, imaging lab, and a three-generation pedigree for each animal. First, variance components for ultrasound carcass measurements were estimated with a univariate animal model for each breed and imaging laboratory separately by multiple trait derivative free restricted

maximum likelihood. Genetic correlations between laboratories for longissimus muscle area, percent intramuscular fat, and subcutaneous fat were estimated with tri-variate animal models treating measurements from each image interpretation laboratory as a separate trait. Technician explained 12-27%, 5-23%, and 4-26% of variance for IMF, SFD and LMA respectively across all three breeds. Variance contributed by technician was often greater than variance contributed by additive genetics but almost always less than that explained by contemporary group. Genetic correlations between labs across breeds ranged from 0.79 to 0.95 for IMF, 0.26 to 0.94 for SFD and 0.78 to 0.98 for LMA. Most genetic correlations were relatively high ($\mathbf{r_g} \geq 0.80$). Overall, both technician and imaging laboratory contributed to phenotypic variation of ultrasound carcass measurements.

CHAPTER ONE: REVIEW OF LITERATURE

INTRODUCTION

Carcass merit has become increasingly important for beef producers with the inclusion of quality and yield grading systems, premiums for certain carcass traits, and consumer preferences for higher quality beef products (Perkins et al., 1992; Robinson et al., 1992; Wilson 1992). These factors combined have created a demand by beef breeders for genetic evaluation of carcass traits. Carcass traits are among the more heritable (h^2 = 0.26 - 0.42) economically relevant traits in beef cattle, which could result in faster genetic improvement for them if carcass phenotypes are available (Hough and Silcox, 2010). As defined in the 9th Edition of the Beef Improvement Federation's Guidelines for Uniform Beef Improvement Programs, heritability refers to the amount of phenotypic variation which is attributable to additive genetic effects. A trait with a higher heritability estimate means heritable genetic effects explains more of the variation for that trait versus a trait with a lower heritability, which in turn would lead to more rapid response to genetic selection for that particular trait (Hough and Silcox, 2010).

Phenotypes can be used as a predictor of genetic merit for highly heritable traits, but these phenotypes still need to be collected before selection can occur. Gathering enough carcass data, however, to make accurate genetic predictions poses as an obstacle for cattle breeders (Robinson et al., 1992). Prior to the use of ultrasound, the only way to gather carcass values was after the animal had been harvested. To predict breeding values for carcass traits on live animals, carcass merit was measured on relatives, in particular progeny of the animal. Progeny carcass records resulted in lowly accurate breeding value predictions unless a large number of carcass phenotypes on an animal's offspring were collected. Accurate estimated breeding values (EBVs) for carcass merit therefore were

almost exclusively available only for older sires. Collection of carcass phenotypes of progeny is also subject to misidentification of animals and expensive relative to collecting ultrasound carcass data on the sires themselves as yearlings. Further, carcass data can only be collected at slaughter. Therefore, it can take upwards of three and a half years to gather carcass measurements on progeny of sires when taken into consideration that bulls are not usually mated with females until approximately 15 months of age, a 9 month gestation period, and another 18 months until calves reach slaughter age. In contrast, using ultrasound technology to collect the carcass data allows it to be utilized within weeks of the measurements being collected on yearling animals.

IMPORTANCE OF ULTRASOUND

Carcass ultrasound may allow accurate prediction of carcass merit and result in faster genetic improvement than using abattoir measurements alone (Crews et al., 2003; Crews and Kemp, 2002; Greiner et al., 2003; Herring et al., 1994; Perkins et al., 1992a; Reverter et al., 2000; Robinson et al., 1992; Wilson et al., 1990; Wilson 1992). Ultrasound technology provides cattle breeders with a relatively simple, non-invasive, and inexpensive method of gathering carcass data on live animals that is sufficient enough to create estimated breeding values for across-herd genetic evaluations (Crews et al., 2003; Reverter et al., 2000; Robinson et al., 1993; Stouffer et al., 1961; Wilson 1992).

Carcass merit can be considered to be an economically relevant trait (ERT) in the beef industry. As described by Enns (2010), a trait is considered economically relevant if it has a direct effect on the profitability of an operation through either cost of production or income. Beef producers who retain ownership of calves or producers who buy feeder

calves to finish, especially those that sell on grid pricing, would utilize carcass merit as an ERT. An indicator trait can be used in place of an ERT if the two are genetically correlated. The use of an indicator trait is advantageous if it is easier, faster, or cheaper to collect and results in higher accuracy of selection, higher selection intensity, or both (Enns, 2010). Carcass ultrasound measurements can be classified as an indicator trait for carcass merit because carcass ultrasound is genetically correlated with carcass merit phenotypes (r_G= 0.54 to 0.83) and can be measured while the animal is still alive (Crews et al. 2001).

The equipment used to perform carcass ultrasound includes a transducer and the ultrasound machine. The transducer contains high frequency sound waves which penetrate the hide and the waves are reflected back to it from tissue interfaces. A cross-section image is then produced and displayed on the ultrasound machine screen (Houghton and Turlington, 1992). Cattle are prepared for ultrasound by removing debris and clipping the hair where the transducer will be placed. An ultrasound technician will use ultrasound gel or vegetable oil as a couplant for the transducer. A couplant is necessary to fill the tiny air pockets between the transducer and the hide in order to produce a clearer image since sound waves do not travel efficiently through air (Perkins et al., n.d.). The technician then places the transducer on the desired location to produce an image of body composition. Once a clear image in the proper region is achieved, the image is saved and sent to an ultrasound imaging laboratory. Laboratory technicians gather measurements from the images on ultrasound longissimus muscle area (ULMA), ultrasound subcutaneous fat depth (USFD), ultrasound percent intramuscular fat (UIMF), and ultrasound rump fat depth (URFD). These measurements are then sent to the

appropriate breed association where the data can be used in genetic evaluations (Greiner et al., 2003).

HISTORY OF ULTRASOUND MEASUREMENT OF CARCASS MERIT IN BEEF CATTLE

Livestock ultrasound methods have been evolving since the early 1950s (Stouffer and Westervelt, 1977). Continued research and development since then has led to the current widespread use of ultrasound technology in the beef seedstock industry. Carcass ultrasound has also made its way to the forefront of the beef and meat industries as being an important tool for estimation of carcass trait genetic predictions.

Some of the first ultrasound procedures consisted of numerous individual measurements which were then plotted to create a rough outline of the desired measurement. The outline could then be manually measured to gather an estimate for that trait (Stouffer, 2004). Dr. James R. Stouffer was one of the leading pioneers in developing ultrasonic procedures and technologies used for livestock. One of the first machines developed by Stouffer to collect ultrasound carcass data was a reflectoscope, which was equipped with a motor, point transducer and Polaroid camera to capture the image (Stouffer et al., 1961). The transducer was mounted to a curved guide that was placed at the 13th rib of beef animals. The point transducer would then move along the guide performing the ultrasound through an open gap in the center of the guide. The ultrasound image would then be produced on the camera film, which could later be manually measured.

Many of the original ultrasound machines used to collect carcass data on beef animals were designed for human medical purposes, not livestock. Although this technology was beneficial to the livestock industry, ultrasound carcass measurement had several early limitations. Some of these limitations included lack of portability of the ultrasound equipment and sensitivity to cattle working conditions (i.e. dust, cold) (Perkins et al., 1992a). Another disadvantage to the machines was the method of measuring the area of the ULMA. The ULMAs were first measured manually using a planimeter. A planimeter is an instrument used to measure areas, usually of irregular shapes (American Mathematical Society, 2008). The technician would trace the scan image on acetate paper, which could then be measured with a planimeter (Greiner et al., 2003). As technology advanced, the planimeter was replaced by digital area measurements which increased accuracy of ultrasound predictions. Unfortunately, the ultrasound transducer used to capture the ULMA image was not long enough to capture the entire area in one picture. Ultrasound scan technicians would have to take two pictures of the muscle and then merge the pictures together at the medial and lateral halves to acquire an estimate of ULMA (Perkins et al., 1992; Robinson et al., 1992). Eventually a transducer that was long enough to capture the entire longissimus muscle cross-section in one scan was created specifically for cattle (Herring et al., 1994).

Early on, ultrasound images were interpreted by the same technician who performed the ultrasound. Many of the studies completed before the 2000s utilized this method of ultrasound evaluation. Currently, interpretation of ultrasound images is done at one of three Ultrasound Guidelines Council (UGC) accredited ultrasound laboratories by certified laboratory technicians. Third party interpretation is used to reduce technician

and animal owner bias. Accredited imaging laboratories are also used to reduce variation among ultrasound interpretations from different laboratories. However, the degree of similarity among images interpreted by different laboratories is unknown.

The use of ultrasound can be a reliable tool in predicting carcass measurements in beef cattle, as long as skilled technicians perform the scan and interpretation (Herring et al., 1994). Technicians need to be trained to collect ultrasound carcass images. Numerous studies state the accuracy of ultrasound increased when scan technicians were considered "experienced" or "well trained" (Greiner et al., 2003; Perkins et al., 1992b; Reverter et al., 2000; Robinson et al., 1992). Many studies had the same technicians scan different animals over multiple years to demonstrate that years of experience improved accuracy of ultrasound carcass scans (Greiner et al., 2003; Perkins et al., 1992b). However, Perkins et al. (1992a) found that years of experience did not always correlate with accuracy of ultrasound carcass measurements. The technicians used in Perkins et al. (1992a) had beginner's level experience so increased accuracy over time might be expected. Specific criteria necessary for a technician to be considered "experienced" versus "inexperienced" have not been identified.

HERITABILITY AND GENETIC CORRELATIONS BETWEEN CARCASS TRAIT PHENOTYPES

Previous literature reported heritability estimates for carcass traits of beef cattle as moderate to high relative to other beef traits. Higher heritability of carcass traits leads to higher selection accuracy, resulting in faster genetic change. Genetic improvement of carcass merit should therefore be achievable if carcass phenotypes can be readily

obtained. As discussed earlier, however, carcass trait phenotypes are impossible to directly obtain on live animals, decreasing the effectiveness of this strategy.

Heritability estimates for carcass traits measured at slaughter

From 1991 to 2017, most longissimus muscle area (LMA) carcass heritability estimates were between 0.07 and 0.97 (Table 1-1). The majority of estimates in this review were between 0.32 and 0.46. Hassen et al. (1999) reported LMA carcass heritability estimates of 0.07; in contrast, Pariacote et al. (1998) reported an LMA heritability estimate of 0.97. The 0.07 estimate from Hassen et al. (1999) was derived from a group 428 Simmental influenced steer calves; this estimate differs from their estimate (0.21) derived from 486 bulls in the same study. The estimate from Pariacote et al. (1998) of 0.97$\pm$0.21 was obtained on 1,292 Shorthorn steers. The specific causes of these anomalous estimates could not be identified in either study, but it should be noted that the number of animals used by Hassen et al. (1999) was small, likely resulting in less precision.

Subcutaneous fat depth (SFD) carcass heritability estimates from 1991 to 2017 generally ranged from 0.05 to 0.49, less variable than those of LMA (Table 1-1). The majority of estimates however, fall in the same range as those of LMA (0.26 to 0.42). The highest heritability estimate for SFD was 0.49 (Arnold et al., 1991) and the lowest estimate was 0.05 (Hassen et al., 1999). Once again, Hassen et al., (1999) reported an abnormally low heritability estimate, this time on bull data. The next lowest estimate reported was 0.25 by Su et al. (2017), also on Simmental calves.

The studies used in this review utilized marbling scores of the carcass with the exception of Reverter et al. (2000) who reported carcass intramuscular fat (IMF). Marbling scores represent the amount and distribution of IMF in the LMA (Hale et al., 2013). The United States Department of Agriculture (USDA) utilizes eleven degrees of marbling which range from Practically Devoid to Abundant (Hale et al., 2013). Percent intramuscular fat is a continuous value that quantifies the amount of fat within the LMA. Marbling score (MARB) heritability estimates have remained fairly constant from 1991 to 2003 compared to LMA and SFD. The more constant heritability estimates may be because MARB is measured by categories whereas other carcass traits are continuous measurements. Estimates in this review ranged from 0.35 to 0.54 (Table 1-1). Most MARB heritability estimates ranged from 0.36 to 0.43, falling in the ranges noted for LMA and SFD.

Heritability estimates for carcass traits measured by ultrasound

As previously stated, ultrasound carcass measurements can be used as an indicator trait of carcass merit and body composition. It is equally important that indicator traits are also heritable in order to make genetic improvements when utilizing them for selection. The ULMA heritability estimates from 1991 to 2017 were between 0.11 and 0.51 (Table 1-2). Most of these estimates ranged between 0.25 and 0.44, corresponding with estimates noted for the majority of carcass LMA (0.32-0.46).

Ultrasound SFD heritability estimates from 1991 to 2017 ranged 0.09 to 0.69 (Table 1-2). Most of the estimates ranged between 0.26 and 0.53. Unlike carcass heritability estimates, USFD was more variable than ULMA. These results are somewhat

surprising and conflict with the assumption that measurement of USFD is generally more precise than ULMA. Error related to fat measurements may come from misinterpretation of fat deposits on fatter animals or simply pressure applied to the transducer during ultrasound. Pressure applied to the transducer during scanning may distort the shape and depth of the outer fat, leading to less accurate ultrasound carcass estimates (Perkins et al., 1992a). Heritability estimates varied but a general trend of increasing ultrasound carcass heritability estimates for ULMA and USFD was observed over time (Figure 1-1). This trend of increasing heritability might be explained by advances in ultrasound technology, image processing, improved training for ultrasound and imaging laboratory technicians, or a combination of the above.

Fewer heritability estimates for ultrasound percent intramuscular fat (UIMF) were reported because UIMF was not routinely measured until the early 2000s. The UIMF heritability estimates reported by Reverter et al. (2000) and Crews et al. (2003) averaged 0.34. This average was similar to the average ULMA and USFD estimates of 0.34 and 0.36.

Genetic correlations between carcass traits measured by ultrasound and at slaughter

For ultrasound measurements to be effective indicator traits for carcass merit, they should be highly genetically correlated with their respective measure of carcass merit. Several studies reported positive genetic correlations between carcass traits measured by ultrasound and the corresponding abattoir carcass traits of their progeny (Bertrand, 2002; Crews et al., 2003; Crews and Kemp, 2001; Reverter et al., 2000). Genetic correlations

between measurements of carcass traits and carcass trait estimates made using ultrasound reported from 1992-2003 were variable but usually greater than 0.60 (Table 1-3).

Overall, genetic correlation estimates tended to be more variable for LMA ultrasound and abattoir measurements than for SFD (Greiner et al., 2003). Most studies have also demonstrated a higher accuracy associated with the use of ultrasound to measure USFD relative to ULMA (Greiner et al., 2003; Perkins et al., 1992a; Perkins et al., 1992b). Accuracy of a trait is positively related to the strength of the genetic correlations involving the indicator trait and ERT. For example, if accuracy of the ultrasound measurement decreases, then the genetic correlation between ultrasound and actual carcass measurements will also decrease. There are several possible explanations for lower ULMA accuracy. First, early ultrasound transducers were too short to capture the entire ULMA in one scan. Technicians with these transducers were forced to use the split-screen method to evaluate ULMA, resulting in less accurate results (Perkins et al., 1992b). Accuracy of ULMA has increased with this improvement. Another possible explanation for the lack of confidence in ULMA estimates is the interference of subcutaneous fat with the clarity of the ultrasound image. Cattle with higher rib fat estimates had lower accuracy ULMA estimates (Greiner et al., 2003). This interference caused by subcutaneous fat makes it difficult to clearly define the edges of the longissimus muscle, especially the ventral portion, resulting in less accurate ULMA estimates (Herring et al., 1994). There can also be measurement technician bias when measuring ULMA (Greiner et al., 2003; Robinson et al., 1992). Technicians can have a tendency to over or underestimate the ULMA depending if their measurements diverge to either side of the muscle boundary (Greiner et al., 2003). Finally, lower ULMA

accuracies versus USFD may be attributable to the physical shape of the two traits. The longissimus muscle has the shape of an elongated rectangle or oval with an area that can range from 70 to 116cm^2 whereas USFD is a linear measurement that ranges from one to three centimeters as seen in Chapter Two.

Because of the inconsistencies across breeds and even within breeds between sexes and among carcass measurements, estimates of heritability and genetic correlation should be used with caution when making selection decisions. However, most studies consistently found that 1) both carcass merit measured at the abattoir and ultrasound measurements of carcass merit were moderately to highly heritable and 2) ultrasound measurements of carcass merit were highly genetically correlated with their respective carcass phenotypes collected at the abattoir. These studies provide evidence that genetic selection for carcass merit by ultrasound is feasible.

SOURCES OF CARCASS ULTRASOUND VARIATION

Human error may contribute to a large part of the variation in ultrasound carcass estimates. Ultrasound technicians undergo a rigorous certification process managed by the UGC. Technician accreditation has been recommended to increase accuracy of ultrasound carcass evaluations (Greiner et al., 2003; Herring et al., 1994). Different methods of accreditation have been studied over the years to determine what skills are most important to focus on and what levels of accuracy are acceptable for someone to become a certified ultrasound technician. Robinson et al. (1992) developed their own accreditation standards for ultrasound technician certification. Technician candidates were challenged on three areas: theory, repeatability, and accuracy. To become certified,

candidates were required to score at least 80% on a 25 question multiple-choice test, have acceptable standard errors among repeated ultrasound measurements (<1.5mm for URF, <1.0mm for USFD, and <6.0cm^2 for ULMA), and acceptable correlations between ultrasound and abattoir carcass measurements (≥.90 for fat and ≥.80 for LMA). Ultrasound scan technique was significantly associated with technician candidates who passed and those who did not. Most candidates accurately interpreted fat measurements but not always LMA. The LMA image is often more difficult to read and some transducers used were not big enough to capture the entire muscle in one picture. The Robinson et al. (1992) study, however, was published prior to the development of the longer transducer that can capture the entire LMA in one scan. The LMA results may differ if technicians all utilized a longer transducer. As stated earlier, inefficient equipment can lead to decreased measurement precision and accuracies. Technician experience was positively associated with accuracy of ultrasound carcass measurements (Robinson et al., 1992). However, technician experience information is not always available and although experience may play a role in technician accuracy, it is not practical to include experience as an adjustment factor in genetic predictions because of the lack of consistency. More experience was not always associated with increased accuracy of measurements as discussed below.

As long as a technician achieves a certain level of scan accuracy, he or she can become accredited by the UGC (Ultrasound Guidelines Council, 2020). Technicians may vary in their accuracy of ultrasound carcass measurements as long as this threshold is met. All data reported by certified technicians is treated the same (Ultrasound Guidelines Council, 2020). Years of technician experience and accuracy of evaluation were

positively correlated, but exceptions occur (Robinson et al., 1992). Technician skill was associated with accuracy of ultrasound measurements, but was not always correlated with years of experience (Perkins et al., 1992a). Evidence suggested that focusing on improving skill of ultrasound technicians rather than only using more experienced technicians will result in improved accuracy of ultrasound carcass evaluations (Robinson et al., 1992). The UGC also only allows approved ultrasound equipment to be used to record images. This rule helps improve accuracy of ultrasound images and also makes it easier for laboratory technicians to interpret images (Ultrasound Guidelines Council, 2020).

As described earlier, earlier ultrasound transducers used were not long enough to capture the entire ULMA in one scan. The technician would have to take multiple scans and merge the pictures together to estimate ULMA (Robinson et al., 1992; Perkins et al., 1992b). This procedure resulted in very low accuracies of ULMA, causing concerns about whether ULMA should be used as a predictor of abattoir LMA (Herring et al, 1994). Newer transducers have been made which are long enough to allow the entire ULMA to be scanned in one picture (Herring et al., 1994). This single technological improvement has likely contributed to the increase in accuracy of ULMA measurements (Greiner et al., 2003; Herring et al., 1994; Perkins et al., 1992b). Herring et al. (1994) looked at differences in accuracies between two different types of ultrasound equipment when using the same technicians. Differences in accuracies of ultrasound carcass measurements were found between types of equipment. The least accurate machine had a smaller transducer, which required technicians to use the split-screen method of measuring ULMA. The ULMA measurement alone accounted for most of the error

between equipment, which was expected from previous research (Herring et al., 1994). Over the years, more precise and accurate ultrasound equipment has been developed. These advances in ultrasound equipment have made image interpretation easier, thus increasing accuracy of ultrasound carcass measurements (Herring et al., 1994). Ultrasound equipment settings also affect accuracy of ultrasound carcass estimates (Perkins et al., 1992b). The UGC has certified system settings based on equipment, software, probe, and frame grabber used by the technician. These settings assist technicians in obtaining clear and consistent images. UGC accredited technicians must use certified ultrasound equipment and corresponding certified settings. This improves homogeneity of images produced across technicians.

Placement of the ultrasound transducer can also affect accuracy of carcass ultrasound estimates (Perkins et al., 1992a; Perkins et al., 1992b). The USFD and ULMA estimates are taken between the 12^{th} and 13^{th} ribs on beef cattle. This area is easy for trained ultrasound technicians to identify, but transducer placement between the 12^{th} and 13^{th} ribs may vary slightly among technicians. The URFD measurements are taken at the P8 site on the hind end of the animal. This location, however, is easier to locate on a carcass versus a live animal (Greiner et al., 2003; Robinson et al., 1992). Much of the error in URFD estimates is due to misplacement of the transducer and is part of the reason URFD measurements are not widely utilized.

The method in which the animal is prepared for ultrasound can also be a contributing factor to ultrasound variation. It is a common practice to clip the hair where the ultrasound scan will be taken. Cleaning off excess dirt and debris is also a common practice to prepare an animal for ultrasound (Perkins et al., 1992a; Perkins et al., 1992b).

Length of the hair or cleanliness of the hide can affect clarity of the scan, thus affecting how easily the scan can be interpreted by imaging laboratories (Perkins et al., 1992b).

The type of couplant used may also be a source of ultrasound carcass measurement variation (Greiner et al., 2003). A couplant is a substance used to assist the transducer in creating full contact with the animal. Acoustic impedance is large where air is trapped between the transducer and hide; the couplant aids in filling those spaces (Greiner et al., 2003). Vegetable oil is commonly used due to ease of availability and cost, but specialized ultrasound gels and other materials are also available. The amount of variation contributed by couplant has not yet been evaluated in beef carcass ultrasound measurements.

Greiner et al. (2003) noted that measurement error was also present at abattoirs when collecting carcass data. The method of removing the hide at an abattoir affects the amount of fat remaining for carcass measurements, which can ultimately affect the accuracy of the measurement (Herring et al., 1994; Perkins et al., 1992a; Robinson et al., 1992). Hide pullers have a tendency to remove excess fat along with the hide resulting in underestimated abattoir carcass fat measurements, especially at the 12^{th}-13^{th} rib area. Thus, the ultrasound measurement may actually be a more accurate estimate of fat than the abattoir measurement (Herring et al., 1994). Hide removal may also be the main contributing factor to variation in accuracy of ultrasound measurements between left and right sides of the same animal (Robinson et al., 1992). How much fat is removed with the hide on each side of the animal would affect the accuracy of the abattoir measurement thus affecting correlations between ultrasound and abattoir carcass data. Herring et al. (1994) also reported that method of suspension and dehydration of the carcass during

chilling may change abattoir carcass measurements. Physical changes in carcass composition or shape during rigor mortis may also affect measurements at the abattoir (Perkins et al., 1992b). Due to the changes of carcass composition at the abattoir, it has been suggested that ultrasound measurements may be a more accurate measure of carcass traits than actual carcass measurements (Brethour, 1992). Similarly, Terry et al. (1989) suggested that ultrasound measurements may be a better predictor of actual carcass measurements in pork carcasses. While accuracy of technician is important as previously discussed, Perkins et al. (1992a) argued that degree of fatness and muscling play a larger role in ultrasound error than technician experience.

CONCLUSION

Ultrasound would play little to no role in beef cattle breeding decisions and genetic predictions if this technology was not an accurate predictor of carcass merit. Ultrasound carcass measurements are highly heritable and highly correlated with abattoir carcass measurements. Ultrasound carcass measurements have gained traction because of their accuracy, ease of use, cost efficiency, and ability to non-invasively collect carcass data on live animals. Ultrasound measurements that are both accurate and precise are crucial in order for producers to maintain current levels of genetic progress (Greiner et al., 2003).

The UGC oversees ultrasound data collection and evaluation to ensure accuracy and usability of this data by the beef industry, specifically by breed associations. The UGC is comprised of a board of directors involving breed associations, imaging laboratories, field technician representatives, and research scientists and is overseen by

the US Beef Breeds Council. Breed associations pay dues to have access to the certified ultrasound data from UGC accredited laboratories to use for their own genetic predictions.

As of 2019, UGC had three accredited laboratories and 123 certified field technicians. The laboratories, technicians, and equipment used by all parties are certified by rigorous standards set by the UGC. The UGC field technician certifications must be renewed every two years to stay valid. Field technician certification includes a written exam and live animal scans. Technicians are evaluated on ultrasound scan image quality, repeatability, and standard error of prediction. While technicians are active, they are also required to participate in continuing learning activities such as seminars and professional meetings. The degree to which this certification process is successful at meeting the assumption of homogeneous residual variance is unknown.

Even with the regulation methods in place by the UGC, variation among technicians in measuring ultrasound carcass phenotypes may be significant. Couplant used, transducer placement and technique contribute to variation among technicians, which in turn contribute to environmental variation and decreased heritability of ultrasound carcass measurements. Similarly, variation among ultrasound laboratories that interpret the ultrasound images may be significant, also leading to decreased heritability. Currently, technician and imaging laboratory are included as part of the contemporary group that is used as a fixed effect in National Cattle Evaluation (NCE). An assumption of the NCE is that additive genetic and residual variances are homogeneous (Van Vleck, 1987), which may be false if phenotypic variance contributed by technician and/or laboratory . One consequence of heterogeneous variation is that different ranges of EBVs

would be observed among technicians and laboratories. Selection would favor animals evaluated by technicians and laboratories with more variable EBVs, leading to decreased genetic change if this increased variability is not associated with increased additive genetic variance (Hill, 1984; Vinson, 1987).

Robinson et al. (1992) pointed out that while the use of ultrasound for beef carcass measurements is effective for making selection decisions, development and maintenance of ultrasound procedures is critical for the continued use of ultrasound in genetic predictions. The beef industry has continuously improved accuracy of carcass genetic predictions by ultrasound as evidenced by increased carcass ultrasound heritability, genetic correlations with carcass merit, and selection accuracy of carcass EBVs.

TABLES AND FIGURES

Table 1-1. Carcass heritability estimates measured at slaughter

Reference	Sex of animals	Breed	LMA	SFD	MARB	RFD
Arnold et al. (1991)	Steer	Hereford	0.46	0.49	0.35	
Wilson et al. (1993)	Steer/heifer	Angus	0.32	0.26		
Moser et al. (1998)	Steer/heifer	Brangus	0.39	0.27		
Pariacote et al. (1998)	Steer	Shorthorn	0.97	0.46		
Hassen et al. (1999)	Bull Steer	Angus/ Simmental/ Composite	0.21 0.07	0.05 0.42		
Reverter et al. (2000)	Bull/heifer Bull/heifer	Angus Hereford	0.26 0.38	0.28 0.27	0.43[a] 0.36[a]	0.44 0.08
Kemp et al. (2002)	Steer	Angus	0.45	0.35	0.42	
Crews et al. (2003)	Steer/heifer	Simmental	0.46	0.35	0.54	
Su et al. (2017)		Hereford Simmental	0.47 0.32	0.41 0.25		

[a] Reverter et al. (2000) reported percent intramuscular fat, not marbling score. LMA = carcass longissimus muscle area, SFD = carcass subcutaneous fat depth, MAR = carcass marbling score, RFD = carcass rump fat depth. Blank spaces = not reported.

Table 1-2. Carcass heritability estimates measured by ultrasound

Reference	Sex of animals	Breed	ULMA	USFD	UMARB	URFD
Arnold et al. (1991)	Steer	Hereford	0.25	0.26		
Johnson et al. (1993)	Steer/heifer	Brangus	0.40	0.14		
Robinson et al. (1993)		Angus/ Hereford	0.21	0.30		0.37
Shepard et al. (1996)	Bull/heifer	Angus	0.11	0.56		
Moser et al. (1998)	Steer/heifer	Brangus	0.29	0.11		
Reverter et al. (2000)	Bull Bull Heifer Heifer	Angus Hereford Angus Hereford	0.37 0.41 0.46 0.34	0.47 0.09 0.54 0.27	0.18 0.28 0.47 0.12	0.51 0.25 0.59 0.37
Kemp et al. (2002)	Steer	Angus	0.29	0.39		
Crews et al. (2003)	Bull Heifer	Simmental Simmental	0.37 0.51	0.53 0.69	0.47 0.52	
Su et al. (2017)		Hereford Simmental	0.31 0.44	0.29 0.37		

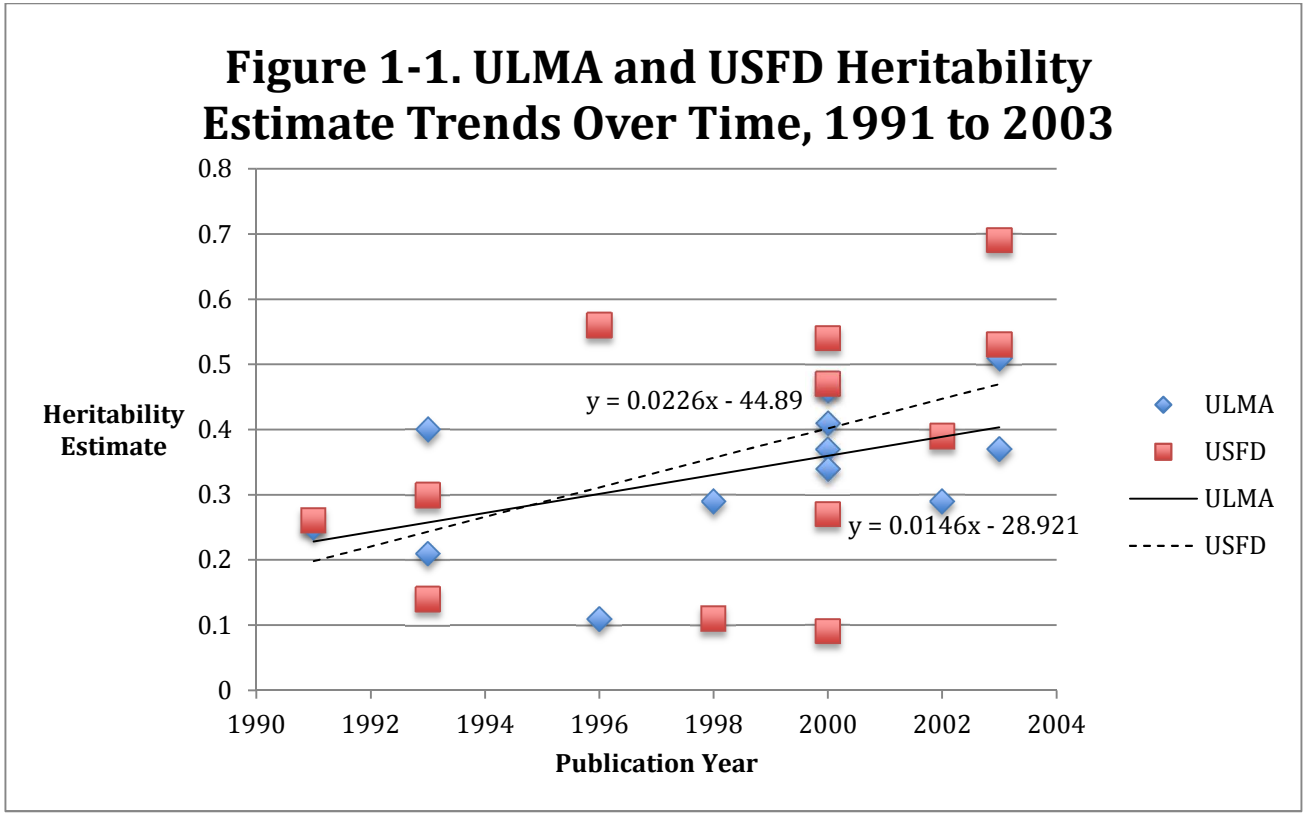
ULMA = ultrasound longissimus muscle area, USFD = ultrasound subcutaneous fat depth, UIMF = ultrasound intramuscular fat, URFD = ultrasound rump fat depth. Blank spaces = not reported.

Table 1-3. Genetic correlations between carcass traits measured by ultrasound and at abattoir

Reference	Sex of animals	Breed	USFD × SFD	ULMA × LMA	UIMF × MAR	URFD × RFD
Perkins et al. (1992a)	Steer	Crossbred	0.75	0.60		
Perkins et al. (1992b)	Steer	Brown swiss, Zebu-cross, Corriente, British cross	0.86	0.79		
Robinson et al. (1992)		Commercial (British/European breeds)	0.90	0.87		0.92
Moser et al. (1998)	Steer/heifer	Brangus	0.69	0.66		
Reverter et al. (2000)	Bull Bull Heifer Heifer	Angus Hereford Angus Hereford	0.79 0.87 0.99 0.02	0.29 0.94 0.16 0.46	0.47[a] 0.28[a] 0.46[a] 0.93[a]	
Crews and Kemp (2001)	Bull Heifer	Composite Composite	0.23 0.66	0.71 0.67		
Dewitt and Wilton (2001)	Bull	11 breeds	0.66	0.80	0.80	
Bertrand (2002)	Bull/heifer	Brangus	0.69	0.89	0.70	

Kemp et al. (2002)	Steer	Angus	0.82	0.69	0.90
Crews et al. (2003)	Bull Heifer	Simmental	0.79 0.83	0.80 0.54	0.74 0.69
Greiner et al. (2003)	Steer	Composite	0.89	0.86	
Su et al. (2017)		Hererford Simmental	0.74 0.28	0.81 0.57	0.54 0.73

[a] Reverter et al. (2000) reported percent intramuscular fat, not marbling score. USFD = ultrasound subcutaneous fat depth, SFD = carcass subcutaneous fat depth, ULMA = ultrasound longissimus muscle area, LMA = carcass longissimus muscle area, UIMF = ultrasound intramuscular fat, MAR = carcass marbling score, URFD = ultrasound rump fat depth, RFD = carcass rump fat depth. Blank spaces = not reported.



ULMA = Ultrasound longissimus muscle area

USFD = Ultrasound subcutaneous fat depth

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CHAPTER TWO: PARTITIONING VARIATION IN MEASUREMENTS OF BEEF CARCASS TRAITS USING ULTRASOUND

INTRODUCTION

The use of ultrasound to predict beef carcass traits has been around since the 1950s (Stouffer and Westervelt, 1977). Beef carcass ultrasound can be used to predict longissimus muscle area, subcutaneous fat, intramuscular fat, and rump fat on live cattle. For U.S. beef cattle genetic evaluations, ultrasound images are collected by an Ultrasound Guidelines Council (UGC) accredited field technician and these images are then interpreted by one of three UGC certified imaging laboratories. These imaging laboratories are Centralized Ultrasound Processing Lab in Ames, IA, International Livestock Image Analysis in Harrison, AR, and UltraInsights in Pierce, CO. Laboratory technicians interpret the carcass ultrasound images and send the results to the respective breed association. Breed associations are then able to utilize the carcass ultrasound data in genetic predictions. Collection of ultrasound data has likely contributed to faster genetic change in carcass traits. For example, since 1998, when the centralized ultrasound processing procedure as described above was implemented, the American Angus Association has observed an average increase of 0.31 USDA marbling score and 2.9 cm^2 LMA among current sires (1998-2018).

Ultrasound field technician and imaging laboratory are critical parts to the evaluation of ultrasound carcass measurements and yet little is known about their contribution to variation of ultrasound carcass phenotypes. Currently, technician and imaging laboratory are included as part of the contemporary group that is used as a fixed effect in National Cattle Evaluation (NCE). An assumption of the NCE is that residual variances are homogeneous (Van Vleck, 1987), which may be false if technician and/or laboratory contribute to phenotypic variation for these traits. One consequence of

heterogeneous variation is that different ranges of estimated breeding values (EBVs) would be observed among technicians and laboratories. Selection may favor animals evaluated by technicians and laboratories with more variable EBVs, leading to decreased genetic change if this increased variability is not associated with increased additive genetic variance (Hill, 1984; Vinson, 1987). Ultrasound technicians and imaging laboratories go through accreditation processes designed by the UGC to reduce this variation. However, the degree to which this certification process is successful at meeting the assumption of homogeneous residual variance is unknown.

Our hypothesis was technician and laboratory contribute to variation in carcass traits measured by ultrasound resulting in violation of the homogeneous residual variance assumption. We first quantified variance contributed by technician for these ultrasound carcass traits. Because imaging laboratory and technician variance components could not be separated, the contribution of imaging laboratory to ultrasound carcass measurements was estimated by calculating genetic correlations between laboratories for the same trait. Our second objective was to estimate genetic correlations between ultrasound carcass traits interpreted by different laboratories (e.g., subcutaneous fat depth interpreted by Lab 1 and subcutaneous fat depth interpreted by Lab 2). A high genetic correlation would indicate that imaging laboratory contributes little to variation in carcass traits measured by ultrasound.

MATERIALS AND METHODS

Live animals were not used for our analyses; thus, approval from the South Dakota State University Institutional Animal Care and Use Committee was not required.

Ultrasound carcass data from 2015 to 2017 was provided by the American Angus Association (AAA; n=281,982), American Hereford Association (AHA; n=49,602), and American Simmental Association (ASA; n=59,576) for a total of 391,160 records. The carcass ultrasound data received by the breed associations were the interpretations made by imaging laboratories that would be used to calculate estimated breeding values for carcass traits. Contemporary group, technician, imaging laboratory, longissimus muscle area (LMA), subcutaneous fat depth (SFD), and percent intramuscular fat (IMF) were provided when available on each animal in the dataset (Table 2-1). The three carcass traits were all measured by ultrasound. Ultrasound data was not adjusted for fixed effects. Technician and laboratory identification were coded to maintain anonymity. Technicians certified by the UGC collected ultrasound images. A total of 136, 102, and 146 technicians collected ultrasound data used in this study by the AAA, AHA, and ASA respectively. The median number of ultrasound images collected by each technician was 792, 198, and 104 for data collected from the AAA, AHA, and ASA respectively. Only data interpreted by the three UGC certified laboratories (Centralized Ultrasound Processing Lab, International Livestock Image Analysis, and UltraInsights) were analyzed in this study. Contemporary groups were defined by each breed association and included effects of herd, year, and season. A three-generation pedigree for each animal was also provided. Data from each breed association was analyzed separately. Because information was collected from the breed associations, we did not have access to information on management or environment for these animals. Sex and age of animal when scanned were not included in our analysis. Age of animal when ultrasound scans are collected to be used for genetic evaluations should be 320-460 days for AAA, 270-

500 days for ASA, and 301-530 days of age for AHA. Therefore, it is expected that animals in this dataset were scanned within these age ranges.

Multiple trait derivative free restricted maximum likelihood (MTDFREML) was utilized for estimation of (co)variance components and genetic correlations (Boldman et al., 1995). Convergence was assumed when the variance of the -2 log L in the simplex was less than $1x10^{-10}$. Univariate animal models were fitted for each trait and laboratory combination from each breed for variance component estimation (9 models total). Variance components were estimated within laboratory because technicians often reported ultrasound images to the same laboratory, resulting in a lack of independence between technician and laboratory. For the AHA and ASA data, pedigrees included all sires, dams, grandsires and granddams. A total of 87,339 animals and 5,008 sires were included in the pedigree for the AHA data. For the ASA data, 79,513 animals and 3,902 sires were included in the pedigree file. Only 157 (mean F=0.17) and 228 (mean F=0.028) animals had non-zero inbreeding coefficients in the AHA and ASA pedigrees respectively. Our analyses did not include inbreeding. Because of size limitations within the MTDFREML software, the AAA pedigree could not be formulated the same as the other breeds. Instead, the AAA pedigree was formulated with only sire and maternal grandsire. A total of 78,149 animals and 5,007 sires were included in the AAA pedigree file. None of these animals had non-zero inbreeding coefficients. From these pedigrees, MTDFREML produced an inverse relationship matrix among animals. Variance components were estimated fitting the model

$$y_{ijk} = \mu + t_i + c_{ij} + a_{ijk} + e_{ijk}$$

where y_{ijk} is the phenotype of the carcass ultrasound for the k^{th} animal; μ is the overall mean applied to all observations; t_i is a random effect of the i^{th} technician; c_{ij} is a random effect of the j^{th} contemporary group scanned by the i^{th} technician; a_{ijk} is a random effect of additive genetics by the k^{th} animal; and e_{ijk} is a residual deviation from the model effects. Effects were assumed normally distributed as follows

$$t \sim N(0, I\sigma_t^2) \qquad c \sim N(0, I\sigma_c^2) \qquad a \sim N(0, A\sigma_a^2) \qquad e \sim N(0, I\sigma_e^2)$$

where *t* is a random effect of technician; *c* is a random effect of contemporary group; *a* is a random effect of animal; *e* is a random effect of residual; *I* is the identity matrix; *A* is the animal additive numerator relationship matrix; σ_t^2 is a technician variance; σ_c^2 is a contemporary group variance; σ_a^2 is an additive genetic variance; and σ_e^2 is a residual variance. Within contemporary group, heritability (h^2) estimates of ultrasound carcass traits among laboratories were calculated as follows

$$h^2 = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_e^2}$$

Technician was not included in the denominator of the above equation because only one technician would collect scans for each contemporary group. Ultrasound technician and contemporary group were not independent of imaging laboratory; therefore, we were unable to partition variance components due to imaging laboratory. To estimate the contribution of imaging laboratory to carcass traits measured by ultrasound, genetic correlations were estimated between each combination of the three laboratories for each trait (e.g. SFD for Lab 1 and SFD for Lab 2). Covariance components, EBVs, and their associated accuracies were estimated with MTDFREML as before except with a bivariate model. The model fitted for variance and covariance estimation was as follows

$$\begin{bmatrix} y_{ik} \\ y_{jk} \end{bmatrix} = \begin{bmatrix} z_c & 0 \\ 0 & z_c \end{bmatrix} \begin{bmatrix} c_{ik} \\ c_{jk} \end{bmatrix} + \begin{bmatrix} z_t & 0 \\ 0 & z_t \end{bmatrix} \begin{bmatrix} t_{ik} \\ t_{jk} \end{bmatrix} + \begin{bmatrix} z_a & 0 \\ 0 & z_a \end{bmatrix} \begin{bmatrix} a_{ik} \\ a_{jk} \end{bmatrix} + \begin{bmatrix} z_e & 0 \\ 0 & z_e \end{bmatrix} \begin{bmatrix} e_{ik} \\ e_{jk} \end{bmatrix}$$

where y_i is ultrasound carcass measurement *k* for Lab *i*; y_j is the ultrasound carcass measurement *k* for Lab *j*; z_c is an incidence matrix relating random contemporary group effects *c* to observations; z_t is an incidence matrix relating random technician effects *t* to observations; z_a is an incidence matrix relating random animal effects *a* to observations; z_e is an incidence matrix relating random contemporary group effects *e* to observations, and all other terms as previously defined.

Standard errors of genetic correlations were calculated as follows (Bijma and Bastiaansen, 2014)

$$SE(\hat{r}_g) = \sqrt{\frac{\frac{1}{r_{ik}^2 r_{jk}^2} + \left(1 + \frac{0.5}{r_{ik}^4} + \frac{0.5}{r_{jk}^4} - \frac{2}{r_{ik}^2} - \frac{2}{r_{jk}^2}\right) r_G^2 + r_G^4}{N - 1}}$$

where r_g is the genetic correlation; r_{ik} is the average accuracy of EBVs for *N* sires for trait *k* interpreted by laboratory *i*; r_{jk} is the average accuracy of EBVs for sires for trait *k* interpreted by laboratory *j*; and *N* is the number of sires with images interpreted by both laboratories *i* and *j*. Spearman's rank correlations were calculated between sire EBVs with images interpreted by both labs *i* and *j*.

RESULTS

Ultrasound technician consistently contributed to heterogeneous variance in every lab-trait-breed combination. Technician explained 4% to 27% of phenotypic variance across all traits and breeds (Tables 2-2 to 2-4). A clear trend was not consistently observed for percent variation explained by technician across all laboratories and breeds.

However, technician variation explained more percent phenotypic variation than additive genetics for LMA across all laboratories and breeds, except for Angus interpreted by Lab 3 and Herefords interpreted by Lab 2 and Lab 3 (Table 2-2). Percent variation explained by technician and additive genetics were more similar for SFD, with the exception of Herefords interpreted by Labs 1 and 2 where technician explained 10% and 5% of phenotypic variation respectively (Table 2-3). Neither technician nor additive genetics consistently explained more phenotypic variation for IMF across all laboratories and breeds (Table 2-4). However, the percent variation explained by technician ranged from 12-27% for IMF. Taken together, technician variation explained part of the phenotypic variation for LMA, SF, and IMF across all laboratories and breeds. Often, technician variation explained as much or more phenotypic variation as additive genetics.

Differences in percent variation explained by technician were observed among imaging laboratories. Technician explained the least or one of the least amounts of phenotypic variation for SFD compared to the other two ultrasound measurements for Lab 2 (Tables 2-2 to 2-4). In contrast, SFD interpreted by Lab 3 consistently explained the highest or one of the highest percent technician variation among all breeds. Technician explained the highest amount of variation for LMA, and IMF by Lab 1 relative to the other laboratories (Tables 2-2 & 2-4). In contrast, technician submitting ultrasound images to Lab 2 explained the lowest or near lowest amount of phenotypic variation relative to other labs for SFD and IMF. Lab 3 explained the least amount of technician variation across breeds for LMA. The amount of variation explained by technician was also different among breeds. Data interpreted for the ASA by Labs 1 and

2 consistently had the largest percent variation explained by technician for LMA and IMF (Tables 2-2 to 2-4). No clear pattern emerged for Lab 3.

Heritability estimates for ultrasound carcass traits across breeds were moderately high (Table 2-5). Estimates for carcass traits across laboratories ranged from 0.25 to 0.67 for all breeds. Intramuscular fat across laboratory had the highest heritability estimates among carcass traits for each breed. These results coincide with previous literature of reported heritability estimates of ultrasound carcass measurements (Kemp et al., 2002; Reverter et al., 2000; Robinson et al., 1993).

Genetic correlations between imaging laboratories for each trait in each breed were generally high (Table 2-6 to 2-8). Genetic correlations between all pairs of laboratories within breeds ranged from 0.26 to 0.98 across all ultrasound measurements. Hereford SFD genetic correlations were the lowest estimates compared to all other breeds and carcass traits ranging from 0.26 to 0.70 (Table 2-7). Genetic correlation estimates for all other traits and breeds were $\geq$0.78. Genetic correlations were highest between Labs 1 and 3 for all traits and breeds except for IMF and SFD in Angus and Hereford, where correlations were highest between Labs 1 and 2 (Tables 2-6 to 2-8). Spearman's rank correlations between EBVs based on image interpretations from different laboratories were also generally high and positive (Tables 2-6 to 2-8). Rank correlations were above 0.90 with the exception of LMA between Labs 1 and 2 for Simmental data and all laboratory combinations for Hereford SFD. Taken together, imaging laboratory did not have a major impact of EBV estimation or ranking of genetic merit of animals, albeit lower correlations were observed between laboratories for some trait-breed combinations, in particular Hereford SFD observations. Spearman's rank correlations complimented the

genetic correlation results. The consistently high and positive results suggest that laboratory does not have a significant effect on ultrasound carcass measurements and EBVs.

DISCUSSION

Technician variance

Technician contributed to the phenotypic variance of LMA, SFD, and IMF measured by ultrasound among Angus, Simmental, and Hereford cattle. Lab 2 utilizes a different technology than Lab 1 and Lab 3 to interpret ultrasound images, which may be contributing to the lower proportion of phenotypic variance explained by technician for IMF and SFD interpreted by Lab 2. Simmental IMF was the only instance where proportion of phenotypic variance explained by technician was not the lowest for Lab 2 when compared to other laboratories for SFD and IMF. Ultrasound estimates for subcutaneous fat depth are often more accurate than longissimus muscle area (Perkins et al., 1992a). Generally, subcutaneous fat depth is easier to interpret than longissimus muscle area. As shown by Greiner et al. (2003), the definition of the outline of the longissimus muscle that makes up the longissimus muscle area can be affected by the amount of fat present. The more backfat, the less easily the ventral edge of the longissimus muscle can be defined, thus leading to less accurate interpretations. Also, the longissimus muscle area has the shape of an elongated rectangle or oval with an area that can range from 70 to 116 cm^2 whereas subcutaneous fat depth is just a linear measurement that ranges from one to three mm. Considering these factors may help interpret the lower overall proportion of phenotypic variance by technician for backfat

versus longissimus muscle area. Proportion of phenotypic variance explained by technician is different than zero for all trait, laboratory, and breed combinations. In some cases, technician even explains a larger proportion of variance than additive genetics. These results suggest that residual variation in our national cattle evaluations for three major North American beef breeds is not homogeneous.

Effect of imaging laboratory

Genetic correlations between imaging laboratories were generally very high, the lowest being 0.26 between Lab 2 and 3 for Hereford SFD. This low correlation may be attributed to the different technology utilized by Lab 2. Generally, technician explained a lower percent of phenotypic variation for measurements interpreted by Lab 2. Further, genetic correlations between labs were generally highest between Labs 1 and 3. Although the genetic correlations are high, in many instances they are different from one. Taken together, some evidence exists that imaging laboratory contributes to ultrasound carcass variation, although the contribution of laboratory was less than the contribution of variance by technician. However, Robertson (1959) suggested that genetic correlations greater than 0.80 should be treated as the same trait. Only six of our genetic correlations were less than 0.80, suggesting imaging laboratory is largely not contributing to heterogeneous variance in National Cattle Evaluations. Among the six genetic correlations <0.80, three were found within Simmental data and three were estimated between laboratories for Hereford SFD. It should be noted that the standard error of the genetic correlations suggests that four of these six genetic correlations were not different

from 0.80. If you use the more rigorous threshold of 1.0, than more of our estimates suggest imaging laboratory is causing heterogeneous variation.

Heritability estimates

Within contemporary group, heritability estimates for ultrasound LMA ranged from 0.27 to 0.50, SFD estimates ranged from 0.26 to 0.47 and IMF estimates ranged from 0.34 to 0.67 across breeds. These estimates were moderately high which is expected for carcass traits. Previous literature describing carcass ultrasound traits of Continental cattle breeds found heritability estimates ranging from 0.29 to 0.42 for LMA, 0.18 to 0.51 for SFD and 0.20 to 0.33 for IMF (Kemp et al., 2002; Reverter et al., 2000). These values are comparable to the estimates found in this analysis. The IMF heritability estimates tended to be higher than what previous literature has found, which may be due to improvement of ultrasound technology or processes for scanning and interpreting IMF.

Limitations of research

While our results found variation among ultrasound technicians and laboratories, the cause of this variation cannot be identified. Technician and laboratory variance can stem from a number of factors. Ultrasound machine, transducer and scanning technique have been shown to contribute to technician variance (Greiner et al., 2003; Herring et al., 1994; Perkins et al., 1992). Ultrasound equipment used by each technician was not available so we were unable to look at differences in variation among equipment types. Understanding the effect of ultrasound equipment on ultrasound carcass phenotypes would be helpful for developing best practices for ultrasound carcass evaluation.

Other limitations to this research were lack of information on the sex of the animal. We were not able to analyze differences between bulls, steers, or heifers, which have been previously analyzed (Crews et al., 2003; Reverter et al., 2000). Variance components were partitioned by additive genetics, technician and contemporary group within technician. All other contributing variance factors are accounted for in the residual variance component. Factors that contribute to residual variance remain unknown from these analyses. More information on animals and technicians may help explain more of the residual variance with further investigation.

Research strengths

New ultrasound research in general has somewhat plateaued since the early 2000s. These analyses provide up-to-date results on the use of ultrasound in genetic predictions. The data used in this research represents a significant proportion of registered cattle in the United States. Results from these analyses likely extend to other breeds as well. It also represents the first large-scale attempt at comparing technician and imaging laboratory variance for ultrasound carcass genetic evaluation.

Industry implications

Ultrasound technician and laboratory are critical parts to estimating carcass ultrasound measurements. The results from Tables 2-2 through 2-4 would violate the assumption by current National Beef Cattle Evaluations that residual and additive genetic variances are homogeneous. The results also indicate technician variance is not zero. These violations of previous assumptions show improvements in the technician

certification process may be needed. Variance among ultrasound technicians should be addressed by future work into the causes of variation among technicians. Reducing this variance will help improve the accuracy of ultrasound carcass measurements and genetic predictions. Genetic correlations between laboratories were generally high which suggests they play a lesser role in the contribution of variance to ultrasound measurements than technician. However, these correlations were often statistically different from 1, which demonstrates variability between laboratories. Accounting for variation contributed by technician and laboratory would increase the accuracy of selection and result in faster genetic improvement of carcass traits for beef cattle.

CONCLUSION

Technician was a contributing factor to variance in every ultrasound measurement for each of the three beef breeds. It is likely that the assumption of homogeneous residual variance is violated when estimating breeding values from carcass ultrasound images. Accounting for heterogeneous residual variance contributed by ultrasound technician may increase the accuracy of genetic predictions where ultrasound data is utilized. Ultrasound scans from imaging laboratories were highly genetically correlated which suggests they play a lesser role in the contribution of variance to carcass ultrasound measurements. However, the correlations were often different from one and in some cases, particularly SFD collected from the AHA, were much lower than expected if image processing laboratory was not affecting carcass ultrasound phenotypes.

TABLES

Table 2-1. Summary of ultrasound data

	Angus (AAA)	Hereford (AHA)	Simmental (ASA)
Number of animals	281,982	49,602	59,576
Number of technicians	136	102	146
Number interpreted by Lab 1	147,069	15,804	30,016
Number interpreted by Lab 2	68,809	8,690	7,332
Number interpreted by Lab 3	66,104	24,634	19,246
Mean scan age (days)	375.7	377.9	356.0
Mean LMA, cm^2 (SD)	77.4 (5.9)	69.2 (5.6)	82.6 (5.9)
# of LMA records	65,954	43,380	48,298
Mean SFD, cm (SD)	0.68 (0.27)	0.57 (0.26)	0.54 (0.25)
# of SFD records	65,959	30,548	48,298
Mean IMF, % (SD)	4.47 (3.58)	3.20 (2.52)	3.35 (2.72)
# of IMF records	65,971	43,382	48,298

LMA = longissimus muscle area; SFD = subcutaneous fat depth; IMF = % intramuscular fat; SD = standard deviation

Table 2-2. Results from partitioning phenotypic variance of longissimus muscle area (LMA) into components

		Variance components and percentages of phenotypic variance							
Breed	Lab	σ_a^2	%	σ_t^2	%	$\sigma_{c:t}^2$	%	σ_e^2	%
Angus (AAA)									
	Lab 1	16.87	7 ± 1	53.98	23 ± 4	124.13	54 ± 3	35.06	15 ± 1
	Lab 2	16.65	6 ± 1	42.58	16 ± 6	162.95	61 ± 4	45.10	17 ± 1
	Lab 3	17.41	9 ± 1	13.43	7 ± 3	129.10	68 ± 2	29.28	15 ± 1
Hereford (AHA)									
	Lab 1	18.85	9 ± 1	34.24	17 ± 4	120.75	59 ± 3	30.50	15 ± 1
	Lab 2	20.45	8 ± 1	15.57	6 ± 3	169.03	70 ± 2	35.97	15 ± 1
	Lab 3	14.75	8 ± 1	8.14	4 ± 3	143.16	74 ± 2	28.11	14 ± 1
Simmental (ASA)									
	Lab 1	27.31	13 ± 1	57.21	26 ± 5	93.89	43 ± 3	38.60	18 ± 1
	Lab 2	33.35	13 ± 2	60.64	23 ± 8	126.81	49 ± 5	40.31	15 ± 2
	Lab 3	30.57	12 ± 1	49.98	20 ± 6	133.84	55 ± 4	30.67	13 ± 1

% = percentage of phenotypic variance explained by previous listed variance component ± standard error

σ_a^2 = additive genetic variance

σ_t^2 = technician variance

$\sigma_{c:t}^2$ = contemporary group variance

σ_e^2 = residual variance

Table 2-3. Results from partitioning phenotypic variance of subcutaneous fat depth (SFD) into components

		Variance components and percentages of phenotypic variance							
Breed	Lab	σ_a^2	%	σ_t^2	%	$\sigma_{c:t}^2$	%	σ_e^2	%
Angus (AAA)									
	Lab 1	0.98	13 ± 1	1.48	19 ± 3	3.58	47 ± 2	1.64	21 ± 1
	Lab 2	0.87	11± 1	0.92	12 ± 5	4.26	54 ± 3	1.79	23 ± 2
	Lab 3	1.08	15 ± 2	1.44	19 ± 6	3.46	47 ± 4	1.42	19 ± 2
Hereford (AHA)									
	Lab 1	0.86	13 ± 1	0.64	10 ± 2	3.18	47 ± 2	2.04	30 ± 1
	Lab 2	0.80	13 ± 2	0.33	5 ± 3	3.27	52 ± 2	1.93	31 ± 2
	Lab 3	0.74	10 ± 2	1.68	23 ± 9	3.16	43 ± 5	1.75	24 ± 3
Simmental (ASA)									
	Lab 1	1.43	25 ± 2	1.15	20 ± 4	1.58	28 ± 2	1.59	28 ± 2
	Lab 2	0.92	22 ± 3	0.70	16 ± 6	1.35	31 ± 3	1.32	31 ± 3
	Lab 3	0.93	17 ± 2	1.24	23 ± 6	2.17	39 ± 3	1.15	21 ± 2

% = percentage of phenotypic variance explained by previous listed variance component ± standard error

σ_a^2 = additive genetic variance

σ_t^2 = technician variance

$\sigma_{c:t}^2$ = contemporary group variance

σ_e^2 = residual variance

Table 2-4. Results from partitioning phenotypic variance of percent intramuscular fat (IMF) into components

		Variance components and percentages of phenotypic variance							
Breed	Lab	σ_a^2	%	σ_t^2	%	$\sigma_{c:t}^2$	%	σ_e^2	%
Angus (AAA)									
	Lab 1	0.34	20 ± 2	0.43	25 ± 4	0.56	33 ± 2	0.37	22 ± 1
	Lab 2	0.52	30 ± 3	0.21	12 ± 5	0.73	43 ± 3	0.26	15 ± 2
	Lab 3	0.51	22 ± 2	0.33	15 ± 5	1.03	45 ± 3	0.41	18 ± 2
Hereford (AHA)									
	Lab 1	0.16	16 ± 1	0.22	22 ± 4	0.33	34 ± 2	0.27	28 ± 2
	Lab 2	0.15	26 ± 2	0.07	12 ± 5	0.23	39 ± 3	0.13	23 ± 2
	Lab 3	0.24	17 ± 2	0.20	14 ± 6	0.69	48 ± 4	0.32	22 ± 2
Simmental (ASA)									
	Lab 1	0.28	27 ± 2	0.27	27 ± 4	0.26	25 ± 2	0.23	22 ± 2
	Lab 2	0.17	26 ± 3	0.10	16 ± 6	0.22	34 ± 3	0.16	25 ± 3
	Lab 3	0.31	24 ± 2	0.18	14 ± 4	0.55	42 ± 2	0.26	20 ± 2

% = percentage of phenotypic variance explained by previous listed variance component ± standard error

σ_a^2 = additive genetic variance

σ_t^2 = technician variance

$\sigma_{c:t}^2$ = contemporary group variance

σ_e^2 = residual variance

Table 2-5. Heritabilities (±SE) of ultrasound carcass traits

		Ultrasound carcass trait		
Breed	Lab	LMA	SFD	IMF
Angus (AAA)				
	Lab 1	0.32 ± 0.02	0.37 ± 0.02	0.48 ± 0.02
	Lab 2	0.27 ± 0.03	0.33 ± 0.03	0.67 ± 0.04
	Lab 3	0.38 ± 0.03	0.43 ± 0.03	0.55 ± 0.04
Hereford (AHA)				
	Lab 1	0.35 ± 0.02	0.26 ± 0.02	0.34 ± 0.02
	Lab 2	0.35 ± 0.03	0.25 ± 0.03	0.49 ± 0.03
	Lab 3	0.34 ± 0.03	0.29 ± 0.03	0.42 ± 0.03
Simmental (ASA)				
	Lab 1	0.41 ± 0.02	0.47 ± 0.02	0.55 ± 0.02
	Lab 2	0.45 ± 0.05	0.41 ± 0.05	0.52 ± 0.05
	Lab 3	0.50 ± 0.03	0.45 ± 0.03	0.54 ± 0.03

LMA = longissimus muscle area

SFD = subcutaneous fat depth

IMF = percent intramuscular fat

Table 2-6. Genetic correlations (±SE) between labs interpreting ultrasound longissimus muscle area (lower diagonal) and Spearman's rank correlations of estimated breeding values for longissimus muscle area (LMA) interpreted by each lab (upper diagonal) estimated within American Angus (AAA), Hereford (AHA), and Simmental (ASA) breeds

Breed		Lab 1	Lab 2	Lab 3
Angus				
	Lab 1		0.99	1.00
	Lab 2	0.94 ± 0.04		0.99
	Lab 3	0.96 ± 0.04	0.94 ± 0.04	
Hereford				
	Lab 1		0.95	1.00
	Lab 2	0.92 ± 0.06		0.96
	Lab 3	0.98 ± 0.06	0.88 ± 0.06	
Simmental				
	Lab 1		0.88	0.94
	Lab 2	0.78 ± 0.06		0.93
	Lab 3	0.85 ± 0.05	0.80 ± 0.06	

Table 2-7. Genetic correlations (±SE) between labs interpreting ultrasound subcutaneous fat depth (lower diagonal) and Spearman's rank correlations of estimated breeding values for subcutaneous fat depth (SFD) interpreted by each lab (upper diagonal) estimated within American Angus (AAA), Hereford (AHA), and Simmental (ASA) breeds

Breed		Lab 1	Lab 2	Lab 3
Angus				
	Lab 1		0.99	0.98
	Lab 2	0.93 ± 0.04		0.98
	Lab 3	0.92 ± 0.04	0.92 ± 0.04	
Hereford				
	Lab 1		0.82	0.77
	Lab 2	0.70 ± 0.11		0.49
	Lab 3	0.58 ± 0.14	0.26 ± 0.14	
Simmental				
	Lab 1		0.95	0.99
	Lab 2	0.82 ± 0.05		0.93
	Lab 3	0.94 ± 0.04	0.79 ± 0.06	

Table 2-8. Genetic correlations (±SE) between labs interpreting ultrasound percent intramuscular fat (lower diagonal) and Spearman's rank correlations of estimated breeding values for percent intramuscular fat (IMF) interpreted by each lab (upper diagonal) estimated within American Angus (AAA), Hereford (AHA), and Simmental (ASA) breeds

Breed		Lab 1	Lab 2	Lab 3
Angus				
	Lab 1		0.99	0.99
	Lab 2	0.95 ± 0.03		0.97
	Lab 3	0.94 ± 0.03	0.89 ± 0.03	
Hereford				
	Lab 1		0.97	0.97
	Lab 2	0.89 ± 0.06		0.93
	Lab 3	0.87 ± 0.07	0.80 ± 0.06	
Simmental				
	Lab 1		0.94	0.97
	Lab 2	0.79 ± 0.05		0.96
	Lab 3	0.88 ± 0.04	0.87 ± 0.05	

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SUMMARY

The use of ultrasound to measure beef carcass trait has numerous advantages compared to abattoir carcass measurements alone due to the ease and efficiency of the process. Carcass ultrasound measurements are generally less expensive and less time consuming to obtain. Ultrasound measurements can also be retrieved on live animals, which provides opportunity for utilization by seedstock producers. Previous literature has shown ultrasound measurements are positively genetically correlated with measurements pertaining to beef carcass merit and also generally explain more phenotypic variation compared to other traits such as fertility. This data demonstrates the efficacy of ultrasound as an indicator trait for carcass merit. However, even if ultrasound measurements of carcass traits are highly heritable, environment affects phenotypic variation for this trait. These environmental effects include but are not limited to technician, ultrasound equipment, scan technique and imaging laboratory

Ultrasound technician and laboratory are critical parts to the estimation of ultrasound carcass measurements. Both ultrasound technicians and laboratories go through certification processes by the UGC which are designed to reduce the variation among them. It is also assumed by the NCE that additive genetic and residual variance are homogenous among laboratories. From my analyses, technician was contributing to variation of ultrasound carcass measurements reported to three of the larger North American beef breed associations. Residual variation was heterogeneous among laboratories and genetic correlations were often different from one between laboratories when interpreting ultrasound images for the same trait. The latter result suggested that

images interpreted by different laboratories should not always be considered the same trait, which suggests imaging laboratory may be contributing to variance of ultrasound carcass measurements.

The results of these analyses suggest that processes for technician certification, ultrasound equipment certification, or both may need to be refined by the UGC. Consistency among imaging laboratories may also need to be improved. Overall, the continuation of improvement of ultrasound methods and technology are crucial to improving carcass ultrasound measurement utility and relevance for the beef industry