THE EFFECT OF GROWTH-PROMOTING IMPLANTS AND FEEDING DURATION ON LIVE PERFORMANCE AND BEHAVIORAL CHARACTERISTICS, BIOMETRIC MEASUREMENTS, EMPTY BODY COMPOSITION, AND ENERGY RETENTION OF SERIALLY-HARVESTED BEEF STEERS

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ABSTRACT

The current study strives to understand the effects of an extended release trenbolone acetate + estradiol-17β growth promoting implant upon live growth performance, feeding behavior, skeletal growth, and empty body composition of crossbred beef steers over a feeding period of 378 d compared to non-implanted controls.

In experiment 1, Charolais x Angus steers {n = 80; start of trial body weight (BW) 271 ± 99 kg} were randomly allocated to implant treatment and harvest date in a 2 x 10 factorial experiment. Steers were paired within genetic group according to initial BW, frame score, and adjusted final body weight (AFBW). Within each pair, a steer was randomly allocated to one of two treatments; implanted with Revalor-XS (REV; 200 mg TBA + 40 mg E_2 containing 4 uncoated pellets and 6 pellets with a proprietary time release coating technology) on d 0 and d 190 or non-implanted control (CON) to represent a non-hormone treated cattle (NHTC) marketing strategy. Eight steers comprised of 4 pairs were randomly assigned to 1 of 10 harvest dates at d 0, 42, 84, 126, 168, 210, 252, 294, 336, and 378 DOF. Steers were fed in open lot dirt surface pens (20 animals/pen) equipped with 4 GrowSafe^{TM} nodes per pen. Body weight was recorded at each harvest period and individual consumption data were recorded multiple times per day via electronic identification (EID) reads every second. Average daily gain (ADG) was 9.4% greater (P < 0.01) for REV steers (1.42 kg REV vs 1.30 kg CON) during the 378d trial. Dry matter intake (DMI) did not differ (P = 0.15) between treatments but

averaged 8.7 kg during the trial and decreased ($P < 0.01$) in a quadratic manner from 3.2% of BW during the initial period to 1.03% of BW after 378 DOF. Implanting with REV improved ($P < 0.05$) gain to feed ratio (G:F) by 8.2% during the trial, however a TRT x DOF interaction ($P < 0.05$) occurred after 293 DOF whereby REV steers became less efficient. Consumption visit frequency was 48.8 events/d during the initial period and decreased ($P < 0.01$) during the trial ending at 16.1 events/d. Daily consumption time began at 111 min/d during the initial period and decreased ($P < 0.01$) by 0.12 and 0.15 min/d for CON and REV, respectively. Implanted steers spent approximately 8 and 7.5 min/d less ($P < 0.01$) visiting and consuming feed, respectively. Singular consumption visits lasted 2.80 min/event during the initial period and increased ($P < 0.01$) 0.1 min/event for each 42 d period. Dry matter intake per consumption event began at 2.5 kg/event and increased ($P < 0.01$) 0.3 kg/event for each 42 d period. Implanted steers consumed 0.05 kg DM more ($P < 0.01$) per consumption event than CON. Consumption rate for each consumption event was greater ($P < 0.01$) for REV (290 g/min CON vs. 422 g/min REV). These data indicate live growth performance and feeding behavior were impacted by both growth enhancement technology and duration of finishing.

In experiment 2, 24 h prior to each of the 10 harvest dates, all steers were measured for hip height, rump length, hip width, shoulder height, 2/3 body length (BL), body depth, body width, and frame score. Forty-eight h after harvest, a digital image was obtained of the lateral aspect of the right side of each carcass. Carcass area, maximum length and width were digitally measured against a common standard. Body width was 1.17 cm greater ($P < 0.01$) in REV steers and 2/3 BL tended ($P = 0.06$) to be greater in CON steers. Hip height increased ($P < 0.01$) 0.05 cm each d during the 378 d feeding

period. Rump length increased ($P < 0.01$) 0.03 cm/d. Hip width increased ($P < 0.01$) 0.06 cm/d. Shoulder height increased ($P < 0.01$) 0.06 cm/d. Two-thirds BL increased ($P < 0.01$) 0.11 cm/d. Body depth increased ($P < 0.01$) 0.07 cm/d. Body width increased ($P < 0.01$) 0.04 cm/d. Steers administered REV yielded 516 cm^2 greater ($P < 0.01$) surface area on ½ of the carcass, or one side, than CON; moreover surface area increased 21.0 cm^2 /day. No TRT effect ($P = 0.57$) was observed for maximal carcass length, however maximal carcass width was 3.9 cm greater ($P < 0.01$) for REV steers. Steer carcasses increased 0.16 cm/day in length and 0.07 cm/day in width. These data indicate biometric measurements and carcass dimensions were impacted by both growth enhancement technology and duration of finishing.

In experiment 3, during harvest and fabrication, samples were collected to determine empty body composition via proximate analysis of blood, hide, internal cavity components, bone, and carcass soft tissue. Proximate analysis of each tissue was multiplied by mass to assimilate empty body percentages of moisture (EBM), crude protein (EBP), ether extractable fat (EBF), and ash (EBA). Retained energy (RE) was calculated as the difference between the baseline steers (n = 8; initial steers harvest on d 0) and those representing each treatment across harvest endpoints, as was empty body weight gain (EBWG), hot carcass weight gain (HCWG), and ratio of HCWG to EBWG. Metabolic ratio (MR) was calculated as the ratio of RE to daily megacalorie consumption (DMC). Using individual laboratory results for each animal, the difference in total energy was calculated and averaged by treatment and harvest day by subtracting values for each animal from the mean of the baseline steers. Moisture, protein, fat, and ash accretion (MA, PA, FA, AA, g/d, respectively) was calculated as the difference measured in grams

per day on trial amongst each treatment and harvest endpoint with the baseline steers representing d 0. Empty body moisture decreased ($P < 0.01$) in a quadratic trend at approximately 0.0373%/d beginning at 61.9% on d 0 and ending at 47.8% on d 378. Empty body protein decreased ($P < 0.01$) linearly by approximately 0.0071%/d beginning at 18.7% on d 0 and ending at 16.0% on d 378. Empty body fat increased ($P < 0.01$) in a quadratic trend at approximately 0.0450%/d beginning at 14.0% on d 0, until d 294 and plateaued at approximately 32.0% through d 378. Empty body ash remained constant ($P = 0.29$) over the feeding period (5.5% - 5.8%). Empty body protein (16.7% CON vs 17.4% REV) and EBA (5.4% CON vs 5.7% REV) were greater ($P < 0.01$) for REV steers, and EBM (50.7% CON vs 51.6% REV) tended to be greater ($P = 0.07$) for REV steers. In contrast, EBF (27.3% CON vs 25.3% REV) was greater ($P < 0.01$) for CON steers. Ratio of EBP to EBF was less ($P < 0.05$) for CON steers (0.692:1) compared to 0.752:1 for REV steers and decreased ($P < 0.01$) approximately 0.002/d from at 1.378 on d 0 to 0.542 on d 378. Empty body weight gain was 2129 g/d during the initial 42 d period and decreased in a linear fashion ($P < 0.01$) to 1185 g/d at d 378, decreasing in gain 2.5 g/d. Hot carcass weight gain was similar as it decreased from 1479 to 962 g/d in a linear fashion ($P < 0.01$) across the feeding period, slowing by 1.4 g/d. Empty body moisture weight, EBPW, EBFW, and EBAW increased ($P < 0.01$) 520, 190, 490, and 80 g/d from d 0-378, all increasing ($P \leq 0.01$) in a quadratic fashion. Implanted steers exhibited an increase ($P < 0.01$) in EBWG and HCWG (1695.5 and 1359 g/d) compared to CON (1457 and 1169 g/d), or a 239 and 190 g/d increase. Implanted steers also contained more ($P < 0.01$) EBMW, EBPW, and EBAW (+20.7, +8.5, and +3.1 kg) than CON. These results reflect PA, MA, and AA, as REV steers exhibited increased ($P <$

0.01) tissue accrual by +67.3, +162.3, and +19.1 g/d, respectively, compared to CON. Fat accretion did not differ over time ($P = 0.42$) and between treatments ($P = 0.76$). Protein to fat accretion ratio was greater ($P < 0.01$) in REV (0.48) compared to CON (0.35). Protein to fat accretion ratio also decreased ($P < 0.01$) across DOF starting at 0.54 on d 0 and ending at 0.39 on d 378. These data indicate that growth-promoting implants alter composition of gain during the finishing period and protein accretion is increasing at a decreasing rate while fat is increasing at an increasing rate.

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DEDICATION

This thesis is dedicated to my family:

To my grandparents, Jack and Zoe Kirkpatrick of Post, TX,

To my grandparents, Johnny and Nelda Allen of Liberty City, TX,

To my parents, Joel and Rhonda Kirkpatrick,

To my brother, Zack,

Each of you have made priceless contributions to my education, my being, and my life. I thank you for molding me into the man I am today. It brings me great joy knowing that my late grandparents are always looking down at me and smiling. I love you all so much.

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Chapter I

INTRODUCTION

In beef cattle, tissue accretion in regards to protein, fat, and bone differ as the animal's physiological age advances (Koch et al., 1978). Maintenance energy requirements are estimated as a function of metabolic BW ($BW^{0.75}$; Fox and Black,1984), whereas gain requirements are a result of the composition of gain and the proportion of fat versus protein accretion (Garrett, 1959). On high-energy dense rations, fat accretion of both the empty body and carcass occurs late in the growth phase at an accelerated rate (Simpfendorfer et al., 1974). The increase in protein and fat accrual as a proportion of gain results in a higher energy requirement in the latter phase of the feeding period, resulting in reduced feed efficiency.

Lofgreen and Garrett (1968) developed a system that described how metabolizable energy (ME) in feed could be quantified and separated as net energy for maintenance (NEm) and gain (NEg). Lofgreen and Garrett (1968) also estimated the caloric requirement for maintenance at 77 kcal*$BW^{0.75}$. Data related to serial harvest of fed cattle concluded that growth rate and fat deposition increased across DOF (Zinn et al., 1970).

Garrett and Hinman (1969) described relationships amongst the animal empty body, carcass density and carcass composition. Fox et al. (1976) reported linear relationships between the empty body weight (EBW) and HCW in beef cattle. Guiroy et al. (2001) developed models to estimate empty body fat (EBF) using carcass grading parameters.

Use of growth technologies such as anabolic implants containing components such as estradiol, trenbolone acetate, progesterone, testosterone, and zeranol have been utilized since the Food and Drug Administration's (FDA) approval of oral diethylstilbestrol in 1956 (Johnson et al., 2013). These products are well documented to enhance rate of growth, feed utilization efficiency, and ultimately add value to the beef production system through increased tissue accretion over time (Apple et al., 1991).

The development of individual feed data utilizing radio frequency (RF) identification and specialized bunks containing load cells have allowed producers to quantify intake, performance, and feeding behavior on an individual basis versus pen basis (Hickman, 2000). This technology allows large data sets to be gathered easily versus individual visual observation. Being able to identify individual animal performance and behavior may aid producers in selecting animals that are more efficient.

Individual feeding systems have been developed over time such as the Calan system (American Calan Inc., Northwood, NH), Pinpointer system (Pinpointer, UIS Corporation, Cookville, TN), Insentec (Hokofarm Group BV, Marnesse, Netherlands), and the most recent, GrowSafe (GrowSafe Systems ltd. Airdrie, Alberta). The GrowSafe system works with a RF ear tag to quantify visits and time spent at the bunk in conjunction with quantity of feed consumed. This technology can be useful in monitoring

large pen settings to evaluate factors that influence social interactions regarding eating patterns and performance.

The sigmoid "S" growth curve of beef cattle can be modeled by three parameters; size, rate, and stages of accelerated or inhibited growth (Brody, 1945; Blaxter, 1968; Fitzhugh, 1976). Rate of growth and size can be non-invasively quantified in live animals by use of biometric measurements. Measuring variables such as body weight, shoulder height, hip-height, pelvic dimensions, and body depth and width will accurately determine both body dimensions and skeletal frame size of live animals (Reed et al., 2017). These body measurements can also aid researchers in quantifying post-mortem characteristics including carcass dimensions, dressing percentage, yield grades, and carcass composition (Cook et al., 1951; Fisher et al., 1975; De Paula et al., 2013). Understanding skeletal growth and using biometric measurements has allowed the industry to become more efficient in sorting cattle within groups in pen settings to better utilize days to market readiness and to determine when the animals have reached desired carcass traits (Reid et al., 2017).

The primary objectives of this study included three investigations. All experiments evaluated changes in serially harvested Charolais x Angus steers implanted with Revalor-XS (REV; Merck Animal Health, Madison, NJ), or non-implanted control (CON) across a wide range of DOF. The first investigation involved utilizing the GrowSafe system to determine live performance and feeding behavior and how REV affected these variables over time. The second evaluated skeletal growth over 378 d utilizing biometric measurement technology (Performance Cattle Company, Amarillo, TX), while also evaluating carcass dimension growth across DOF. The final experiment

focused on changes in empty body and carcass composition and the effect of REV on enhancing the utilization of energy in regards to empty body and carcass composition over time as the steers grew across multiple marketing endpoints.

Chapter II

REVIEW OF LITERATURE

2.1 Growth Physiology of the Bovine

The growth of muscle, fat, and bone can be summarized into the term composition of gain. Composition of gain can be defined as the accretion of carcass components when nutrient uptake supplied by the diet is utilized by the body. Cattle consuming a ration that exceeds their individual maintenance requirement over a period of time will exhibit the addition of body components including bone and soft tissues such as fat and muscle (Trenkle and Marple, 1983). In today's beef industry, research has often focused on the value added by incremental gains in carcass soft tissues and bone. This segment will focus on specific interactions that must take place in a beef animal's body to allow for the development and growth of muscle, fat, and bone in fed cattle.

2.1.1 Accretion of Muscle and Hyperplasia. Myogenesis, or muscle fiber formation, is a process that includes many steps and processes. Picard et al. (2002) and Oksbjerg et al. (2004) explained these processes in detail. The embryonic mesoderm segments into structures termed somites. The somites then enter a process that will determine the particular myogenic precursor. When the precursor is determined, migration occurs

allowing for formation of limb musculature. Once in place on the limb, the cells are called myoblasts. These myoblasts can undergo several proliferations which will lead to an increase in cell number. The myoblasts will fuse to adjacent myoblasts to form syncytial tubes which undergo further proliferation to form myotubes. The myotubes will become the correct diameter and length due to muscle-specific genetic coding and form skeletal muscle. The prenatal formation of muscle cells and hyperplasia is of extreme importance in regards to mature animal muscle structure during harvest at the end of its life.

2.1.2. Muscle Fiber Hypertrophy. Post-natal muscle fiber development depends on endogenous growth hormones such as somatotropin, insulin, and insulin-like growth factors I and II. Owens et al. (1993) outlined these hormones in relation to muscle hypertrophy. The hormones previously listed have a pronounced effect on muscle satellite cells. The hormones effect the satellite cells by affecting cell efficiency, leading to increased transcription and translation of skeletal muscle DNA. Exogenous hormones delivered to active binding sites in skeletal muscle also contribute to muscle hypertrophy and satellite cell efficiency (Johnson et al., 2013). The majority of muscle cell DNA is accumulated postnatal (Koohmaraie et al., 2002) through the activities of skeletal muscle satellite cells.

2.1.3. Accretion of Lipids. The biosynthesis of lipids requires the liver and adipose tissue with respect to fatty acid synthesis (Nafikov and Beitz, 2007). In non-lactating ruminants, the biosynthesis of fatty acids occurs in preexisting adipose tissue. Ducharme and Bickel (2008) described lipid accretion as a method for organisms to store excess energy when caloric intake surpasses the level of energy needed for maintenance. The

storage of lipids in the form of the endocrine organ adipose tissue involves the formation of triacylglycerides, with other forms of storage described as lipid droplets in eukaryotic cells. These lipid droplets that are formed intracellularly mimic the structure of circulating lipoproteins, in that they consist of esterified lipids incased by a phospholipid monolayer and various proteins (Brassaemle, 2007). These lipid droplets serve as an energy depot for the organism, which in times of low energy may be utilized via the activity of lipid hydrolases for the utilization of stored energy (Martin and Parton, 2006). Although important to the animal as a storage molecule, once harvested, the overall quantity of lipids in the carcass become an important factor in most marketing channels with carcasses possessing greater levels of intramuscular fat (marbling) being valued higher than cattle exhibiting less fat at the same hot carcass weight. Cell diameter of adipose tissue increases exponentially as cattle mature up to 12 months of age, with a linear increase until 2 years of age (Wegner et al., 1998). With most cattle in the United States following a traditional cow-calf/backgrounder/finishing system, this exponential growth most likely would occur when the animal is utilizing a forage-based ration existing of hay or other pasture (native grasses or wheat) that is typically low in caloric value then followed by a high energy concentrate ration fed during the finishing phase. Etherton and Walton (1986) described the total body energy of a finished beef animal derived from adipose tissue at 80-90%. The lipid depots (internal, intermuscular, intramuscular, and subcutaneous) in a finished animal are comprised of 70-90% lipids, 5-20% water, and 5% connective tissue with overall amount of total body adipose represented by each depot as 45% intermuscular, 38% internal and 17% subcutaneous

(Etherton and Walton, 1986). Jeremiah et al. (2003) indicated that intramuscular fat of various muscles in beef carcasses ranged from 3 to 11%.

2.1.4 Accretion of Bone. Bone formation is a process that occurs throughout the animal's lifetime. Ohlsson et al. (1998) reviewed bone growth and development with regard to growth hormone (GH). The process of longitudinal bone growth starts with pre-chondrocytes in the germinal cell layer differentiating and undergoing clonal expansion in chondrocyte columns in the growth plate. Cellular components located in the hypertrophic area mature and degenerate and are slowly incorporated into the structure of bone. Growth hormone plays an important role in the process of bone growth. The direct effect of GH and insulin-like growth factor I (IGF-1) on chondrocytes has been theorized and studied with the understanding of GH occurring during different stages of cell growth. Hunziker (1994) reviewed bone growth and regulation in which the cellular and biological processes were discussed and focused on the postnatal period of animals. The basis for longitudinal bone growth focuses on the epiphyseal growth plate cartilage. Growth plates in bone are located near the proximal and distal ends of long bones. Elongation of bones occurs in the diaphyseal portion of the bone which is continuously dislocated from the center of the bone. Longitudinal bone growth is effected by the activity of growth plate cartilage, which is mediated by multiple factors of the endocrine system (Brighton, 1978). Bone growth plates are organized in a manner that the chondrocytes are placed in a vertical column and function as a structural unit of longitudinal bones (Brighton, 1978). The activity of these areas of bone growth leads to continuous addition of new cells to the cartilage that exists in these regions.

2.2 Carcass vs Live Rate of Gain during the Finishing Period

Rate of carcass gain during the finishing period of fed cattle production has the greatest effect of value optimization for producers whom sell cattle on a dressed or formula basis. Measuring feed utilization of the carcass may allow producers to market cattle at an optimum carcass, rather than live, endpoint.

McDonald et al. (2007) investigated the change in gain of the shrunk body and carcass across days on feed (DOF) in beef cattle. As DOF increased, dressed yield increased at a rate of 0.097 percentage points on a daily basis. Transfer of weight from the shrunk body to the carcass in this trial indicated an increase of 0.003 percentage units per day on feed. At the beginning of the finishing period of cattle, roughly 60% of the weight gained by the animal was related to muscle, fat, and bone contained within the carcass. When cattle were serially harvested, the data suggested that after a finishing period of 100 d, over 80% of the weight gained by the animal was growth of carcass components. Feed utilization based on weight gain transfer to the carcass and shrunk body was also illustrated. These data illustrated that feed utilization across DOF became less efficient for both measurements; however, the increase in carcass feed to gain was 0.007 kg per day with that of the shrunk body being 0.16 kg per d; calculated intercepts of 3.16 and 1.91, respectively. These slopes indicate that feed utilization change across DOF by the carcass is not as drastic compared to feed utilization of the shrunk body.

In a review of growth and development of fed cattle, Owens et al. (1995) compiled data from various research trials to illustrate the change in live weight, empty body, carcass, and lean weights. Of cattle on pasture for 145 d, the empty body, carcass, and lean weight comprised 77, 52, and 44% of live body weight. In addition, during the feedlot period of the investigation, empty body weight, carcass weight, and lean weight

gained 118, 87, and 71% relative to live body weight. These data illustrated how the composition of gain changes over time relative to energy intake and overall physiological maturity with cattle having increased empty body gain during the finishing period.

2.3 Comparative Harvest of Fed Cattle.

Lofgreen and Garrett (1968) developed a system aimed at expressing energy requirements for cattle as well as feed energy values for growing and finishing cattle. Data from five comparative slaughter trials utilizing beef type steers (n = 118) and heifers (n = 118) was compiled to test the model first introduced by Lofgreen (1963). Energy status and utilization of cattle varied with amount fed as well as the nutrient status of the diet. It was recognized that as level of feeding fell, the net energy of that same feed increased and vice versa. This outcome led Lofgreen and Garrett (1968) to partition energy values for cattle based on their separate energy needs. Therefore, a system was created that predicted net energy requirement for maintenance (NEm) and gain (NEg). To determine NEm, heat produced from the animal must be ascertained, and thus heat produced at an energy intake of zero must be measured. This was accomplished by serial harvest of cattle to measure energy retained in the empty body as well as energy lost in the form of feces, urine, and methane. The NEm requirement based on this study was determined to be 77 kcal*$BW^{0.75}$. This equation was a starting point for nutritionists or producers to determine the energy provided by the feedstuff and how it affected gain of the empty body.

In later studies, focus was placed on the estimation of empty body weight (EBW) from the hot carcass weight (HCW) of fed cattle. Fox et al. (1976) compiled data from 99 Hereford steers that were slaughtered at 364 and 454 kg live weight. Regression

equations were developed that ascertained empty body weight with a simple r of 0.91 and standard error (SE) of 13.5kg (EBW = 1.40(chilled carcass weight, kg) + 40.2). Lofgreen et al. (1962) developed equations previously (EBW = 1.45(HCW) + 70; simple *r* of 0.97, SE of 0.03). Garrett and Hinman (1969) also developed an equation (EBW = 1.36(HCW) + 30.3; simple r of 0.99, SE of 5.8). The differences of these equations are the methods used to determine EBW and using hot vs cold carcass weights. Fox et al. (1976) and Lofgreen et al. (1962) equations were developed using an EBW that was calculated by measuring live weight and subtracting all gut fill (residual feed contents). Equations developed by Garrett and Hinman (1969) measured EBW by subtraction of all digestive tract contents including fill and tissues. These differences definitely affected the slope and intercept of prediction equations developed.

Nichols (1991) investigated various implant strategies compared to non-implanted control across 5 slaughter periods. Implanted steers exhibited greater ADG and intake while outperforming control steers regarding feed efficiency. Specific gravity was utilized for carcass composition and TBA + E-17β combination implants exhibited improved protein accretion while decreasing percentage of fat accretion.

In more recent trials, the composition of cattle has become the focus in an effort to explain the effects of various growth promotants on tissue partitioning. Hutcheson et al. (1997) evaluated various growth promoting compounds on the composition of the empty body. Twenty-four genetically identical steers were utilized in which 4 animals served in each harvest group with each steer within group receiving a different treatment. Treatments included administration of an estrogenic, androgenic, a combination of estrogenic and androgenic implants, and a non-implanted control. Control cattle had the

least EBW of all cattle, with increased gastrointestinal tract and total organ mass. No differences were observed for moisture, protein, fat, and ash as a percentage of the empty body. However, absolute weights of moisture and protein were less for the control group. In conclusion, the use of growth promotants increased protein retention and led to a repartitioning effect in which organ mass became less as a percentage of EBW in cattle receiving estrogenic implants.

Guiroy et al. (2001) compiled data from 9 comparative slaughter trials to quantify body composition and feed requirements for cattle fed in groups and to model beef cattle growth and estimate feed consumption on an individual animal basis. Of the 9 studies, 8 utilized the Hankins and Howe (1946) method and 1 used whole carcass grind and chemical analysis method to determine body composition. A total of 1335 steers and heifers were used in model development related to prediction of empty body fat (EBF) from carcasses. The model developed by Guiroy et al. (2001) used fat thickness (FT), HCW, quality grade (QG), and longissimus muscle area (LMA) to estimate EBF. The equation developed {EBF = 17.76207 + (4.68142 x FT) + (0.01945 x HCW) + (0.81855 x QG) – (0.06754 x LMA)} had a R^2 of 0.61 and root mean square error of 3.52. The use of comparative slaughter and body composition in determining retained energy allows producers to estimate how changes in diet energy effect outcomes related to carcass finish and quality.

McEvers (2014) conducted a serial harvest and evaluated a β-2 adrenergic agonist {Zilpaterol Hydrochloride (Z), Merck Animal Health, Madison, NJ} in calf-fed Holstein steers. Steers supplemented with Z exhibited increased EBW, HCW, HCW gain, dressed yield, carcass soft tissues (CST), empty body moisture, and empty body protein

compared to control steers regardless of DOF. Control steers exhibited more fat accretion (1.7%) overall. Chemical composition from carcass and non-carcass component whole grind allowed for equations to be developed to estimate empty body fat, empty body protein, and retained energy.

Walter (2015) conducted indirect calorimetry and comparative slaughter trials to examine energy and protein metabolism and empty body composition of cattle supplemented with Z, while also being fed maintenance and *ad libitum* intakes. Moisture, protein, and fat gains were decreased from maintenance diet compared to *ad libitum*. Zilpaterol hydrochloride tended to increase nitrogen retention and modify heat production during maintenance by increasing carbon dioxide production. Days on feed, energy level intake and Z supplementation affected live performance, carcass grading factors, empty body and carcass composition and efficiency of gain.

2.4 Modeling Chemical Composition of Fed Cattle

Modeling chemical composition of cattle has been a topic for many years. Murray (1919) indicated that chemical composition of a live animal could be predicted by keeping the fat-free body of the animal constant in composition. Lush (1926) focused on development of equations derived from the dressed yield as well as the wholesale rib for prediction of carcass fatness. Equations developed by regressing dressed yield and percentage of fat in the rib were highly correlated to actual carcass fatness (+0.84 and 0.89, respectively). However, determining the chemical composition of whole animals has numerous challenges, including funding or large amounts of capital invested, and also labor to conduct these trials. Due to these constraints, trials have been conducted to capture measurements using methods that are less expensive and less intensive. Moulton

et al. (1922) were the first investigation to suggest the use of the wholesale rib as an estimate for carcass composition. Hankins and Howe (1946) developed procedures to use a portion of the IMPS 103 ribeye roll to estimate carcass composition. This was much less labor intensive than grinding the whole carcass and performing chemical analysis to determine total carcass moisture, protein, fat, and ash.

2.4.1 The Hankins and Howe Method of Estimating Carcass Chemical Composition and Yield. The objective of Hankins and Howe (1946) was to provide a basis for carcass composition utilizing a less expensive sample to represent the whole carcass. The investigators determined that the 9-10-11 rib portion (taken from the primal currently known as the IMPS 103 ribeye roll) could be used as a sample representing the entire carcass. Carcasses were weighed warm approximately 30 minutes after dressing procedures had ceased. After weighing, carcasses were shrouded according to the industry standard at the time, and chilled for 48 to 72 hours at 1.1 °C. Carcass right sides were used and weighed cold along with primary cuts that included the chuck, brisket, plate, rib, loin, and round. The standing rib portion was removed from the cranial portion of the carcass by sawing a line that separated the carcass at the 5^{th} and 6^{th} rib with the caudal portion being removed at the 12^{th} and 13^{th} rib. The 9-10-11 rib sample was derived from the standing rib roast (IMPS 103) by using a knife to crowd the rear edges of the 8^{th} and 11^{th} ribs. Removal of the *longissimus dorsi* muscle did not include any other muscles such as the *spinalis dorsi* that is traditionally intact. Once removed, the physical components of the 9-10-11 rib including separable fat, lean, and bone were weighed. Lean and fat were thoroughly ground and later analyzed for proximate analysis.

Equations were developed from both the physical and chemical composition of the 9-10-11 rib dissections. Separable lean of the carcass was estimated as (Separable lean, % = 15.56 + (0.81 x separable lean of the rib dissection) with a simple *r* of 0.85. Separable fat of the carcass was estimated as (Separable fat, % = 3.06 + (0.82 x separable fat, % of rib dissection) with a simple *r* of 0.93. Separable bone of the carcass was estimated as (Separable bone, % = 4.30 + (0.61 x separable bone, % of the rib dissection) with a simple *r* of 0.83. Prediction of chemical composition of the carcass included moisture, protein, and ether extract. For prediction of carcass moisture %, an equation with a simple *r* of 0.93 was developed (Moisture, % = 14.90 + (0.78 x moisture, % of the rib dissection). For prediction of carcass protein %, an equation with a simple *r* of 0.84 was developed (Protein, % = 5.98 + (0.66 x protein, % of the rib dissection). For prediction of carcass ether extract %, an equation with a simple *r* of 0.66 was developed (Ether extract, % = 21.33 + (2.03 x ether extract, % of the rib dissection). Visual representations of these data in Hankins and Howe (1946) indicate cattle were homogenous and no outliers appeared in the data. The equations developed from this investigation are still used in current research methodology, however, the accuracy of these classical equations have been subject to evaluation.

Crouse and Dikeman (1976) re-examined methods of predicting beef carcass chemical composition; they suggested that estimated intramuscular fat content and subcutaneous fat thickness should be coupled with 9-10-11 rib dissection data to better describe variations in carcass chemical composition.

Walter et al. (2016) evaluated the rib dissection method compared to carcass grind regarding body composition in beef steers fed maintenance or *ad libitum*, supplemented

with Z or no Z. The authors concluded that there were strong correlations ($r > 0.80$) between separable lean and fat of the 9-10-11 rib to separable lean and fat of the carcass, however chemical composition of the carcass was moderately correlated ($r < 0.50$) to the 9-10-11 rib chemical composition.

McEvers et al. (2018) evaluated the rib dissection method compared to carcass grind regarding body composition in calf-fed Holstein steers supplemented Z. Compared to the original work from Hankins and Howe (1946), the correlations of rib dissection simple *r* values to carcass values were lower than observed in the original data. The original simple *r* values for the 9-10-11 rib section's moisture, protein, fat, and ash were reported as 0.92, 0.83, 0.91, and 0.51, respectively. McEvers et al. (2018) reported that simple *r* values were considerably weaker with values being 0.66, 0.31, 0.75, and 0.37 for the relationships of rib dissection moisture, rib dissection protein, rib dissection ether extract, and rib dissection ash with carcass moisture, carcass protein, carcass ether extract, and carcass ash, respectively.

2.4.2 Estimating Carcass Chemical Composition using Specific Gravity. Kraybill et al. (1952) has been known as the earliest investigation utilizing specific gravity to determine separable fat and moisture in beef carcasses. Specific gravity, or relative density, is a ratio of the density of a substance to that of a standard substance, such as water. The equations developed from this study were derived from the specific gravity of Hereford steers and heifers. This study developed two equations, one for carcass fat {Carcass fat, % = 100 x (4.802 / carcass specific gravity – 4.366)} and moisture {Carcass moisture, % = 100 x (3.896 – 3.486 / carcass specific gravity)}. The simple *r* values of carcass specific gravity to carcass fat and moisture were 0.956 and 0.984 respectively.

Reid et al. (1955) developed equations expressing relationship of carcass chemical composition. The equations used Kraybill et al. (1955) as a starting point and then further regressed them to calculate composition of the empty body. The composition of fat in the empty body was calculated using the following equations: Fat in the empty body, % = 355.88 + (0.355 x moisture in the empty body, %) – (202.906 x Log (moisture of the empty body, %)). Once the percentage of EBF is calculated, the percentage of fat-free dry matter, % = 100 – (moisture, % + EBF, %). Protein of the empty body can then be calculated using the known value of fat-free dry matter by using the following equation (Protein, % = 80.93 – (0.00101 x age of animal in days)). Ash contained within the empty body can then be calculated using the following relationship where Ash, % = (fat-free dry matter, %) – (protein, %). Using these equations to calculate values of EBF and empty body protein (EBP), the calories stored in the body may be calculated by utilizing 5.23 and 9.37 calories representing the energy value on a per gram basis for protein and fat in the body (Atwater and Bryant, 1900).

These early investigations allowed researchers to design comparative slaughter studies that estimated retained energy in beef cattle. Garrett and Hinman (1969) developed several equations that described the relationship between carcass and empty body composition. The equations are as follows: EB moisture = 0.9702(carcass moisture, %) + 3.92; simple *r* of 0.99, SE of 0.74; EBF, % = 0.9246(carcass fat, %) – 0.647; simple *r* of 0.99, SE of 0.53; EB nitrogen % = 0.7772 (carcass nitrogen, %) + 0.713; simple *r* of 0.96, SE of 0.05; and EB ash, % = 0.6895(carcass ash, %) + 0.844; simple *r* of 0.96, SE of 0.09. These equations enabled the estimates of chemical composition of the carcass from specific gravity to be further utilized to estimate body composition. From these

estimates, utilization of physiological energy values for fat and protein could be used to estimate energy retention of the body.

2.4.3 Whole-Body ^{40}K Counting. Estimating body composition by use of potassium-40 counting is feasible because of the direct relation of potassium to lean body mass and its indirect relation to fat. Potassium is the only single element found in body tissue that has a predictive value of body composition. It is mostly found in intracellular space, and thus, total body potassium is indicative of total body cell mass. Potassium is not found in adipose tissues in any significant amounts, therefore if potassium is present in the fat-free tissues as a constant percentage, a value for total body potassium can be converted to a weight of lean body mass (Ward, 1968).

Approximately 0.012% of all naturally occurring potassium is made up of the radioactive isotope ^{40}K. The remainder is composed of the stable isotopes ^{39}K and ^{41}K. Because potassium-40 emits gamma radiation at 1.46 MeV, the intensity of 1.46-MeV gamma emission from the body can be used to estimate total potassium content. From these values, total body protein and lean mass can be estimated, assuming the mass of protein or muscle versus potassium is constant (Schmidt et al., 1974).

Lohman et al. (1968) reported that the standard error (SE) for the estimation of total mass of potassium in beef carcasses was 3.4% and the corresponding figure for carcass lean mass was 4.2%. Breidenstein et al. (1968) used 103 steers representing 4 breed types and harvested at 4 different weights to compare several methods of determining carcass lean muscle mass. Fifty four-steers were subjected to whole body counting after consuming a low-counting diet for one week. Constants for breed type were included in all regressions except those using whole body potassium and physical

measurements of the live animal. The dependent variable was weight or percentage of carcass lean muscle mass. Whole body ^{40}K counting resulted in the lowest coefficient of variation of any regression model except the model including standard trimmed lean, which had a coefficient of variation of only 1.4%.

The ^{40}K method has proved useful in research studies. Only a few research stations in the United States contain a ^{40}K whole body counter. Furthermore, facilities must have special shielding from background radiation due to the low levels of ^{40}K being measured. Factors that restrict ^{40}K being used in commercial industry include random error due to counting statistics, instability of the counting apparatus, and variation in sensitivity due to differences in body geometry and position of the animal.

2.4.4 Ultrasonics. Ultrasonics are based on the principle of high frequency sound signals passing through tissues, and when an interface between two tissues is encountered, some sound is reflected back. A pulse generator sends electrical pulses that are converted into sound signals in the transmitter. These signals are then passed through the tissues until they are reflected at an interface. The reflected signals picked up by the receiver can be amplified and shown in a visual form by an oscilloscope. Variations in the time taken for the reflected signals to return to the transmitter-receiver are used to measure variations in the distances of the boundaries between tissues (Miles, 1978). Recent developments in ultrasonics have led to a new interest in the use of ultrasonic techniques for estimating body composition in meat-producing animals (Recio et al., 1986).

"A" mode ultrasonic machines display echo amplitude against time which is shown on the screen as peaks superimposed on a time baseline. The distance between the peaks represents the thickness of the tissues being measured. For "B" mode machines, the

signals are shown on a cathode ray tube as a series of bright spots. Thickness of the tissues is represented by the distance between successive bright spots. These machines have a single transducer that moves across the body of the animal on a track. As the transducer moves, a picture is displayed on a cathode ray screen. An example is the Scanogram machine.

Real-time machines produce an instantaneous picture by rapid electronic switching from element to element. This principle is similar to what was previously described, except that movements of tissues can be seen due to the continuous nature of the picture. Interpretation of results for "B" mode machines and real-time scanning usually requires the tracing of depths and areas from pictures. This can now be accomplished by using planimeters linked to microprocessors or computers (Alliston, 1983).

Application of ultrasonics to the measurement of carcass traits of meat-producing animals was first reported in the United States by Stouffer et al. (1959). Ultrasonic scanning predicts body composition with a degree of accuracy similar to the corresponding cut surface measurements on the carcass.

Andersen et al. (1982) provided a comparative report on 5 ultrasonic machines (the Scanogram, the Danscanner, the Philips, the Ohio, and the Bruel and Kjaer). The Bruel and Kjaer was less accurate than the other four. There were no differences detected among the other four units in terms of predicting body composition traits. A more recent review of literature (Miller et al. 1986; Recio et al. 1986) indicated that real-time ultrasound measurements obtained by experienced operators can accurately predict carcass composition traits. The real-time ultrasound live measures of *longissimus dorsi*

area, 12th rib, and shoulder fat thickness were correlated to the comparable carcass measurements with r^2 = 0.98, 0.88, and 0.79, respectively.

2.5 The Effect of Growth Promoting Implants

Due to decreased supply of cattle, the beef industry continues to utilize technology that improves feed efficiency and yield to meet consumer demand. Use of exogenous steroidal hormones implanted into the animal's ear has become a common practice in most feedyards due to increases in growth and the efficiency observed.

2.5.1 History and Mechanism of Action of Implants. Steroidal implants containing exogenous hormones such as trenbolone acetate (TBA), estradiol 17-β (E_2), estradiol benzoate, progesterone, testosterone, and zeranol are commonly used in implants placed in the ear of beef cattle that are to be harvested for meat. Implants are placed into the middle third of either ear of the animal. Once inserted, the small pellets which are compressed and contain small amounts of material such as lactose or cholesterol (serving as hormonal carriers) begin to enter the blood stream (Anderson and Johnson, 2004). Steroid-binding globulins bind to the hormones from the implant and will deliver the hormone to target tissues.

Johnson et al. (2013) reviewed the historical timeline of growth technologies. The first growth promotant approved in 1954 by the Food and Drug Administration (FDA) was a compound known as diethylstilbestrol (DES); it was supplemented to cattle in the diet at a concentration of 2-11 mg/animal. In 1956, the first implant utilized in the beef industry known as Synovex-S contained estradiol benzoate and progesterone for use in beef steers. In 1958 an estradiol benzoate/testosterone propionate implant was approved

for use in beef heifers. In 1968, melengestrol acetate (MGA) was approved for use as a feed additive for heifers to control estrus. In 1972 DES was removed from the market due to human health concerns related to its use as a human pharmaceutical. The first synthetic testosterone analog implant was approved in 1987 and was known as TBA. It has similar androgenic properties to testosterone, however the anabolic activity of TBA regarding proliferation of skeletal muscle satellite cells may be 10 to 50 times greater than testosterone (Bouffault and Willemart, 1983). In 1991, a modern form of estrogen used in implants for steers and heifers was approved. This compound, known as E_2 was commonly used in addition with TBA in stocker and fed steers and heifers for increased efficiency of gain.

The mechanism of action regarding estrogenic compounds utilized in modern implants has been described by Johnson et al. (1996) and Anderson and Johnson (2004). Estrogenic compounds increase the relative size of the pituitary gland and increase the amount of somatotroph. The increase of somatotroph tissue in the pituitary gland may have direct effects in growth hormone output from the pars distalis of the pituitary gland. Other effects are related to the pituitary gland becoming more receptive to somatotropin releasing factor with increased production of IGF-1. These changes work synergistically to alter levels of circulating somatostatin which leads to muscle hypertrophy through increased protein synthesis.

Johnson et al. (2013) described the mechanism of action of androgenic implants as an increase in skeletal muscle hypertrophy. Trenbolone acetate, the primary androgen used in modern implants, works directly on skeletal muscle tissue to promote hypertrophy. Gorski et al. (1990) and Trenkle (1997) postulated that the mode of action

of exogenous androgenic hormones increase growth-enhancing endogenous hormones such as IGF-1 and growth hormone (GH) through their binding to cystolic receptors. The binding of these receptors in skeletal tissues stimulates the gene expression and translation of both IGF-1 and GH leading to hypertrophy of muscle fibers through an increase in number of satellite cells and reduced cortisol levels. The mechanism of action of TBA could also include changes in circulating glucocorticoid cortisol, which serves as a catabolic hormone in the body. These shifts in circulating hormone allow for reductions in protein turnover leading to increased muscle hypertrophy. Through the direct effects of TBA on skeletal muscle in terms of protein turnover and changes in glucocorticoids coupled with direct effects of estrogenic compounds affecting pituitary output and indirect effect of changes in binding characteristics, the synergistic nature combining the two compounds is commonly used currently to aid with rapid muscle hypertrophy and increased growth efficiency.

2.5.2 Effects of Growth Promoting Implants on Feeding Performance. Hunt et al. (1991) investigated the use of TBA and estradiol in steers and bulls. Steers receiving a TBA and estradiol combination implant had increased average daily gain (ADG) of 23% compared to steers treated with only TBA and non-implanted steers during the growing phase. All treatments exhibited similar feed intake and no difference in feed to gain (F:G).

Perry et al. (1991) investigated the effects of TBA/E2 combination implants vs. non-implanted control in three breeds of cattle (Holstein, Angus, and Angus x Simmental). The researchers concluded ADG was increased 17, 26, and 21%, DMI was

increased 8, 10, and 5%, feed efficiency was improved 9, 15, and 14% in Holstein, Angus, and crossbred steers, respectively.

Bartle et al. (1992) conducted experiments to determine correct dosage and carrier for TBA and E2 in feedlot steers. The researchers reported combination TBA/E2 implants improved ADG, DMI, and feed efficiency by 18%, 7%, and 10% compared to non-implanted controls, respectively.

Johnson et al. (1996) investigated differences between cattle implanted with combination TBA/E2 and no implant on feeding performance and carcass characteristics and composition. Implanted cattle consumed more dry matter; however, no differences were reported. Average daily gain was increased during most periods (17.5 and 23.9% increase for the period d 0 to d 40 and d 41 to d 115, respectively) measured with a 11.7% decrease in feed to gain during the first 40 DOF.

Merck Animal Health (2008) compared performance of 360 English x Continental crossbred steers implanted with Revalor IS/S reimplant program, Revalor XS delayed release implant, and non-implanted controls fed for 177 d. Dry matter intake, ADG, and feed efficiency were 10.7, 22.3, and 10.1% greater for implanted steers compared to controls on a live basis. Dry matter intake was 0.4 kg greater in steers implanted with Revalor XS compared to Revalor IS/S, but ADG and feed efficiency did not differ among these treatments.

Merck Animal Health (2008) investigated feedlot cattle performance comparing 240 English x Continental crossbred steers implanted with Revalor XS to negative

controls (sham implanted) fed for 215 d. Average daily gain, DMI, and feed efficiency were improved by 20, 10, and 8.4%, respectively, due to implantation.

Table 2.1 Improved performance from TBA/E2 implantation in previous literature

	Percent improvement from TBA/E2 implantation compared to non-implanted cattle		
Author	Average Daily Gain	Dry Matter Intake	Feed Efficiency
Hunt et al. (1991)	23	No difference	No difference
Perry et al. (1991)	21	8	13
Bartle et al. (1992)	18	7	10
Johnson et al. (1996)	21	No difference	11.7
Merck Animal Health (2008)	22	11	10
Merck Animal Health (2008)	20	10	8

2.6 Development of Individual Feed Data.

For years cattle producers have used performance traits to help increase their output and ultimately their profit margins. Average daily gain has typically been the performance measurement that producers have utilized in selection criteria for cattle replacements. However, it has been recognized that more efficient animals will yield higher profits, and as a result producers have started to view feed efficiency (F:G) as an important variable that should be included in selection criteria. Feed efficiency is expressed as unit of feed consumed per unit of BW gained. Therefore, the smaller the value, the more efficient the animal is at converting feed into BW gain. There are several factors that can make one animal more efficient than another animal. For example, maintenance energy requirements can differ between animals causing some animals to be more efficient. In the beef cattle industry, F:G is typically measured as the average efficiency on a pen basis during the finishing period only. However, there may be large

variations among individual animals in a pen. One does not know how much a particular animal eats compared to another animal within the same pen. In order to measure feed efficiency in individual animals, they would have to be housed individually. However, this is not realistic in commercial facilities. Profitability is a function of both inputs and outputs, with the consideration for reducing inputs to improve efficiency of the entire system and increase profitability. One manner in which profitability can be increased is to identify, with the use of technology, those animals that are more efficient. Until recently, confining individual animals in a single pen or stall was the only means by which measurements such as feed intake could be obtained to determine the efficiency of an individual animal. However, confining animals for the measurement of individual intake can alter behaviors such as feeding and drinking (Albright and Arave, 1997), and diminishes opportunity for social interaction among animals that may occur in typical feedlot pens. As a result, it would be difficult to compare the data from group-housed animals to that of individually housed animals. As technology advances, several systems have been developed to allow data collection from individual animals housed within a penned group.

2.6.1 Animal Identification and Individual animal Observation. Traditionally, animal scientists have used marking techniques such as brands, paints and ear tags to identify individual animals. They used these markings to recognize individual animals during behavioral observations including eating, drinking, and lying (Augsberg, 1990). However, animal observation is extremely labor intensive and often includes all hours of the day (Gibb et al. 1998). These methods are not practical when monitoring a large number of animals simultaneously.

2.6.2. Feeding Systems and Electronic Identification. Feeding behavior information has been of interest to researchers for decades. This information has been collected with systems, some as simple as a strain gauge mounted to record the amount of feed consumed in a meal event (Suzuki et al. 1969), whereas others involve complex electrical components.

Electronic systems such as the Calan method (American Calan Inc., Northwood, NH) consist of a series of gates that are opened by individual transponders worn around the neck of each animal. Once an animal approaches the proper gate, that gate will unlock and allow the animal to push the gate open and eat from the assigned feeder. By measuring feed allotments and feed refusal (orts) from each feeder, individual intake can be obtained. During the two to three week learning period, cattle are gradually restricted access to feeders, narrowing down the choices to their assigned feeder. The cattle are penned as a group with the Calan gate system, however this assigned feeding spot at the bunk most likely alters the feeding dynamics to some degree. The Calan headgate system's main advantages are that the system and replacement parts are inexpensive, a variety of diets can be fed simultaneously and it has a high degree of accuracy (Cole, 1995). The major disadvantages are the extensive labor requirements, difficulties in training animals, manual measurement of feed intake, and in the event that there is mechanical error, the animals cannot eat because the gate is rendered inoperable.

The Pinpointer system (Pinpointer, illS Corporation, Cookville, TN) uses a transponder worn around the neck of the animal, which identifies that animal as it enters the feeding stall. A microprocessor continuously monitors the disappearance of feed, as well as duration and frequency of attendance while the animal is in the stall. While this

system is very user friendly and accurate (Cole, 1995), the main disadvantage is that it alters feeding patterns and competitive feeding behavior of the animal. This system also requires significant time to train animals and staff, and there is a dropout rate among animals in that not all cattle can be trained to use the system. Other disadvantages are that it has a high initial cost, and is limited to use with dry diets that will flow through the feed hopper (Cole, 1995). There are also limitations to the number of animals one can simultaneously feed with the Pinpointer system, in which the researcher indicated that no more than 15 finished weight steers may be used at one time.

The Insentec system (Hokofarm Group BV, Marnesse, Netherlands) uses transponder collars attached to an animal's neck that transmits real time data to a data collection server. This system measures feed intake and time of each visit, DMI, time spent at the feeder measured in minutes and number of visits. Feed tubs are suspended on load cells to determine intake levels (Gaspers et al., 2014).

The recent development of an electronic feed bunk monitoring system (GrowSafe Systems Ltd., Airdrie, Alberta) that uses radio frequency (RF) technology could be a key component in providing the beef industry with a way of tracking individual feeding behavior and performance characteristics. The GrowSafe behavior system enables individual animal feeding behavior to be monitored in large pen settings, which are typical of commercial production units. With this system, researchers can monitor the number of visits to the bunk, the location along the bunk, and the length of time the animal is at the bunk. The behavior system has been coupled with an individual intake system composed of sections of a feed bunk with tubs suspended on load cells to record individual intake. The system consists of a hard rubber mat lining the backside of the

bunk equipped with an antenna, a reader panel, and a transponder encased in a plastic ear tag in the animal's ear. The antenna radiates a 134.2 kHz electromagnetic field so that once the tagged animals come within 50.4 cm of the antennae the transponder number is recorded. The individual intake system is designed with a varying number of individual animal walk-in stalls with each stall having dimensions of 1.50 m depth, 1.09 m wide, and 1.40 m height, and equipped with adjustable bars to decrease width to 0.61 m for smaller animals or remain expanded at 1.09 m for larger animals. Each bunk has a feed tub suspended on four load cells that continuously monitor the weight of the feed, and allows only one animal access to each section at a time. Feed intake for a single feeding event is determined by taking the weight of the feed present in the feed tub prior to the animal's arrival minus the amount remaining after it's departure. This is completed for each meal event, and the total consumed for a 24 h period results in the estimate of the animal's daily intake. Each animal has access to a plastic rectangular feed tub situated on load cells that continually monitor changes in the tub weight, which is related to feed disappearance. The tub has dimensions of 0.97 m depth X 0.38 m width X 0.53 m height. Data recorded from the intake system consists of a date, time, location, and a weight value detected from the load cells.

Several research studies using the GrowSafe System have been conducted to document feeding behavior and its relationship to intake in feedlot cattle. Initial studies indicated that animals on a predominately barley silage diet spent 86.4 min/d at the feed bunk with 84% of this time spent consuming feed (Schwartzkopf-Genswein et al., 1999). The GrowSafe System has also identified a poor correlation between feeding duration (head-down only) and ADG of individual animals (Streeter et al., 1999; Schwartzkopf-

Genswein et al., 2002). Grouping animals into outcome groups based on ADG showed that animals which have spent the least amount of time at the bunk had the greatest ADG (Streeter et al., 1999).

The GrowSafe system has the capability of providing researchers with a better insight of what influences social interactions among group-penned cattle have on eating patterns and general performance.

2.7 Sigmoid Growth Curve and Methods to Estimate Live Animal Skeletal Growth

If animal growth is measured from conception to death, the data usually follow a flattened "S" shape called the sigmoid curve. The term "growth curve" usually evokes the image of a sigmoid curve depicting a lifetime sequence of measures of size, often body weight. More general terminology would be size-age curves (weight-age, hip height-age, heart girth-age) (Fitzhugh, 1976). Common characteristics of growth models involve two biological parameters. The first parameter establishes the position of an animal or group of animals in the general size space at a given age, usually maturity (Fitzhugh, 1976). The second parameter is concerned with growth rate relative to body size. When the size parameter refers to mature size, this "rate" parameter defines average maturing time, which Blaxter (1968) and others have related to intrinsic efficiency of growth. In addition to the size and rate parameters, a third is often used to partition the growth curve into two stages. Brody (1945) called "self-accelerating" and "self-inhibiting" stages during which growth rate velocity is increasing or decreasing, respectively. Transition between these two stages establishes the point of inflection of the sigmoid growth curve (Fitzhugh, 1976).

Biological changes that occur over a period of time can be defined by utilizing biometric measurments. Non-invasive measurements that will be discussed in regards to cattle are, and not limited to body weight, hip height, rump length, hip width, shoulder height, 2/3 body length, body depth, and body width. These measurements may be acquired manually or by a computerized measuring system that specializes in accurately determining body dimensions and skeletal frame size of live animals (Reed et al. 2017).

2.7.1 Biometric Evaluation of Live and Carcass Growth. Cook et al. (1951) evaluated body measurements and how they compared to carcass characteristics such as slaughter grade, carcass grade and dressing percentage. Sixty-two Shorthorn steers were fed to an average BW of 408.2 kg and measured prior to harvest. Measurements included height at withers, height at chest floor, circumference of fore-flank, width at shoulder, and length of body. The circumference of the fore-flank was positively correlated (r = 0.43) with dressing percentage, indicating that steers exhibiting a wider fore flank expressed a greater probability of increased dressing percentage. Wither height was negatively correlated (r = -0.19) to slaughter grade, and shorter steers exhibited a higher slaughter grade. The conclusion which was reached indicated that body measurements may accurately predict dressed yield of carcasses.

Carcass composition in relation to biometric body measurements has also been investigated. Fisher et al. (1975) selected 25 measurements to be assessed on 15 Hereford steers. A single technician performed the measurements which included circumference of cannon bone, height at withers, width of shoulders, circumference of heart girth, rear flank girth, width of ribs, width of paunch, length of loin, depth of rib point, depth of hooks, depth of patella from base of the tail, circumference of hind leg, length of pelvis

girdle, depth of patella from dorsal midline, length of patella to posterior midline, width of rump, depth of rump, length of hindquarter, skinfold thickness at flank, and skinfold thickness at brisket. Measurements were performed on the day of harvest for each steer. The investigators reported that 22 of the 25 mean square variances were significant in regards to determining body composition from body measurements.

Comerford et al. (1988) investigated pre-weaning and post-weaning growth, hip-height, and pelvic size over a five year period. Various breeds were selected with 699 animals evaluated. Animals were weighed every 14 d in the first 3 years and the last 2 years animals were weighed every 28 d. Animals were fed in a feedlot setting at a mean age of 217 d and randomly allocated to slaughter groups based on age, weight, and mating type. At the mean age of 379 d, every animal was measured for yearling weight, hip height, pelvic height, pelvic width, and pelvic area. Weaning weight was highly correlated with yearling pelvic width (r = 0.74), yearling hip height (r = 0.049), and yearling pelvic area (r = 0.085). Investigators concluded that biometric measurements may accurately estimate hip height in different breed types of yearling calves. Heinrichs and Hargrove (1987) developed a prediction equation using biometric measurements (BW and shoulder height) to estimate weight and wither height for 24 month old Holstein heifers when measured before or equal to 24 months of age.

Fernandes et al. (2010) investigated prediction equations for body area and volume of crossbred bulls. Forty genetically different yearling bulls were serially harvested in three groups on d 0, d 90, and d 220. Bulls were also fed different planes of nutrition within each harvest group. Bulls were measured (hook width, pin width, pelvic girdle length, rump depth, rump height, abdomen width, body length, height at withers,

rib depth, girth, and body diagonal length) the day prior to harvest. Prediction equations were developed to estimate body area and body volume. Investigators reported $r^2 = 0.995$ and $r^2 = 0.999$ with a root mean square error of 0.307 and 0.005 for body area and body volume, respectively. It was reported that body area and volume may be predicted with a high degree of accuracy from biometric measurements.

In a more recent study, De Paula et al. (2013) evaluated prediction of carcass composition utilizing biometric measurements in beef cattle. Forty-four crossbred bulls were serially harvested in five groups every 84 d throughout a 310 d period under tropical grazing conditions. Cattle were weighed and measured (hook bone width, pin bone width, abdomen width, body length, rump height, height at withers, rib depth, girth circumference) the day prior to harvest. After harvest, carcasses were measured to determine subcutaneous fat, internal fat, intermuscular fat, carcass physical fat, empty body chemical fat, fat thickness of 12^{th} rib, and 9-10-11 rib section fat. In regards to total body surface and body volume, r^2 values were reported at 0.908 and 0.997, respectively. Investigators concluded that the development of an equation using 9-10-11 rib fat as a predictor, in combination with shrunk BW (SBW), was a better predictor of carcass physical fat and empty body physical fat than using the 9-10-11 rib section by itself. Physical and chemical carcass fat and empty body fat composition of grazing cattle may be improved using body measurements as a predictor.

Understanding cattle growth in regards to skeletal growth and utilizing biometric measurements to predict growth and composition has improved the industry's ability to select for traits and to become more efficient in sorting cattle within pens to determine amount of days required before market readiness. Research will continue to improve

methods of biometric measurements, allowing further understanding of growth of different sexes, breeds, and ages of cattle. Individual animals may be managed more efficiently when growth over time can be quantified.

Table 2.2 Equations from review of literature

Author	Item	Equation
Kraybill et al. (1952)	Carcass fat	{Carcass fat, % = 100 x (4.802 / carcass specific gravity – 4.366)}
Kraybill et al. (1952)	Carcass moisture	{Carcass moisture, % = 100 x (3.896 – 3.486 / carcass specific gravity)}
Reid et al. (1955)	EBF	EBF, % = 355.88 + (0.355 x moisture in the empty body, %) – (202.906 x Log (moisture of the empty body, %))
Reid et al. (1955)	% fat free dry matter	100 – (moisture, % + EBF, %)
Reid et al. (1955)	EBP	(Protein, % = 80.93 – (0.00101 x age of animal in days)
Reid et al. (1955)	EBA	Ash, % = (fat-free dry matter, %) – (protein, %)
Lofgreen et al. (1962)	EBW	EBW=1.45(HCW) + 70
Lofgreen and Garret (1968)	NEm requirement	77 kcal/$BW^{0.75}$
Garrett and Hinman (1969)	EBM	EBM = 0.9702(carcass moisture, %) + 3.92
Garrett and Hinman (1969)	EBF	EBF, % = 0.9246(carcass fat, %) – 0.647
Garrett and Hinman (1969)	EBP	EBP % = 0.7772 (carcass nitrogen, %) + 0.713
Garrett and Hinman (1969)	EBA	EBA % = 0.6895(carcass ash, %) + 0.844
Garrett and Hinman (1969)	EBW	EBW=1.36(HCW) + 30.3
Fox et al. (1976)	EBW	EBW=1.40(chilled carcass weight) + 40.2
Guiroy et al. (2001)	EBF	{EBF = 17.76207 + (4.68142 x FT) + (0.01945 x HCW) + (0.81855 x QG) – (0.06754 x LMA)}

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CHAPTER III

THE EFFECT OF DAYS ON FEED AND TRENBOLONE ACETATE + ESTRADIOL-17β IMPLANTATION ON FEEDING BEHAVIOR AND GROWTH PERFORMANCE OF CHAROLAIS x ANGUS STEERS ACROSS SERIAL HARVEST ENDPOINTS

3.1 Abstract

A serial harvest study was conducted to evaluate days on feed (DOF) and trenbolone acetate + estradiol-17β administration on feeding behavior and live growth performance of steers across various harvest endpoints. Charolais x Angus steers {*n* = 80; start of trial body weight (BW) 271 ± 99 kg} were randomly allocated to implant treatment and harvest date in a 2 x 10 factorial experiment. Steers were paired within genetic group according to initial BW, frame score, and adjusted final body weight (AFBW). Within each pair, a steer was randomly allocated to one of two treatments; implanted with Revalor-XS (REV; on d 0 and d 190) or non-implanted control (CON). Eight steers comprised of 4 pairs were randomly assigned to 1 of 10 harvest dates at d 0, 42, 84, 126, 168, 210, 252, 294, 336, and 378 DOF. Steers were fed in open lot dirt surface pens (20 animals/pen) equipped with 4 GrowSafe^{TM} nodes per pen. Body weight was recorded at each harvest period and individual consumption data were recorded multiple times per day via electronic identification (EID) reads every second. The GLIMMIX procedure of SAS was used to test the fixed effects of DOF and treatment

(TRT) with pair as random effect. A repeated measures design was used with DOF as the repeated measure by animal. Average daily gain was 9.4% greater ($P < 0.01$) for REV steers (1.42 kg REV vs 1.30 kg CON) during the 378 d trial. Dry matter intake did not differ ($P = 0.15$) between TRT but averaged 8.7 kg during the trial and decreased ($P < 0.01$) from 3.2% of BW to 1.03% of BW after 378 DOF. Implanting with REV improved ($P < 0.05$) gain to feed ratio (G:F) by 8.2% during the trial, however a TRT x DOF interaction ($P < 0.05$) occurred after 293 DOF whereby REV steers became less efficient. Consumption visit frequency was 48.8 events/d during the initial period and decreased ($P < 0.01$) during the trial ending at 16.1 events/d. Daily consumption time began at 111 min/d during the initial period and decreased ($P < 0.01$) by 0.12 and 0.15 min/d for CON and REV, respectively. Dry matter intake per consumption event began at 2.5 kg/event and increased ($P < 0.01$) 0.3 kg/event for each 42 d period. Consumption rate (g/min) for each consumption event was 290 CON and 422 REV ($P < 0.01$), which decreased for CON (20 g/min) and increased for REV (0.4 g/min) for each 42 d period ($P < 0.01$). These data indicate live growth performance and feeding behavior were impacted by both growth enhancement technology and duration of finishing.

3.2 Introduction

Due to decreased supply of cattle, the beef industry must utilize technology catering to improved feed efficiency and yield to meet consumer demand. The use of exogenous steroidal implants has become a common practice in most feedyards. Steers receiving a TBA/E2 combination implant compared to non-implanted controls had improved ADG and G:F of 18-23% and 8-13%, respectively, (Hunt et al. 1991; Bartle et al. 1992; Merck Animal Health 2008). Overall, the utilization of growth promoting

implants in the fed beef industry will result in increased protein accrual efficiency compared to non-hormone treated cattle.

Cattle producers have used performance traits to help increase their output and profitability. Using traits such as DMI, ADG, and G:F, producers make genetic and management decisions. Feed efficiency is typically measured on a pen basis due to the nature of current large pen cattle feeding practices. However, one does not know how much a particular animal eats compared to another animal in the same pen. Technology has advanced in order to determine individual animal performance and feeding behavior without altering the social interaction observed in animals being housed and fed in large pens. The recent development of an electronic feed bunk monitoring system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) uses radio frequency technology to monitor animals in a large pen setting, typical of commercial production. Several research studies (Schwartzkopf-Genswein et al. 1999; Schwartzkopf-Genswein et al. 2002; Walter et al. 2016) using the GrowSafe System have been conducted to document feeding behavior and its relationship to intake in feedlot cattle. The objective of this experiment was to elucidate the live performance characteristics and consumption behavior response of typical beef steers utilized in today's commercial systems over a 378 DOF finishing period with a TBA + E-17β implant being administered to determine optimal DOF and REV effect over DOF.

3.3 Materials and Methods

All experimental procedures involving live animals were approved by the Institutional Animal Care and Use Committee (IACUC) 01-08-18 at West Texas A&M

University (WTAMU) and followed the guidelines described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, Savoy, IL.)

3.3.1 Live cattle procedures and trial design

Steers (n = 120) were acquired from a ranch source in Grand View, ID, (Simplot Land and Livestock) and shipped to Agri-Research Center, Inc. (Canyon, TX) feedyard. Steers were weaned immediately prior to departure. Calves were genotyped using the GeneSeek Genomic Profiler Bovine 50K panel (Neogen Genomics, Lincoln, NE) from tail hair samples obtained at weaning. Genotypes were formatted for use in PLINK 1.9 (Chang et al., 2015) and checked for call rate greater than 0.90. Single nucleotide polymorphisms (SNP) markers with minor allele frequency less than 0.05 were removed from the analysis. An identity-by-state (IBS) matrix was first constructed within PLINK 1.9 to quantify genetic distance between all pairs of individuals in the analysis. Next, complete linkage clustering was performed with PLINK 1.9 to create four genetic groups in which the IBS distance was minimized between individuals within a group and maximized between groups. Weaning weight (WW) was 250 ± 107 kg.

Upon arriving on August 24, 2018, steers were placed into 4 large pens with access to chopped hay, top dressed with starter ration. Steers were allowed to acclimate for 24 d to ration and environment before initial processing on September 17, 2018 (d -7). Steers were weighed and measured in regards to biometric measurements of the skeleton with a proprietary system from Performance Cattle Company (PCC) LLC, (Amarillo, TX). Methods regarding this system are further explained in chapter 4. Furthermore,

steers were affixed with electronic identification (EID) (High performance half-duplex HDX ultra EID tag TFP-FDXOTP982-Y/GESMY, Allflex USA Inc., Dallas-Ft. Worth, TX) and SCR ear tags (Allflex USA Inc., Dallas-Ft. Worth, TX).

Using the four quartiles of genetic data and biometric measurement data from d -7 processing, steers were paired within genetic group according to initial shrunk BW, frame score (-11.548 + (0.4878 × hip-height, in.) – (0.0289 × days of age) + (0.00001947 × days of age2) + (0.0000334 × hip-height, in. × days of age) (Beef Improvement Federation Guidelines, 2018), adjusted final body weight (AFBW) (frame score × 100 + 700) (Guiroy et al. 2002), and predicted days to AFBW, or days to terminal (DTT). Within each pair, steers shared the same sire. Furthermore, within each pair, a steer was randomly allocated to one of two treatments; implanted with Revalor-XS {(REV; 200 mg TBA + 40 mg E_2 containing 4 uncoated pellets and 6 pellets with a proprietary time release coating technology, Merck Animal Health, Madison, NJ)} on d 0 and d 190 or non-implanted control (CON) to represent a non-hormone treated cattle (NHTC) marketing strategy. Eighty steers were utilized for this study (40 CON and 40 REV); the remaining 40 steers were held in reserve if needed due to injury, illness, or death loss. Eight steers comprised of 4 pairs were randomly assigned to 1 of 10 harvest dates at d 0, 42, 84, 126, 168, 210, 252, 294, 336, and 378 DOF.

At d 0, steers were processed again, repeating procedures from d -7. Steers were affixed with pre-determined visual identification tags (VID) matched to EID and the appropriate REV steers were implanted in the left ear (remaining REV steers were implanted again with Revalor-XS on d 190 in the right ear, and following both implantations, steers were processed and evaluated for appropriate implant status 20 d

later). All steers were treated for internal and external parasites with Cydectin injectable (Bayer, Shawnee Mission, KS) and Safe-Guard oral drench (Merck Animal Health). Steers were also vaccinated against bovine coronavirus using Bovilus (Merck Animal Health), bovine rhinotracheitis-virus diarrhea, parainfluenza 3, respiratory syncytial virus, *mannheimia haemolytica,* and *pasturella multocida* using Vista Once (Merck Animal Health) on d 0. Steers were also vaccinated against bovine rhinotracheitis-virus diarrhea with Titanium 3 (Elanco Animal Health, Greenfield, IN) and *clostridum perfringins* types C and D – tetani bacterin-toxoid with Vision CD-T with SPUR (Merck Animal Health) on d 190.

Steers were sorted into predetermined pens along with their corresponding treatment steer within each pair. Pairs were randomly placed in pens to allow one pair to come from each of the four pens when the corresponding harvest date for the appropriate 8 steers was reached. The same 6 rations (receiving starter diet, starter diet, starter-intermediate mixed diet, intermediate diet, intermediate-finisher mixed diet, and finisher diet) were fed to all steers across DOF with tylosin, and monensin (Tylan and Rumensin, Elanco Animal Health, Greenfield, IN) being included in 4 of the rations added to the diet (Rumensin in the final 4 rations, and Tylan in the final 2) with an automated micro-ingredient machine (MicroBeef Technology, Amarillo, TX). Vitamins and minerals were added to the diet in the form of a pelleted supplement (Table 3.1).

One steer died on d 165 and another at d 168, both due to heart failure from underlying respiratory conditions. These 2 steers were the only steers to die prior to harvest during the study. On d 221, 4 steers were removed from the study. Two steers that were paired with study animals that died previously (d 165 and d 168) were removed

and two pairs replaced them. The other 2 steers were non-study steers and removed due to disposition (unable to record accurate measurements repeatedly during processing), and possible underlying health issues (bovine respiratory disease). On d 298, 9 non-study steers were removed due to founder and disposition (unable to record measurements repeatedly during processing). After the study concluded, the remaining 25 non-study steers were transported 51 km to a commercial beef processing facility (Caviness Beef Packers, Hereford, TX, USDA Establishment 675) and harvested, as were the previous two groups of cull steers. Carcass data was recorded during the harvest process on all steers that were harvested at this facility.

3.3.2 Feeding behavior data collection

Steers were housed in 4 large dirt surface pens (30 animals/pen) equipped with 4 GrowSafe (GrowSafe System Ltd, Airdrie, AB, Canada) nodes/pen. GrowSafe nodes recorded individual consumption and behavior multiple times per day via EID tag reads every second. Variables logged included date, time, EID, duration, and weight of feed consumed for each feeding. Details of the GrowSafe system have been explained by Schwartzkopf-Genswein et al. (1999), Mendes et al. (2011), and Schwartzkopf-Genswein et al. (2011). The system was monitored daily for unaccounted feed balance. Days with unaccounted balances (14% of data or 53 d) were rejected from the study. When an unaccounted feed balance or adverse weather event occurred, the GrowSafe system automatically deemed the 24 hr period as failed. Prior research on the validation of GrowSafe and missing data has shown that accuracy of DMI was not impacted when up to 30% of the data was missing after 35 d on test (Wang et al., 2006). Daily intake, bunk

visits, feed intake per bunk visit, and duration of bunk visits were calculated and averaged within day by steer.

Methods including recording BW and biometric measurements were repeated for each 42 d period for all remaining steers. All body weights reported included a 4% (BW x 0.96) pencil shrink. At each 42 d period, the 8 steers selected for harvest were sorted and held off feed for 24 hr before slaughter which occurred on the following d.

3.3.3 Statistical analysis

A balanced incomplete block design was utilized, and individual steer was the experimental unit in a 2 × 10 factorial treatment structure. Each pair of animals was considered 1 of 40 blocks. The GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC) was used to test the fixed effects of DOF and TRT during the feeding period. For performance variables and feeding behavior, a repeated measures design was used with DOF as the repeated measure by animal and pair as random effects with several variance-covariance structures evaluated for each variable analyzed. Variance-covariance structures were chosen depending on Akaike's information criterion being closest to zero. All variables analyzed used unstructured as a variance-covariance structure. The KENWARD-ROGER option was used to generate new denominator degrees of freedom. An LSMEANS statement generated means and a PDIFF statement was used to assess differences. Orthogonal contrast statements were utilized to analyze differences in linear and quadratic trends for DOF. Significance was determined at ($P \leq 0.05$) and tendencies were observed at ($0.05 > P \leq 0.10$). If a variable was significant for linear or quadratic DOF effect, the REG procedure of SAS was used to generate DOF coefficients.

3.4 Results and discussion

3.4.1 Live growth performance in response to implant administration and days on feed

Across the 378 d study period, daily DMI exhibited a quadratic response to days on feed ($P < 0.01$; Table 3.2). Daily DMI (8.58 kg CON vs. 8.80 kg REV) was not influenced by treatment ($P = 0.15$). Perry et al. (1991) and Bartle et al. (1992) reported 8 and 7% improvements in DMI from implanting steers. Johnson et al. (1996) reported no difference ($P > 0.10$) in DMI between steers implanted with a combination trenbolone acetate/estradiol 17-β implant (10.07 kg/d) and non-implanted (9.68 kg/d) steers. Hunt et al. (1991) also reported no difference in DMI between implanted steers and non-implanted controls. Dry matter intake peaked during the initial feeding period at d 1-41 (10.12 kg). Dry matter intake decreased ($P < 0.01$) during d 42-83 (8.77 kg), increased ($P < 0.01$) during d 84-125 (8.84 kg), plateaued at a decreasing rate through for the next three 42 d periods (d 126-167, 168-209, 210-251) from 8.82 kg to 7.50 kg, increased ($P < 0.01$) to 8.04 kg at d 252-293, then plateaued again at 9.63 and 8.50 kg for the final two periods (d 294-335 and 336-377, respectively). The quadratic relationship between DMI and DOF during the 378 d study period is estimated by the following equation: {DMI = $(0.0309*DOF^2) – (0.55947 * DOF) + 10.522$; Adj. $R^2 = 0.2480$; RMSE = 1.15; $P < 0.01$}. Walter et al. (2016) also reported a quadratic relationship between DMI and DOF in serially harvested Holstein steers. Previous research by Guiroy et al. (2001) using data from Perry and Fox (1997), reported a linear relationship between DMI and DOF.

Live BW increased ($P < 0.01$; Table 3.2) during the 377 d study period from 271 to 805 kg. Starting and ending BW was different ($P < 0.01$) from each preceding and

succeeding measurement. Starting BW {BWstart = (-3.2398 * DOF^2) + (90.7442 *DOF) + 187.55; Adj R^2 = 0.8852; RMSE = 50.45; $P < 0.01$} and ending BW {BWend = (-2.6086 * DOF^2) + (77.6876 * DOF) + 287.820; Adj. R^2 =0.8361; RMSE = 54.45; $P <$ 0.01) increased in a quadratic fashion over DOF. Walter et al. (2016) agrees with BWend increasing in a quadratic fashion. Serial harvest trials in steers (Vasconcelos et al., 2008; Walter et al. 2016) reported increases in BW as DOF increased. Start and end of period BW was higher ($P < 0.01$) for REV steers (550 and 607 kg, respectively) compared to CON steers (531 and 583 kg, respectively). Beginning of trial BW was 273 kg for CON vs. 273 kg for REV and steers ended the trial at 796 kg for CON and 815 kg for REV. There was no difference ($P > 0.05$) observed for start and end BW within each 42 d period between treatments. End of period BW tended to be heavier ($0.06 \leq P \leq 0.09$) for REV steers for three 42 d periods (d 126-167, 168-209, and 210-251).

Dry matter intake as a % of BW (DMI%BW) was not affected ($P = 0.51$) by treatment. Dry matter intake as a % of BW decreased ($P < 0.01$) during the 377 d study period from 3.22 to 1.03%. For each 42 d period beginning at d 1 and ending at d 167, DMI%BW was different ($P < 0.01$) between each period, then during d 168-209 DMI%BW plateaued at 1.51 and 1.41%, decreased ($P < 0.01$) to 1.19% at d 252, then plateaued again for the remainder of the study at 1.05 and 1.03%. Robinson and Okine (2000) reported data that agrees with the current data in which typical feedlot steers at approximately 300 kg upon entering a feedlot will consume 2.6 DMI%BW and steers finished at 160 DOF consumed approximately 1.6 DMI%BW. The NRC (2000) reported that beef animals fed in typical feed yard settings consumed 2-4 DMI%BW. These

current data suggest that steers consumed an expected DMI%BW during a typical feeding period, however continued to decrease as the feeding period extended beyond 200 d.

Average daily gain was effected ($P < 0.01$) by treatment. Across the 377 d feeding period, CON exhibited an ADG of 1.30 kg, compared to REV exhibiting 1.43 kg, an improvement of 10%. Johnson et al. (1996) reported that implantation with trenbolone acetate/estradiol 17-β increased ADG by 18, 21, and 16% at 40, 115, and 143 DOF. The lesser ADG may be due to the extended feeding period. Average daily gain differed across DOF ($P < 0.01$) and decreased ($P < 0.01$) in a quadratic fashion {ADG = (0.0156 * DOF^2) – (0.3229 * DOF) + 2.482; Adj. $R^2 = 0.5198$; RMSE = 0.41; $P < 0.01$} across DOF. Average daily gain reflected DMI by peaking during the initial period (d 1-41) at 2.24 kg. Average daily gain decreased ($P < 0.01$) each 42 d period from d 42 to d 209 from 1.74 to 0.99 kg, then increased ($P < 0.01$) to 1.46 during d 210-251, decreased ($P < 0.01$) to 0.69 kg during d 252-293, and increased ($P < 0.01$) to 0.92 kg for both d 294-335 and 336-377. Vasconcelos et al. (2008) and Walter et al. (2016) reported decreased ADG over DOF in steers and Rathmann et al. (2012) reported similarly in heifers.

Gain:feed (G:F) was affected by DOF ($P < 0.01$), treatment ($P < 0.05$), and exhibited a treatment x DOF interaction ($P < 0.05$). Implanted steers exhibited greater G:F ratios during all periods until the final two (d 294-377). This observation explains the TRT x DOF interaction as REV became less efficient at the end of the study. The decrease in efficiency may be attributed to REV increased BW and the effects of the implant beginning to essentially wear off. Gain:feed was higher ($P < 0.05$) for REV steers (0.159) compared CON (0.149), a 6.7% improvement. Previous studies comparing implanted cattle and non-implanted controls (Bartle et al., 1992; Johnson et al. 1996;

Merck Animal Health, 2008) report improvements in G:F from 8-10% with the lower percentages reported in studies that fed cattle for a longer amount of time. Gain:feed decreased ($P < 0.01$) across DOF in a quadratic fashion. Walter et al. (2016) reported G:F decreasing in a linear fashion in serially harvested Holstein steers. Gain:feed peaked at d 1-41 at 0.224, decreased ($P < 0.01$) to 0.182 at d 42-82, increased ($P < 0.01$) to 0.201 at d 84-125, decreased ($P < 0.01$) during d 126-167 and d 168-209 to 0.184 and 0.111, respectively, increased ($P < 0.01$) during d 210-251 to 0.165, decreased ($P < 0.01$) during d 252-293, and increased ($P < 0.01$) to 0.121 and 0.115 during d 294-335 and d 336-377, respectively. The increases in G:F could be attributed to implant payout as the implant is designed to release increasing amount of hormone at approximately d 0 and 70 (Nichols et al., 2015). Because REV cattle were re-implanted with another of the same implant at d 190, the hormone release would attribute to being the highest at approximately d 190 and 260, explaining the larger and increased G:F at d 1-41, 84-125, 210-251, and 294-335. The decrease in G:F is observed in previous literature. Rathmann et al. (2012) reported a decrease in G:F in serial harvested beef heifers across DOF. Bond et al. (1982) also observed a decrease in G:F over DOF, ultimately slowing to 0.05 at 70 mo of age. During the period from d 168-209, ADG and G:F measured 0.99 kg and 0.111 kg, respectively and were different ($P < 0.01$) than all other ADG and G:F measurements across DOF except for the final two periods for each measurement (d 294-335 and d 336-377). Conversely, DMI was 7.98 kg and was not different ($P > 0.05$) from the final feeding period. During d 210-251, cattle consumed less feed (7.50 kg) and exhibited a higher ADG (1.46 kg) and G:F (0.165) than the previous period (7.98 kg, 0.99 kg, and 0.111, respectively). The feeding period from d 168-209 occurred from 11 March 2019 to 21

April 2019. The higher intake and lower gains may be attributed to two weather events during this period. On 22 March 2019, a weather event exhibiting 102 km/h wind speeds accompanied with rain and up to 6.35 cm hail impacted the area where cattle were fed. Another event impacted the are on 17 April 2019 in which up to 6 cm hail and flooding was reported (National Weather Service, 2019). This variation in environmental conditions with no wind breaks or cover is likely the cause of poor performance observed during d 168-209. Calvo-Lorenzo (2014) stated that hot and cold weather extremes act as significant stressors in cattle impacting performance and welfare.

3.4.2 Feeding behavior in response to implant administration and days on feed

Feeding behavior was impacted by DOF and TRT (Tables 3.3 and 3.4). Bunk and consumption visit frequency were not different ($P \geq 0.48$) between TRT. Frequency of bunk visits and consumption visits were impacted by DOF in a quadratic fashion ($P < 0.01$). Peak bunk and consumption visits occurred in the initial period on d 1-41 at 55 and 48.8 events/d, respectively. During the next period (d 42-83), bunk and consumption visits decreased ($P < 0.01$) to 34.1 and 31.2, respectively. The 38% decrease in bunk visits and 36% decrease in consumption visits between the 42 d periods can most likely be attributed to competition due to pens containing 28 animals each, having access to only 4 GrowSafe™ nodes for each pen. The documented bunk and consumption visits of this study ranged from 55 to 16.8 and 48.8 to 16.1, respectively. Previous studies analyzing daily bunk visits with GrowSafe™ reported daily frequencies of 18-35 events/d (Nkrumah et al., 2006; Nkrumah et al., 2007; Basarab et al., 2007).

Daily bunk and consumption visit duration were impacted by DOF and TRT (Table 3.3; $P < 0.01$) in a quadratic fashion ($P < 0.01$). Daily bunk and consumption duration were both impacted ($P < 0.01$) by treatment. Implanted steers exhibited less ($P < 0.01$) daily bunk and consumption duration at 64.94 and 62.96 min/d, respectively, compared to CON at 72.94 and 70.46 min/d, respectively, across the 377 d feeding period. Each 42 d period for these variables were not different ($P > 0.05$) between treatments except for the initial period (d 1-41; $P < 0.05$) where REV steers spent 112.02 and 107.77 min/d visiting and consuming from the bunks, respectively, compared to 119.81 and 114.56 min/d, respectively, compared to controls. Overall, REV steers exhibited a 10.97% and 10.64% decrease in daily bunk and consumption duration compared to CON. Daily bunk and consumption duration reflected visit frequency in peaking during the initial period (d 1-41) at 115.9 and 111.2 min/d, respectively. The second 42 d period (d 42-83) also reflected a decrease ($P < 0.01$) in daily bunk and consumption duration at 85.3 and 82.2 min/d; a 26.4% and 26.1% decrease, respectively, from the first period. Daily bunk and consumption duration ranged from 115.9 and 111.2 min/d to 53.7 and 52.8 min/d, respectively, with the least ($P < 0.01$) amount of time spent at the bunk and consuming feed at d 294-335. These data are similar to previous bunk visit reports of 48-74 (Nkrumah et al., 2006), 66.0 (Nkrumah et al., 2007), 73.4 (Mendes et al., 2011), and 53.7 (Walter et al. 2016) min/d.

Singular bunk and consumption duration (min/event) were impacted by DOF ($P < 0.01$) and effected ($P < 0.01$) in a quadratic fashion. There was no difference ($P \geq 0.13$) between TRT for singular bunk and consumption duration. Singular bunk and consumption duration per event were lowest at d 126-167 (2.49 and 2.39 min/event,

respectively) and highest during the final 42 d period (d 336-377) at 3.62 and 3.49 min/event, respectively. Walter et al. (2016) reports similar findings with singular bunk and consumption duration ranging from 2.34 to 3.51 min/event. In relationship to total bunk and consumption visit duration previously discussed, singular bunk and consumption duration per event exhibited an inverse relationship. As DOF increased, animals spent less total time at the bunk overall daily, but spent more time at the bunk and consuming feed for each event. This behavior may be due to decreasing competition for bunk space as more animals were harvested over the feeding period and pens contained fewer animals. Decreasing frequency of visits and increasing time spent per event may also indicate a modification of behavior to satisfy satiety. Oba and Allen (2003) reported that increasing intraruminal infusion of propionate reduced DMI, meal frequency and size. The authors concluded that increasing energy levels from propionate reduced hunger and increased satiety in dairy cattle. Therefore, the cattle in the current study may have eaten more or less frequently with or without greater consumption visit durations to achieve satiety.

Dry matter intake per consumption event and consumption rate for consumption events were both impacted (Table 3.4; $P < 0.01$) by TRT. Implanted steers exhibited an increased ($P < 0.01$) DMI per consumption event (438 kg/event) compared to CON (387 kg/event), or a 13.2% improvement. Consumption rate per consumption event was increased ($P < 0.01$) for REV (422 g/min) compared to CON (290 g/min), or a 45.5% improvement. During period 210-251 DOF, REV steers consumed more ($P < 0.01$) (500 g/min) than CON steers (270 g/min), or eating 85% faster. This observation may indicate that TBA+E2 -17β implantation may lead to a positive feedback regarding appetite

stimulus. Raun and Preston (2002) reported that hormonal implants increase appetite. Days on feed also impacted ($P < 0.01$) DMI per consumption events (g/event) and consumption rate for consumption events (g/min). Dry matter intake per consumption events was effected in a quadratic fashion ($P < 0.01$), as was consumption rate for consumption events ($P = 0.03$). Dry matter intake per consumption event was lowest (0.252 kg/event) during the initial period on d 1-41 and highest (0.557 kg/event) during the final period on d 336-377. From d 42-167, DMI per consumption was not different ($P > 0.05$) and ranged from 0.332 to 0.356 kg/event. Dry matter intake per consumption event increased ($P < 0.01$) to 0.444 kg/event during d 168-209, plateaued from d 210-335 (0.468 to 0.497 kg/event), then increased ($P < 0.01$) to 0.557 kg/event during the final period (d 336-377). Consumption rate began at 377 g/min during the initial period and remained constant ($P > 0.05$), ranging from 393 to 372 g/min through d 293. Consumption rate for consumption events decreased ($P < 0.01$) to 260 and the lowest value, 228 g/min during the final 2 periods (d 294-335 and 336-377), respectively. These results regarding DMI per consumption event and consumption rate agree with Walter et al. (2016) in which reported that Holstein steers consumed 341-542 g DM at rates of 240-561 g/min. Bingham et al. (2009) reported a much slower consumption rate (102 g/min), however the animals were housed in pens in which all animals could eat simultaneously. The lack of competition for feed in this study may have altered eating behavior. Based on feed bunk visit frequency and DMI per consumption event, cattle appeared to meet their satiety levels by adjusting visits and DMI. As competition factors decreased as DOF increased, cattle may not have been pressured to consume feed as quickly and often.

In conclusion, live performance parameters of DMI, ADG, G:F, and DMI as a % of BW decreased in a quadratic fashion while live BW increased quadratically across DOF with REV steers exhibiting higher ADG and feed efficiency until the final two 42 d periods (d 294-377). Feeding behavior parameters of daily bunk and consumption visit frequency and daily bunk and consumption time decreased in a quadratic fashion across DOF, while singular bunk and consumption time, DMI per consumption event, and consumption rate per event decreased across DOF in a quadratic fashion. Implanted steers spent less time at the bunk while consuming more feed at an increased rate compared to CON steers.

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Table 3.1 Dietary ingredients, and formulated nutrient basis of rations fed during 378 d trial.

	Ration 10 (starter)	Ration 8	Ration 5	Ration 9	Ration 6	Ration 7
Days fed (beginning at d 0)	5	9	8	34	15	307
Ingredient, % As Fed Basis						
Flaked Corn,%	31.00	31.00	40.00	52.50	60.00	74.50
Alfalfa Hay,%	38.50	38.50	38.50	32.00	23.00	8.50
Dry Distillers Grain,%	15.00	15.00	6.00	0.00	5.50	5.50
Molasses Blend,%	10.00	10.00	10.00	10.00	5.00	4.00
Fat,%	0.00	0.00	0.00	0.00	1.00	2.00
Micro Ingredient,%	1.00	1.00	1.00	1.00	1.00	1.00
Supplement[1],%	4.50	4.50	4.50	4.50	4.50	4.50
Total,%	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Nutrients, 100% Dry						
Dry Matter, %	80.62	80.62	80.24	78.89	80.87	80.56
NEm Mcal/kg DM	1.58	1.58	1.60	1.70	1.89	2.14
NEg Mcal/kg DM	0.98	0.98	0.99	1.08	1.25	1.46
Crude Protein, %	18.26	18.26	16.05	14.25	14.62	13.62
Non-Protein Nitrogen, %	2.08	2.08	2.08	2.09	1.98	1.96
Crude fat,%	3.42	3.42	3.35	2.98	4.88	6.33
Crude Fiber,%	16.1	16.10	13.90	13.67	9.76	5.92
Calcium,%	1.15	1.15	0.81	1.06	0.70	0.62
Phosphorus, %	0.3	0.43	0.40	0.37	0.38	0.39
Potassium,%	1.67	1.67	1.94	1.36	1.31	0.81
Rumensin, mg/hd	0	0	150	150	250	335
Tylan mg/hd	0	0	0	0	100	100
Vit. A, IU/hd	40000	40000	40000	40000	40000	40000
Vit. D, IU/hd	400	400	400	400	400	400
Vit. E, IU.d	40	40	40	40	40	40
Deccox, mg/hd	113.5	113.5	0	0	0	0
Aureo, mg/hd	5000	0	0	0	0	0

[1] Supplement: 35.41% cottonseed meal, 20.09% limestone, 14.49% corn gluten feed, 11.27% urea, 8.25% dolomite, 6.84% salt bulk, 2.55% ammonium sulfate, 0.38% zinc sulfate, 0.32% vitamin A, 0.16% sodium selenite, 0.12% manganese sulfate, 0.08 copper sulfate, 0.03% vitamin E, and traces of cobalt carbonate and trace sodium with iodine.

Table 3.2 Live performance of steers (n = 72) during a serial harvest study (1-377 d on feed) with 10 slaughter dates

Days on feed		Performance					
	n	Daily DMI	Start BW	End BW	ADG	G:F	DMI %BW
		kg					
CON	36	8.58	531	583	1.30	0.149	1.71
REV	36	8.80	550	607	1.43	0.159	1.69
1-41	72	10.12^{a}	271^{i}	362^{i}	2.24^{a}	0.224^{a}	3.22^{a}
42-83	64	8.77^{b}	360^{h}	431^{h}	1.74^{b}	0.182^{c}	2.44^{b}
84-125	56	8.84^{cd}	431^{g}	500^{g}	1.70^{bc}	0.201^{b}	1.83^{c}
126-167	48	8.82^{c}	503^{f}	568^{f}	1.61^{cd}	0.184^{c}	1.64^{d}
168-209	40	7.98^{c}	567^{e}	607^{e}	0.99^{e}	0.111^{e}	1.51^{e}
210-251	32	7.50^{c}	597^{d}	656^{d}	1.46^{d}	0.165^{d}	1.41^{e}
252-293	24	8.04^{de}	664^{c}	692^{c}	0.69^{f}	0.083^{f}	1.19^{f}
294-335	16	9.63^{e}	700^{b}	737^{b}	0.92^{e}	0.121^{e}	1.05^{f}
336-377	8	8.50^{cde}	769^{a}	805^{a}	0.92^{ef}	0.115^{e}	1.03^{f}
SEM		0.39	17.7	19.0	0.09	0.009	0.08
P-Values							
DOF		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TRT		0.15	<0.01	<0.01	<0.01	<0.05	0.98
TRT X DOF		0.85	0.77	0.88	0.15	<0.05	0.98
Linear		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Quadratic		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

$^{a, b, c, d, e, f}$ Least squares means within a column lacking a common superscript letter differ ($P < 0.05$)

Table 3.3 Eating behavior of steers (n = 72) implanted with Revalor XS (REV; n = 36) or control (CON; n = 36) during a serial harvest study (1-377 d on feed) with 10 slaughter dates

		Eating behavior					
Days on feed	*n*	Bunk visit frequency	Consumption visit frequency	Daily bunk duration	Daily consumption duration	Singular bunk attendance	Singular consumption event
		events/d		min/d		min/event	
CON	36	28.1	25.9	72.94	70.46	2.92	3.04
REV	36	27.2	25.1	64.94	62.96	2.77	2.89
1-41	72	55.0^{a}	48.8^{a}	115.9^{a}	111.2^{a}	2.77^{cde}	2.64^{bcd}
42-83	64	34.1^{b}	31.2^{b}	85.3^{b}	82.2^{b}	2.82^{cd}	2.67^{cb}
84-125	56	28.0^{c}	25.5^{cd}	66.4^{c}	63.7^{c}	2.69^{de}	2.56^{cd}
126-167	48	28.5^{c}	26.5^{c}	64.1^{cd}	62.0^{c}	2.49^{e}	2.39^{d}
168-209	40	23.9^{d}	22.2^{de}	61.0^{cde}	59.0^{cd}	2.90^{cd}	2.78^{bc}
210-251	32	23.0^{d}	21.6^{e}	61.3^{cde}	59.5^{cd}	3.04^{abc}	2.93^{ab}
252-293	24	21.9^{d}	20.7^{e}	57.1^{de}	55.7^{cd}	3.00^{bcd}	2.89^{abc}
294-335	16	17.7^{d}	16.8^{e}	53.7^{e}	52.8^{d}	3.35^{ab}	3.25^{a}
336-377	8	16.8^{d}	16.1^{e}	55.6^{de}	54.3^{cd}	3.62^{a}	3.49^{a}
SEM		3.4	2.9	5.1	4.9	0.26	0.27
P-Values							
DOF		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TRT		0.48	0.49	<0.01	<0.01	0.14	0.13
TRT x DOF		0.95	0.96	0.93	0.95	0.98	0.97
Linear		<0.01	<0.01	<0.01	<0.01	0.01	0.01
Quadratic		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

$^{a, b, c, d, e, f, g, h}$ Least squares means within a column lacking a common superscript letter differ ($P < 0.05$)

Table 3.4 Consumption behavior and intake of steers (n = 72) during a serial harvest study (1-377 d on feed) with 10 slaughter dates

Days on feed	*n*	Consumption behavior	
		DMI per consumption event	Consumption rate for consumption events
		g/event	g/min
CON	36	387	290
REV	36	438	422
1-41	72	252[d]	377
42-83	64	332[c]	372
84-125	56	361[c]	385
126-167	48	356[c]	393
168-209	40	444[b]	379
210-251	32	468[b]	385
252-293	24	446[b]	346
294-335	16	497[ab]	260
336-377	8	557[a]	228
SEM		0.04	0.07
P-Values			
DOF		<0.01	0.21
TRT		<0.01	<0.01
TRT x DOF		0.84	0.41
Linear		<0.01	0.06
Quadratic		<0.01	0.03

[a, b, c, d] Least squares means within a column lacking a common superscript letter differ ($P < 0.05$)

Table 3.5 Quadratic regression equations of live performance and feeding behavior of steers (n =72) during a serial harvest study (1-377 d on feed) with 10 slaughter dates

Item	*n*	Quadratic	Adjusted R^2	Root MSE
Daily dry matter intake, kg	72	$= 0.0309x^2 – 0.55947x + 10.522$	0.2480	1.15
Start body weight, kg	80	$= -3.2398x^2 + 90.7442x + 187.655$	0.8852	50.45
End body weight, kg	80	$= -2.6086x^2 + 77.6876x + 287.820$	0.8361	54.45
Average daily gain, kg	72	$= 0.0156x^2 – 0.3229x + 2.482$	0.5198	0.41
Gain to feed	72	$= 0.0006x^2 – 0.0219x + 0.242$	0.3914	0.04
Dry matter intake as % of body weight	72	$= 0.0512x^2 – 0.7379x + 3.790$	0.8725	0.27
Bunk visit frequency, events/d	72	$= 0.9887x^2 – 13.1114x + 62.486$	0.5410	10.41
Consumption visit frequency, events/d	72	$= 0.8337x^2 – 11.0969x + 55.096$	0.5289	9.07
Daily bunk time, min/d	72	$= 2.0713x^2 – 25.9447x + 134.037$	0.6322	15.80
Daily consumption time, min/d	72	$= 1.9920x^2 – 24.7886x + 128.508$	0.6266	15.13
Singular bunk visits, min/event	72	$= 0.0268x^2 – 0.1599x + 2.796$	0.0690	0.73
Singular consumption visits, min/event	72	$= 0.0271x^2 – 0.1674x + 2.945$	0.0578	0.77
Dry matter intake per consumption event, kg/event	72	$= -0.0020x^2 + 0.0522x + 0.214$	0.3119	0.11

x = DOF

Table 3.6 Quadratic regression equations of live performance and feeding behavior of steers (n = 72) implanted with Revalor XS (REV; n = 36) or control (CON; n = 36) during a serial harvest study (1-377 d on feed) with 10 slaughter dates

Item	*n*	Quadratic	Adjusted R^2	Root MSE
Start body weight, kg				
CON	40	$= -2.9527x^2 + 85.7557x + 193.933$	0.8857	48.32
REV	40	$= -3.5273x^2 + 95.7327x + 181.376$	0.8911	51.36
End body weight, kg				
CON	40	$= -2.1417x^2 + 71.6738x + 290.688$	0.8405	51.60
REV	40	$= -3.0756x^2 + 83.7015x + 284.952$	0.8431	55.11
Average daily gain, kg				
CON	36	$= 0.0200x^2 – 0.3478x + 2.396$	0.4790	0.42
REV	36	$= 0.0111x^2 – 0.2981x + 2.568$	0.5909	0.37
Gain to feed				
CON	36	$= 0.0007x^2 – 0.0257x + 0.233$	0.3157	0.05
REV	36	$= -0.00002x^2 – 0.0180x + 0.250$	0.5051	0.04
Daily bunk time, min/d				
CON	36	$= 2.2855x^2 – 27.6424x + 139.672$	0.6605	15.05
REV	36	$= 1.8571x^2 – 24.2469x + 128.401$	0.6249	15.86
Daily consumption time, min/d				
CON	36	$= 2.1779x^2 – 26.2051x + 133.387$	0.6509	14.46
REV	36	$= 1.8062x^2 – 23.3721x + 123.628$	0.6221	15.20
Dry matter intake per consumption event, kg/event				
CON	36	$= -0.0030x^2 + 0.0557x + 0.201$	0.3993	0.08
REV	36	$= -0.0011x^2 + 0.0487x + 0.227$	0.2856	0.14

x = DOF

CHAPTER IV

THE EFFECT OF DAYS ON FEED AND TRENBOLONE ACETATE +ESTRADIOL 17-β IMPLANTATION ON BIOMETRIC MEASURMENTS AND CARCASS DIMENSIONS OF CHAROLAIS x ANGUS STEERS ACROSS SERIAL HARVEST ENDPOINTS

4.1 Abstract

A serial harvest study was conducted to evaluate days on feed (DOF) and trenbolone acetate + estradiol-17β administration on biometric measurements across various harvest endpoints. Charolais x Angus steers {n = 80; start of trial body weight (BW) (271 ± 99 kg)} were randomly allocated to implant treatment and harvest date in a 2 x 10 factorial experiment. Pairs of steers were randomly allocated to one of two treatments; implanted with Revalor-XS (REV) on d 0 and d 190 or non-implanted control (CON). Eight steers comprised of 4 pairs were randomly assigned to 1 of 10 harvest dates at d 0, 42, 84, 126, 168, 210, 252, 294, 336, and 378 DOF. At each harvest date, all steers were measured for hip height, rump length, hip width (HW), shoulder height (SH), 2/3 body length (BL), body depth and body width (BWID). Forty-eight h after harvest, a digital image was obtained of the lateral aspect of the right side of each carcass. Carcass area, maximum length and maximum width were digitally measured against a common standard. Biometric measurement variables were analyzed as repeated measures via the GLIMMIX procedure of SAS to test the fixed effects of DOF and treatment (TRT) and

carcass dimensional measurements were analyzed using mixed models with pair as random effect; fixed effects were implant treatment and DOF with d 0 BW as a covariate. No TRT x DOF interaction was exhibited ($P \geq 0.13$) for any variable. Body width was 1.17 cm greater ($P < 0.01$) in REV steers and BL tended ($P = 0.06$) to be greater in CON steers. Hip height and SH increased ($P < 0.01$) 0.05 and 0.06 cm/d, respectively, during the 378 d feeding period. Rump length and HW increased ($P < 0.01$) 0.03 and 0.06 cm/d, respectively. Two-thirds BL increased ($P < 0.01$) 0.11 cm/d. Body depth and BWID increased ($P < 0.01$) 0.07 and 0.04 cm/d, respectively. Steers administered REV yielded 516 cm^2 greater ($P < 0.01$) carcass surface area than CON; moreover surface area increased 21.0 cm^2 /day. No TRT effect ($P = 0.57$) was observed for maximal carcass length, however maximal carcass width was 3.9 cm greater ($P < 0.01$) for REV steers. Steer carcasses increased 0.16 cm/day in length and 0.07 cm/day in width. These data indicate biometric measurements and carcass dimensions were impacted by both growth enhancement technology and duration of finishing.

4.2 Introduction

The growth curve of beef producing animals can be generally described as size-age curves (weight-age, hip height-age, heart girth-age; Fitzhugh, 1976). Biometric measurements are used to describe the dimensional measurements taken from designated anatomical points on an animal. Non-invasive measurements used in cattle production and selection include body weight, hip height, and shoulder height. These measurements may be acquired manually or by a computerized measuring system that specializes in accurately determining body dimensions and skeletal frame size of live animals (Reed et al. 2017). Biometric measurements have been used in cattle to compare to or predict other

variables such as carcass characteristics, carcass composition, breed type in relation to hip height, body area, and volume (Cook et al. 1951; Fisher et al. 1975; Comerford et al. 1988; Heinrichs and Hargrove, 1987; Fernandes et al. 2010; and De Paula et al. 2013). Frame score is a convenient way of numerically describing the skeletal size of cattle and is frequently reported as supplementary information to weight and other growth performance data to allow for selection characteristics (BIF, 2016). Understanding cattle growth in regards to skeletal growth and utilizing biometric measurements to predict growth and composition has improved the industry's ability to select for traits and to become more efficient in sorting cattle within pens to determine amount of days required before market readiness (Garrison, 2016). Research will continue to improve methods of biometric measurements, allowing further understanding of growth of different sexes, breeds, and ages of cattle. Individual animals may be managed more efficiently when growth over time can be quantified. The objective of this experiment therefore was to evaluate the days on feed and trenbolone acetate + estradiol-17β implantation on biometric measurements and carcass dimensions of Charolais x Angus steers across serial harvest endpoints.

4.3 Materials and methods

All experimental procedures involving live animals were approved by the Institutional Animal Care and Use Committee (IACUC) 01-08-18 at West Texas A&M University (WTAMU) and followed the guidelines described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, Savoy, IL.) Live animal feeding and growth were described by Kirkpatrick (2020).

4.3.1 Biometric measurements

Biometric data were collected using a proprietary system from Performance Cattle Company, LLC (Amarillo, TX). The measuring device was attached to a working chute (L.Z. Equipment, Garden City, KS) during 6 measurement events at d -7, d 0, d 42, d 84, d 126, and d 168. During d 190 reimplant, few steers were almost too large to fit through the facilities. During d 210, the system was moved and steers were processed in a larger chute (Trojan Livestock Equipment Co., Weatherford, OK). Adjustments were made to alleviate the sheer growth of the animals by diverting to a larger chute from d 210 to the end of the trial. It was then attached to another larger working chute (Daniels Manufacturing Co., Ainsworth, NE) for the reminder of the study (d 252 – d 378).

The system was attached above the chute with two cable displacement transducers, one in the front area and one in the back area of the chute. The cables were linked together with a clevis that was used as the measurement pointer. The clevis worked by touching a designated area of the animal (Figure 4.1), and if there was no movement for 0.3 s in the cables while touching the appropriate area, the system would record the length or distance. The measurement system was calibrated by placing a calibration measuring rod 121.9 cm on the floor in the middle of the working chute, then preceded by touching the working clevis on two predetermined height test spots at 15.2 cm and 106.3 cm, to simulate as if the animal were standing there, each morning prior to data collection (Reed et al. 2017). Once the system was calibrated to the correct height, steers were moved through the chute. Using an elongated “U” shaped rod which length

was known (multiple rods were used throughout the study as steers grew), and also calibrated to the system, an operator placed the bottom side of the rod underneath the animal being sure to secure it against the back of the animal's front leg and bottom of the chest. The top side was above and perpendicular to the animal's spine. Another technician positioned the pointer on top of the rod above the animals shoulder until the system recorded the measurement, and then positioned the pointer directly below the rod and onto the animal's spine at the highest point above the shoulders. These two measurements recorded by the system determined shoulder height and body depth. Immediately after the reading from the shoulder, the technician moved caudally of the animal while palpating for the left hook bone. Once the hook bone was located, the technician positioned the pointer medial from the hook to the midline of the animal; this determined hip height and 2/3 body length. Next, the pointer was positioned to the distal crest of the located hook to determine hip width. Finally, the pointer was moved caudally to be placed on the distal crest of the pin bone to determine rump length. If the animal moved in the process of the continuous measurements, the animal was repositioned and the process was repeated from the beginning until confident of appropriate measurements.

The technician utilized a second tool to determine body width. The tool consisted of an elongated "U" shaped polyvinyl chloride pipes, being able to slide one end of the pipe back and forth, essentially mimicking calipers. A measuring tape was attached to the pipe to determine length when added to the initial length of pipe when not elongated. The tool was positioned perpendicular to the animal's spine and directly caudal to the last, or 13^{th} rib of the animal (Figure 4.2). The measurement was observed on the tape and then

added to the initial length of the tool, and recorded. These measurements were collected for all animals on each processing date (d 0, d 42, d 84, d 126, d 168, d 210, d 252, d 294, d 336, d 378). Frame score was calculated using the Beef Improvement Federation Guidelines for Uniform Beef Improvement Programs (2016) formula (-11.548 + (0.4878 × hip-height, in.) – (0.0289 × days of age) + (0.00001947 × days of age2) + (0.0000334 × hip-height, in. × days of age) (BIF, 2016).

4.3.2 Carcass dimensions

Forty-eight h after harvest, a digital image (iPhone, A1963, Apple Inc., Cupertino, CA) was obtained of the lateral aspect of the right side of each carcass in front of a grid containing 390 black and green contrasting squares (100cm^2 each). Images were individually calibrated to a common standard and digitally measured (imageJ, IJ1.46r, LOCI, University of Wisconsin, WI) for 2-dimensional surface area, maximum carcass length and width. Maximum length was measured from the caudal tip of the hindshank to the cranial edge of the foreshank. Maximum width was measured from the dorsal edge of the crest to the ventral edge of the foreshank (Figure 4.3).

4.4 Statistical Analysis

A balanced incomplete block experimental design was utilized and individual steer was considered the experimental unit in a 2 x 10 factorial treatment structure with each pair of animals considered as 40 blocks. The GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC) was used to test the fixed effects of DOF, TRT, and TRT X DOF interaction for biometric measurement variables and frame score. A repeated measures design was used with DOF as the repeated measure by animal and pair as random effect

with several variance-covariance structures evaluated for each variable analyzed. Variance-covariance structures were chosen depending on Akaike's information criterion being closest to zero. All variables (HH, RL, HW, SH, BL, BD, BWID, and FS) used autoregressive as a variance-covariance structure. The GLIMMIX procedure of SAS was used to analyze fixed effects of TRT, DOF, and TRT x DOF interaction with d 0 BW used as a covariate and pair as random effect for carcass dimensions. The KENWARD-ROGER option was used to generate new denominator degrees of freedom. An LSMEANS statement generated means and a PDIFF statement was used to assess differences. The CONTRAST statements procedures of SAS were utilized to analyze differences in linear and quadratic correlations for DOF. Significance was determined at ($P \leq 0.05$) and tendencies were observed at $0.05 > P \leq 0.10$. If a variable was significant for linear or quadratic effect, the regression procedure of SAS was used to generate DOF coefficients.

4.5 Results and discussion

4.5.1 Biometric measurements of live steers

No treatment x DOF interactions ($P \geq 0.30$) were observed for any variables. Hip height was impacted (Table 4.1; $P < 0.01$) by DOF and increased ($P < 0.01$) in a quadratic fashion. Initial HH averaged 119.0 cm at d 0 and continued to increase each period, in which each 42 d period differed ($P < 0.05$) from the preceding period until d 126. At d 210, HH differed ($P < 0.01$) from d 168. During the first half of the study (d 0 – d 168), HH increased approximately 11.5 cm while during the second half (d 210 – d 378), HH growth slowed and increased approximately 3.7 cm. Over the entire feeding

period, HH increased ($P < 0.01$) by 0.05 cm/d {HH = (-0.0001*DOF^2 + 0.0937*DOF + 118.182); Adj. $R^2 = 0.6657$; RMSE = 4.60; $P < 0.01$; Table 4.3}. Preston (1978) reported that implanting steers with diethylstilbestrol increased HH; however, HH was not affected by implantation in this study. Reed et al. (2017) reported calf-fed Holstein steers exhibited a HH of 136 cm at 225 DOF, which is similar to this study; however, the Holstein steers reached 155 cm after 421 DOF while the current steers reached 138 cm after 378 DOF.

Rump length was impacted ($P < 0.01$) by DOF and increased ($P < 0.01$) in a linear fashion, beginning at 28.6 cm on d 0 and ending at 40.7 cm at d 378, or growing 0.03 cm/d. Hip width, SH, 2/3 BL, and BD were all impacted ($P < 0.01$) by DOF and increased ($P < 0.01$) in a quadratic fashion. The initial measurement of HW was 54.5 at d 0 and increased to 76.8 cm at d 378, or increased 0.06 cm/d. Hip width was widest at d 210 (86.3 cm). This observation may be attributed to experimental error due to incorrect calibration of the system when moving the system to another working chute and animal position. Shoulder height was 109.6 cm at d 0 and increased to 133.6 cm at d 378, or increased 0.06 cm/d. Two-thirds body length was initially 81.0 cm at d 0 and increased to 121.7 cm at d 378, or increased 0.11 cm/d. Body depth was initially 59.7 cm at d 0 and increased to 85.7 cm at d 378, or increased 0.07 cm/d. However, the largest measurement for BD was 91.5 cm at d 252, which was when another change of working chutes was implemented. This large increase may be due to experimental error due to incorrect system calibration and animal position. Body width was initially 41.7 cm at d 0 and increased to 55.1 cm, or increased 0.04 cm/d. Frame score was impacted ($P < 0.01$) by DOF, however, did not exhibit ($P \geq 0.31$) a linear or quadratic response. Frame score did

not differ ($P > 0.05$) between any 42 d periods throughout the trial (Table 4.1). Hip height, SH, and BD in this study are comparable to Loy et al. (1988) that reported 125, 120, and 75 cm, respectively, for implanted comparatively slaughtered Charolais cross steers fed to 189 DOF. De Paula et al. (2013) reports similar biometric measurements regarding HW, BD, body length, and shoulder height in grazing bulls harvested in groups at 0, 84, 168, 235, and 310 days on trial. Fernandes et al. (2010) reported HW, BWID, body length, and SH at 37, 51, 61, 127 in grazing bulls harvested at 490 days of age. The steers in the current study are comparable in regards to live animal measurements and agree with previous literature that BD and body length grow at faster rates than height and hip dimensions when measurements are being recorded after cattle are weaned.

Body width was impacted ($P < 0.01$) by TRT. Implanted steers exhibited increased ($P < 0.01$) body width (51.4 cm) compared to CON (50.3 cm). Two thirds body length tended to be greater ($P = 0.06$) for REV steers (104.8 cm) compared to CON (103.5 cm). Loy et al. (1988) reported that implantation increased body length by 3 cm, however concluded that implantation does not appear to affect skeletal growth. Similar results were exhibited in this study. Implanting steers with REV does not appear to affect skeletal growth in most variables other than BWID. This could be attributed to increased muscling; however with REV exhibiting a 1.1 cm greater BWID, this difference may also be attributed to experimental error regarding operator error during live animal measurement or animal position in the working chute.

4.5.2 Carcass dimensional measures

All carcass dimensions (carcass area, carcass length, and carcass width) were impacted (Table 4.2; $P < 0.01$) by DOF and all increased ($P < 0.01$) in a quadratic fashion. Carcass area was 8117 cm^2 during the initial period (d 0) and was 16039 cm^2 during the final period (d 378), a 97.6% increase, or increasing approximately 21 cm^2/d. Maximum carcass length was 223 cm during the initial period (d 0) and was 284 cm during the final period (d 378), a 27.4% increase, or increasing 0.16 cm/d. Maximum carcass width was 73 cm during the initial period (d 0) and 100 cm during the final period (d 378), a 37% increase, or increasing 0.07 cm/d. Carcass area and carcass width were both impacted ($P < 0.01$) by treatment. Implanted steers exhibited an increased ($P < 0.01$) carcass area (12879 cm^2) compared to CON (12363 cm^2), a 4.0% increase. This increase in carcass surface area may be attributed to the increase in tissue and protein accretion in the carcass from REV. Anderson (1991), Nichols (1991), and Johnson et al. (1996) reported that implanting with TBA/E2 implants increase protein and mass accretion of the carcass. Carcass width was greater ($P < 0.01$) in REV steers (92 cm) compared to CON (88 cm). McGee et al. (2007) reported carcass length and width of Charolais x Holstein Friesian bulls at 139.2 and 52.1 cm. These measurements are much less than the current study; however McGee et al. (2007) utilized the EUROP (Commission of the European Communities, 1982) system for conformation with this study taking place in Ireland. Carcass measurements were outlined by De Boer et al. (1974), in which carcass length is measured essentially without the hindquarter. When adding the length of the hindquarter of the animals to the respective carcass length, similar results are obtained compared to the current study from d 0 to d 126.

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Table 4.1 Effects of Revalor XS[1] implant administration (REV) and days on feed (DOF) on live animal biometric measurements of Angus x Charolais steers (n=80)

	Treatment		Days on feed (DOF)											*P*-values				
Item	CON	REV	0	42	84	126	168	210	252	294	336	378	SEM	TRT	DOF	TRT X DOF	Linear	Quadratic
n	40	40	80	72	64	56	48	40	32	24	16	8						
Hip height, cm	130.8	130.6	119.0^{g}	120.5^{f}	125.0^{e}	129.7^{d}	130.5^{d}	134.3^{c}	134.8^{bc}	136.4^{abc}	139.2^{a}	138.1^{ab}	0.39	0.72	< 0.01	0.99	<0.01	<0.01
Rump Length, cm	34.6	34.6	28.6^{e}	32.0^{d}	32.0^{d}	31.3^{d}	33.8^{c}	33.4^{c}	37.6^{b}	37.6^{b}	39.0^{ab}	40.7^{a}	0.28	0.92	< 0.01	0.30	<0.01	0.12
Hip width, cm	66.8	68.1	54.5^{d}	61.0^{c}	56.7^{d}	56.6^{d}	61.1^{c}	86.3^{a}	75.2^{b}	73.3^{b}	73.0^{b}	76.8^{b}	0.59	0.13	< 0.01	0.34	<0.01	<0.01
Shoulder Height, cm	123.1	122.3	109.6^{g}	112.1^{f}	115.6^{e}	124.8^{b}	122.2^{c}	125.8^{b}	119.4^{d}	132.5^{a}	131.5^{a}	133.6^{a}	0.36	0.11	< 0.01	0.50	<0.01	<0.01
2/3 Body length, cm	103.5	104.8	81.0^{h}	93.3^{g}	98.1^{f}	100.9^{e}	104.5^{d}	105.9^{cd}	107.1^{c}	113.5^{b}	115.6^{b}	121.7^{a}	0.47	0.06	< 0.01	0.94	<0.01	<0.01
Body depth, cm	75.1	75.4	59.7^{i}	61.7^{h}	66.0^{g}	69.6^{f}	72.9^{e}	82.7^{c}	91.5^{a}	78.5^{d}	83.9^{bc}	85.7^{b}	0.27	0.45	< 0.01	0.97	<0.01	<0.01
Body width, cm	50.3	51.4	41.7^{f}	44.7^{e}	46.4^{d}	49.9^{c}	53.1^{b}	55.3^{a}	53.0^{b}	54.0^{ab}	55.1^{ab}	55.1^{ab}	0.28	< 0.01	< 0.01	0.83	<0.01	<0.01
[2]Frame Score	6.04	5.97	6.27^{a}	5.79^{a}	5.98^{a}	6.28^{a}	5.88^{a}	6.2^{a}	5.86^{a}	5.87^{a}	6.18^{a}	5.75^{a}	0.07	0.49	< 0.01	0.98	0.31	0.84

[1]Merck Animal Health, Madison, NJ

[2]Frame Score = -11.548 + (0.4878 × hip-height, in.) – (0.0289 × days of age) + (0.00001947 × days of age2) + (0.0000334 × hip-height, in. × days of age).

[a, b, c, d, e, f, g, h] Least squares means within a row lacking a common superscript letter differ ($P < 0.05$)

Table 4.2 Effects of Revalor XS[1] implant administration and days on feed (DOF) on carcass dimensions of Angus x Charolais steers (n=80)

	Treatment		Days on feed (DOF)										*P*-values					
Item	CON	REV	0	42	84	126	168	210	252	294	336	378	SEM	TRT	DOF	TRT X DOF	Linear	Quadratic
n	40	40	8	8	8	8	8	8	8	8	8	8						
Carcass area, cm^2	12363	12879	8117^{h}	9456^{g}	10499^{f}	12264^{e}	13278^{d}	13255^{d}	13791^{cd}	14334^{c}	15180^{b}	16039^{a}	266	<0.01	<0.01	0.21	<0.01	<0.01
Max carcass length, cm	263	265	223^{g}	240^{f}	255^{e}	262^{de}	268^{cd}	275^{bc}	271^{cd}	279^{abc}	288^{a}	284^{ab}	4.0	0.57	<0.01	0.30	<0.01	<0.01
Max carcass width, cm	88	92	73^{e}	79^{d}	82^{d}	90^{c}	94^{bc}	92^{c}	95^{abc}	97^{ab}	98^{ab}	100^{a}	1.9	<0.01	<0.01	0.13	<0.01	<0.01

[a, b, c, d, e, f g, h]Least squares means within a column lacking a common superscript letter differ ($P < 0.05$)

[1]Merck Animal Health, Madison, NJ

Table 4.3 Linear and quadratic regression equations of biometric measurements and carcass dimensions of steers (n = 80) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

Item	*n*	Linear	Quadratic	Adjusted R^2	Root MSE
Hip height, cm	80	-	= $-0.0001x^2 + 0.0937x + 118.182$	0.6657	4.60
Rump length, cm	80	= $0.0205x + 29.539$	-	0.4116	3.41
Hip width, cm	80	-	= $-0.00001x^2 + 0.0772x + 53.960$	0.3894	9.43
Shoulder height, cm	80	-	= $-0.0001x^2 + 0.0963x + 109.395$	0.6372	5.10
2/3 body length, cm	80	-	= $-0.0002x^2 + 0.1576x + 83.936$	0.7355	6.04
Body depth, cm	80	-	= $-0.0001x^2 + 0.1237x + 57.817$	0.7895	4.75
Body width, cm	80	-	= $-0.0001x^2 + 0.087x + 41.310$	0.6610	3.42
Carcass area, cm^2	80	-	= $-0.0340x^2 + 32.8600x + 8116.923$	0.8605	988.28
Carcass length, cm	80	-	= $-0.0005x^2 + 0.3338x + 225.351$	0.7172	12.36
Carcass width, cm	80	-	= $-0.0002x^2 + 0.1406x + 73.201$	0.7071	5.46

x = DOF

Table 4.4 Quadratic regression equations of biometric measurements and carcass dimensions of steers (n = 80) implanted with Revalor XS (REV; n = 40) or control (CON; n = 40) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

Item	*n*	Quadratic	Adjusted R^2	Root MSE
Body width, cm				
CON	40	$= -0.0001x^2 + 0.0860x + 41.162$	0.6225	3.54
REV	40	$= -0.0001x^2 + 0.0885x + 41.458$	0.7038	3.24
Carcass area, cm^2				
CON	40	$= -0.0258x^2 + 29.2929x + 8155.956$	0.8288	1090.45
REV	40	$= -0.0413x^2 + 36.2871x + 8082.885$	0.9025	836.13
Carcass width , cm				
CON	40	$= -0.0001x^2 + 0.1102x + 73.843$	0.6332	5.71
REV	40	$= -0.0003x^2 + 0.1691x + 72.624$	0.8338	4.29

x = DOF

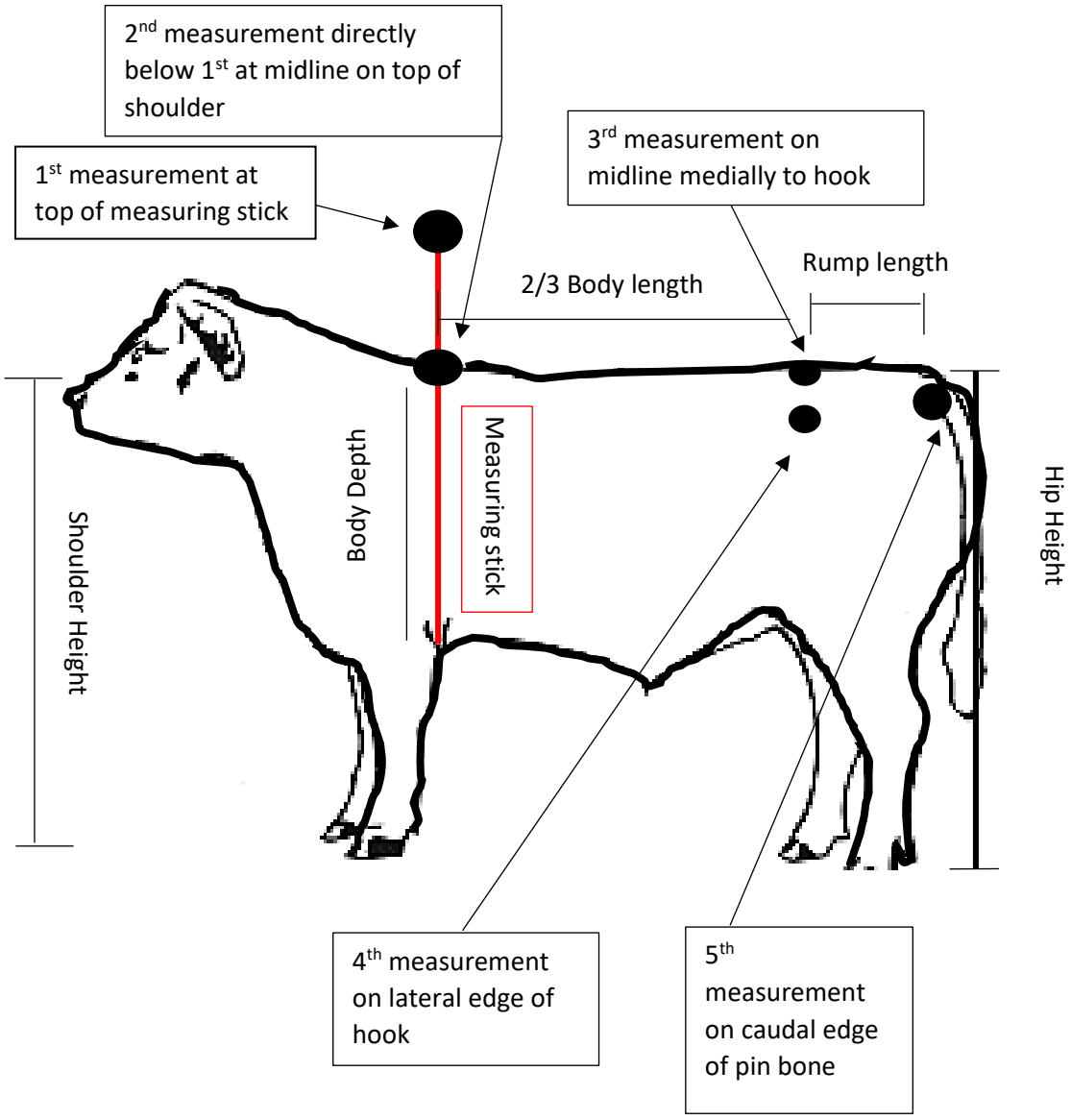

Figure 4.1. Biometric measurement locations and sequence.

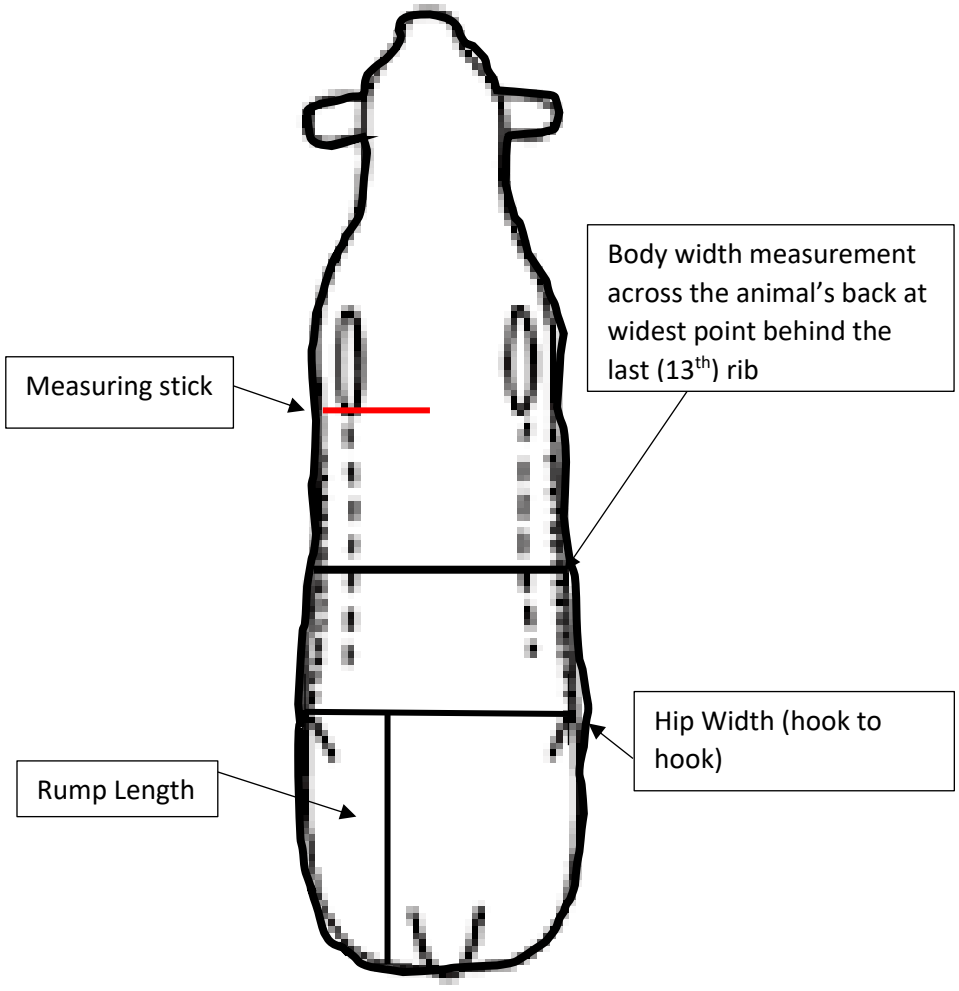

Figure 4.2. Body width, hip width, and rump length measurement locations.

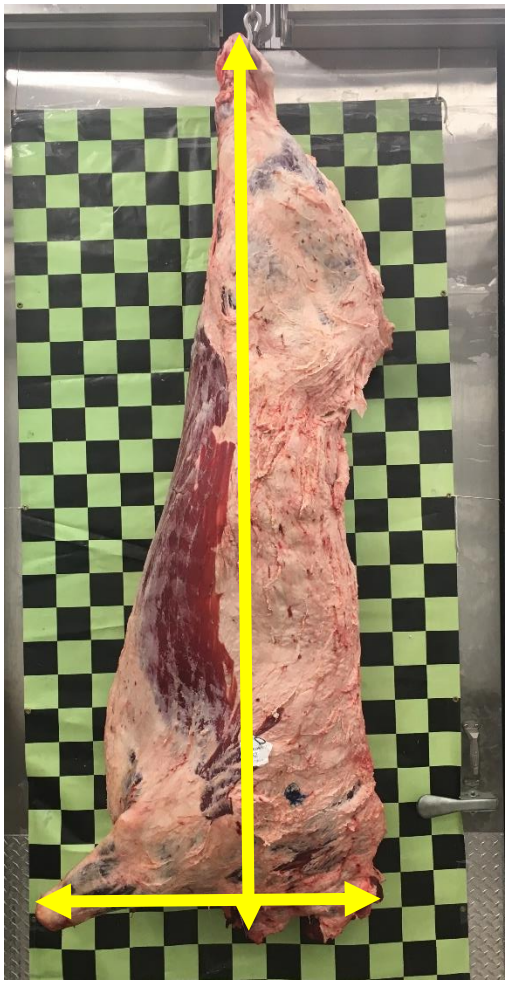

Figure 4.3. Carcass maximum length and width measurements

CHAPTER V

THE EFFECT OF DAYS ON FEED AND TRENBOLONE ACETATE + ESTRADIOL 17-β IMPLANTATION ON EMPTY BODY COMPOSITION AND RETAINED ENERGY OF CHAROLAIS X ANGUS STEERS ACROSS SERIALLY HARVESTED ENDPOINTS

5.1 Abstract

Administration of growth-promoting implants has been shown to alter chemical composition of the empty body in beef cattle. A serial harvest study evaluated days on feed (DOF) and trenbolone acetate + estradiol-17β administration on empty body composition across various harvest endpoints. Charolais x Angus steers {n = 80; start of trial body weight (BW) (271 ± 99 kg)} were randomly allocated to implant treatment and harvest date in a 2 x 10 factorial design. Pairs of steers were randomly allocated to one of two treatments (TRT); implanted with Revalor-XS (REV) on d 0 and d 190 or non-implanted control (CON). Eight steers comprised of 4 pairs were randomly assigned to 1 of 10 harvest dates at d 0, 42, 84, 126, 168, 210, 252, 294, 336, and 378 DOF. Empty body composition was determined via proximate analysis of blood, hide, internal cavity components, bone, and carcass soft tissue. Proximate analysis of each tissue was multiplied by mass to assimilate empty body percentages of moisture (EBM), crude protein (EBP), ether extractable fat (EBF), and ash (EBA). Data were analyzed using mixed models with d 0 BW as a covariate and pair as random effect. No TRT x DOF

interaction was exhibited ($P \geq 0.17$) for any variable. Empty body moisture decreased ($P < 0.01$) in a quadratic trend at approximately 0.0373%/d beginning at 61.9% on d 0 and ending at 47.8% on d 378. Empty body protein decreased ($P < 0.01$) linearly by approximately 0.0071%/d beginning at 18.7% on d 0 and ending at 16.0% on d 378. Empty body fat increased ($P < 0.01$) in a quadratic trend at approximately 0.0450%/d beginning at 14.0% on d 0, until d 294 and plateaued at approximately 32.0% through d 378. Empty body ash remained constant ($P = 0.29$) over the feeding period (5.5% - 5.8%). Empty body protein (16.7% CON vs 17.4% REV) and EBA (5.4% CON vs 5.7% REV) were greater ($P < 0.01$) for REV steers, and EBM (50.7% CON vs 51.6% REV) tended to be greater ($P = 0.07$) for REV steers. In contrast, EBF (27.3% CON vs 25.3% REV) was greater ($P < 0.01$) for CON steers. Ratio of EBP to EBF was 0.692:1 for CON steers compared to 0.752:1 for REV steers ($P < 0.05$) while decreasing ($P < 0.01$) approximately 0.002/d beginning at 1.378 on d 0 and ending at 0.542 on d 378. Implanted steers accrued 68 g/d more ($P < 0.01$) than CON in addition to all steers accruing 605 g/d of fat ($P = 0.42$). These data indicate that growth-promoting implants alter composition of gain during the finishing period.

5.2 Introduction

Animal scientists have extensively researched predicting chemical composition (moisture, protein, fat, and ash) of cattle for almost a century to determine composition of gain (Moulton et al., 1922; Hankins and Howe, 1946; Kraybill et al., 1952; Garrett and Hinman, 1962; McEvers 2014; Walter, 2015). Prior data related to serial harvest of fed cattle concluded that growth rate and fat deposition increased across DOF (Zinn et al. 1970). Experiments related to the energetic efficiency of cattle have been a major focus

since the inception of concentrate feeding of cattle for harvest. Lofgreen and Garrett (1968) developed a system that described how metabolizable energy (ME) in feed could be quantified as net energy for maintenance (NEm) and net energy for gain (NEg). Lofgreen and Garrett (1968) also estimated the caloric requirement for maintenance at 77 kcal*$BW^{0.75}$ to maintain BW. Garrett and Hinman (1969) described relationships amongst the animal empty body, carcass density, and carcass composition. Fox et al. (1976) reported linear relationships between empty body weight (EBW) and hot carcass weight (HCW) in beef cattle.

New growth technologies have focused on improved lean muscle deposition and carcass cutability, which has prompted producers to utilize higher dose combinations of TBA + E2-17β. Nichols (1991) indicated that anabolic implants improved protein accretion and resulted in more retained energy/d or per kg of BW gained. The objective of this experiment was to evaluate feeding duration and trenbolone acetate + estradiol-17β implantation on empty body composition and retained energy of Charolais x Angus steers.

5.3 Materials and methods

All experimental procedures involving live animals were approved by the Institutional Animal Care and Use Committee (IACUC) 01-08-18 at West Texas A&M University (WTAMU) and followed the guidelines described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, Savoy, IL.) Live growth and feeding performance was described by Kirkpatrick (2020), harvest procedures and byproduct yields were described by Pillmore (2020), and fabrication methods were described by Wesley (2020).

5.3.1 Blood, hide, and internal cavity sampling

Steers were harvested 24 h after live procedures in 42 d intervals over 10 harvest endpoints (1, 43, 85, 127, 169, 211, 253, 295, 337, and 379 DOF). Each harvest included 4 steers implanted (REV) with Revalor XS (Merck Animal Health, Madison, NJ) and 4 steers with no implant (CON) representing non-hormone treated cattle (NHTC). Steers were harvested using commercial methods at the West Texas A&M University meat laboratory (Canyon, TX; Establishment 7124. Each individual component that was removed from the animal during harvest was weighed. During exsanguination, a sample of blood was immediately acquired in a Whirl Pak sampling bag (Nasco, Fort Atkinson, WI) and labeled. After hide removal, the hide was weighed using a Dillon EDXtreme EDx-2T Dynamometer (Dillon Force, Fairmont, MN) crane scale. A 100 cm^2 hide sample was taken at the site where the A-mode rump fat variable was acquired, on the right hip. Upon evisceration, all internal cavity components (ICC; heart, lungs, trachea, liver, gallbladder, spleen, pancreas, rumen, reticulum, omasum, abomasum, small intestine, large intestine, mesenteric fat, omental fat, and bladder) were collected and chilled for 24 hr. The kidneys along with kidney, pelvic, and heart fat (KPH), and thymus were removed and placed with the ICC. At the end of the harvest procedure, hot carcass weight (HCW) was recorded as carcasses were moved into the hot box and chilled 48 hr.

The day following harvest, ICC were separated, weighed full and empty, washed of all feed contents and digesta, and placed into a Biro model 548 grinder (Biro Mfg. Co., Marblehead, OH) and thoroughly ground using a course (12.7 mm in diameter) grinding plate. The course ground contents were mixed thoroughly by hand and re-ground using a

fine (3.2 mm in diameter) grinding plate. Once the contents were finely ground, they were hand mixed and the contents were subsampled in triplicate for chemical analysis.

The 100 cm^2 hide samples collected from harvest were removed from the freezer and allowed to thaw. Any subcutaneous fat on the samples was removed. Hide samples were cut into strips approximately 1 cm in width to allow for easier grinding and placed in an Auto IQ NutriNinja blender system (SharkNinja Operating LLC., Needham, MA) and pulverized to a fine consistency. All contents were collected and sampled for chemical analysis. The blender was washed and dried in between each sample.

5.3.2 Carcass soft tissue sampling

After fabrication of the carcass right side, all carcass soft tissues (CST; lean and fat) were thoroughly ground in a Thompson Model 900 mixer/mincer (Thompson Meat Machinery, Crestmead, Queensland, Australia) using a course plate (12.7 mm in diameter). The contents were then fine ground using a fine grinding plate (3.2 mm in diameter). During this secondary grinding phase CST were subsampled in triplicate for chemical analysis. Entire CST contents were sampled according to the previous methods described during the first 5 harvest dates however during the latter 5 harvest dates, fat and lean trim were course and fine ground separately due to the high accumulation of fat in the animals after 210 DOF. These samples were also collected in triplicate (3 lean grind and 3 fat grind for each steer).

5.3.3 Bone sampling

For each carcass side, one long bone (femur) and one flat bone (scapula) were collected to represent carcass bone, vacuum packaged, and frozen for later processing to

determine bone chemical analysis. The femur and scapula from each animal were sliced transversely approximately every 1 cm using a Biro model 3334 band saw (Biro Mfg. Co., Marblehead, OH) along the length of both bones. After each bone was processed, the entirety of the materials removed from the blade were collected, hand mixed, and sampled for chemical analysis. Before the next sample was processed, the band saw was washed with cold water and dried.

5.3.4 Laboratory analysis

Laboratory analysis for all samples was conducted at SDK laboratories, Inc. (Hutchinson, KS). For all carcass and non-carcass samples, determination of moisture was conducted by drying samples at 105°C for a period of 24 hr. Crude fat was determined through the AOAC official method 2003.06 (2006) where approximately 5g samples were ground to a particle size no greater than 1 mm and dried at 102°C for 2 hr prior to using petroleum ether. Crude fat was calculated as the difference of the weight of the test extraction cup plus fat residue and the weight of the empty extraction cup divided by the weight of the test sample multiplied by 100. Crude protein was determined using AOAC method 990.03 (2000) in which the percentage of nitrogen in the sample was multiplied by 6.25 to compute crude protein in the sample (Merrill and Watt, 1973). For determination of ash, AOAC method 942.05 (1943) was used whereby 2 g test portions of each sample were placed in a porcelain crucible and exposed to a temperature of 600°C for a period of 2 hr.

5.3.5 Calculation of empty body, non-carcass and carcass chemical components

Non-carcass components derived from tissues of the ICC, hide, and blood were calculated using laboratory results for moisture, crude protein, crude fat, and ash multiplied by weight of the corresponding component. Chemical composition of CST was calculated using the percentage of each component (lean and fat) comprising the empty body multiplied by laboratory results to reflect overall composition. Laboratory results from bone samples collected from the right femur and scapula of each carcass served as a representative sample for all carcass bone, skull, metacarpals, metatarsals, and oxtail. Composition of the empty body was calculated by weighing each component as a percentage of empty body and multiplying by laboratory results for percentage of moisture, crude protein, crude fat, and ash.

5.3.6 Calculation of energy retention

Retained energy (RE, Mcal/d) was calculated as the difference between the steers (n = 8) harvested at d 0 and those representing each treatment across harvest endpoints. Empty body energy of the baseline steers was calculated using their chemical composition where the caloric value of energy retained as fat and protein was assumed 9.367 and 5.686, respectively (Blaxter and Rook, 1953). Metabolic ratio (MR) was calculated as the ratio of RE to daily megacalorie consumption (DMC). Empty body weight gain (EBWG, g/d), hot carcass weight gain (HCWG, g/d), and ratio of HCWG to EBWG was calculated using the baseline steers as a point of reference for this experiment. Using individual laboratory results for each animal, the difference in total energy was calculated and averaged by treatment and harvest day by subtracting values for each animal from the mean of the baseline steers. Moisture, protein, fat, and ash accretion (MA, PA, FA, AA, g/d, respectively) was calculated as the difference measured

in grams per day on trial amongst each treatment and harvest endpoint with the baseline steers representing d 0.

5.4 Statistical analysis

An balanced incomplete block design was utilized with a 2 x 10 factorial treatment arrangement with 40 pairs of animals designated as blocks. The GLIMMIX procedure of SAS was used to analyze fixed effects of TRT, DOF, and TRT x DOF interaction with d 0 BW used as a covariate and pair as random effects. LSMEANS was used to calculate mean estimates. The KENWARD-ROGER option was used to generate new denominator degrees of freedom. An LSMEANS statement generated means and a PDIFF statement was used to assess differences. Orthogonal contrast statements were utilized to analyze differences in linear and quadratic correlations for DOF. Significance was determined at ($P \leq 0.05$) and tendencies were observed at ($0.05 > P \leq 0.10$). If a variable was significant for linear or quadratic effect, the regression procedure of SAS was used to generate DOF coefficients.

5.5 Results and discussion

5.5.1 Steer body weights and composition

For all comparisons, no TRT x DOF interaction was observed ($P \geq 0.17$; Table 5.1). Fill, dressed yield as a % of EBW (DYEBW), and dressed yield as a % of shrunk body weight (DYSBW) were not different ($P \geq 0.22$) between TRT. In contrast, McEvers (2014) reported Holstein steers supplemented with zilpaterol hydrochloride exhibited greater ($P \leq 0.02$) DYEBW and DYSBW than negative control steers. Shrunk BW was greater ($P < 0.01$) for REV steers (573.9 kg) compared to CON (540.3 kg), a 6.2%

improvement. Empty body weight and HCW were greater ($P < 0.01$) for REV steers (524.3 and 385.0 kg, respectively) compared to CON (496.5 and 362.9 kg, respectively), in which REV steers exhibited a 5.6 and 6.1% improvement. Implanted steers contained more ($P \leq 0.01$) EBP% (+ 0.7%) and EBA% (+ 0.3%), and CON contained more ($P < 0.01$) EBF% (+ 2.0%). Empty body moisture % tended ($P = 0.07$) to be greater in REV (+ 0.9%). Previous researchhas indicated that anabolic implants increase protein in the empty body (Solis et al., 1989; Johnson et al., 1993). Hutcheson et al. (1997) reported that implanted steers exhibited increased EBW, EBP, EBM, and EBA. Shrunk BW, fill, EBW, HCW, DYEBW, DYSBW, and EBF% increased ($P \leq 0.01$) across DOF while EBM% and EBP% decreased ($P < 0.01$) across DOF. Cattle harvested at d 294 had the greatest DYEBW and DYSBW. The increase in DYEBW and DYSBW may be due to the highest % EBF also exhibited by these steers. It has been observed that steers harvested on d 294 were biologically fatter. Describing the relationships for these measurements using orthogonal contrasts, SBW, EBW, HCW, DYEBW, DYSBW, EBM%, and EBF% were calculated as quadratic ($P \leq 0.02$). The relationships of fill and EBP% were linear ($P < 0.01$). Empty body ash % was not impacted ($P = 0.52$) by DOF. Empty body fat and EBM exhibited an inverse relationship with EBF increasing approximately 17% while EBM decreased 14% during the study. Walter (2015) also describes an inverse relationship between EBF and EBM. Empty body fat increased 17% during the 378 d trial whereas EBW increased 487 kg. For every 28.6 kg increase in EBW, EBF increased by 1%. Guiroy (2001) and Walter (2015) reported that for every 14.26 and 12.58 kg increase in EBW, respectively, EBF increased by 1%. Differences between trials may be attributed to age and type of animals. Walter (2015) harvested

steers in a 56 d window in an extended day feeding trial whereas Guiroy (2001) compiled data from 1977 to 2001.

5.5.2 Body composition and retained energy change

Observing all comparisons, TRT x DOF interactions occurred for DMC and AA (Table 5.2; $P < 0.01$ and $P = 0.05$, respectively), and a trend ($P = 0.10$) was calculated for PA. Implanted steers on average exhibited a higher DMC until approximately d 168, in which CON exhibited increased DMC; however there was no TRT effect ($P = 0.86$). Ash accretion interacted between TRT at d 84 and the following during the following period REV AA increased while CON decreased. Hot carcass weight gain (HCWG), empty body moisture weight (EBMW), empty body protein weight (EBPW), empty body fat weight (EBFW), empty body ash weight (EBAW), DMC, total energy, PA, PA:FA, MA, and AA were impacted ($P \leq 0.04$) by DOF. Fat accretion was not affected ($P = 0.41$) by DOF. McEvers (2014) reported the same lack of difference in FA in serial-slaughtered Holstein steers. Empty body weight gain (EBWG) tended ($P = 0.06$) to decrease over DOF. Empty body weight gain was 2128.6 g/d during the first 42 d and decreased in a linear fashion ($P < 0.01$) to 1184.6 g/d during the last 42 d period, or decreasing in gain 2.49 g/d. Hot carcass weight gain also decreased from 1478.6 to 962.4 g/d in a linear fashion ($P < 0.01$) across the feeding period, or decreasing in gain 1.37 g/d. Empty body moisture weight, EBPW, EBFW, and EBAW increased ($P < 0.01$) at 520, 190, 490, and 80 g/d from d 0-378, all increasing ($P \leq 0.01$) in a quadratic fashion. Retained energy and MR were not affected ($P \geq 0.27$) by DOF. Daily Mcal consumption increased 0.01 Mcal/d until d 210, then plateaued during the remainder of the feeding period (d 252-378). Total energy retained within the empty body increased 5.7 Mcal/d from 585 Mcal at

d 0 to 2731 Mcal at d 378 in a quadratic fashion ($P < 0.01$). Protein accretion, MA, and AA decreased ($P < 0.01$) linearly across DOF at 0.51, 1.47, and 0.19 g/d during the feeding period. Fat was accrued at a rate of 605 g/d. The ratio of protein accretion to fat accretion also decreased ($P < 0.01$) linearly from 0.54 to 0.39 from d 42-378. These data indicate protein accretion is slowing down relative to fat as the steers finished across DOF. Daily Mcal consumption and MR reflect each other to indicate feed utilization across DOF. Increased values for MR are an indication of overall efficiency, while decreased values indicate reduced utilization of DMC in the form of RE. This may be comparable to gain:feed values in chapter 3 of this study (Kirkpatrick, 2020).

Empty body weight gain, HCWG, EBMW, EBPW, EBAW, PA, PA:FA, MA, and AA were affected (Table 5.2; $P < 0.01$) by TRT. Implanted steers exhibited an increase ($P < 0.01$) in EBWG and HCWG (1695.5 and 1359 g/d) compared to CON (1456.7 and 1169 g/d), or a 238.8 and 189.9 g/d increase. Implanted steers also contained more ($P < 0.01$) EBMW, EBPW, and EBAW (+20.7, +8.5, and +3.1 kg) than CON. These results reflect PA, MA, and AA, as REV steers exhibited increased ($P < 0.01$) accrual of nutrients by +67.3, +162.3, and +19.1 g/d, respectively, compared to CON. Empty body fat weight was not different between TRT ($P = 0.39$), and increased ($P < 0.01$) from 35.7 kg to 222.1 kg during the feeding period, or 0.49 kg/d. Protein to fat accretion ratio was greater ($P < 0.01$) in REV (0.48) compared to CON (0.35).

These data agree with Nichols (1991) in that androgenic activity of TBA + E2-17β improve protein accretion while non-implanted control store less protein and less retained energy/d. No difference in fat gain agrees with Solis et al. (1989), Johnson et al. (1993), and Hutcheson et al. (1997). Owens et al. (1995) indicated that as an animal's days of

age increased, overall protein and fat masses of the empty body shifts. The authors reported that protein mass reached a peak upon 500 d of age with fat proportionally increasing across days of age. The current data supports previous data with EBPW increasing across initial DOF and reaching a plateau at a slower increasing rate at d 210-252, while EBFW increased across DOF. The Nutrient Requirements of Beef Cattle (1996) indicated that as EBW increased, protein increased at a decreasing rate with fat reserves increasing at an increasing rate. The current study reports that as EBW increased, overall weights of protein and fat increase at differing rates with protein ranging from 44.1 to 114.5 kg (0.19 kg/d) and fat ranging from 35.7 to 222.1 kg (0.49 kg/day).

5.5.3. Composition of empty body weight

Percentage of carcass soft tissues exhibited TRT x DOF interaction (Table 5.3; $P < 0.01$). The author believes this is not a real interaction and may be due to sampling error. When comparing differences across DOF for absolute weights, blood weight, hide weight, ICC weight, bone weight, and CST weight all were impacted ($P < 0.01$) by DOF. Blood weight increased in a linear fashion ($P < 0.01$) from 10.4 to 22.2 kg during the feeding period (d 0-378) or 0.03 kg/d. Hide weight also increased ($P < 0.01$) in a linear fashion from 25.0 to 58.7 kg (d 0-378), or 0.09 kg/d. Internal cavity components weight, bone weight, and CST weight increased in a quadratic fashion ($P < 0.01$). Internal cavity components weight increased from 35.8 to 115.5 kg, or 0.21 kg/d from 0-378 DOF. Bone weight increased from 50.2 to 121.2 kg, or 0.19 kg/d from 0-378 DOF. Carcass soft tissues increased from 120.2 to 411.7 kg, or 0.77 kg/d from 0-378 DOF. Blood , hide , bone , and CST as a percentage of the empty body were affected ($P < 0.01$) by DOF.

Blood %, hide %, and bone % decreased ($P < 0.01$) at rates of 0.003, 0.005, and 0.01 % while CST % increased ($P < 0.01$) 0.02% from 0-378 DOF, all in a quadratic manner ($P < 0.01$). Hide weight, bone weight, and CST weight were affected (Table 5.3; $P \leq 0.05$) by TRT, with blood weight tending to be greater ($P = 0.06$) for REV steers (17.8 vs. 16.2 kg). Hide weight, bone weight, and CST weight were greater ($P \leq 0.05$) for REV steers by 3.6, 3.5, and 18.9 kg, respectively. Hutcheson et al. (1997) and Schmidely et al. (1992) also reported that hide weight is increased due to implants in cattle and goats, respectively. Trenkle (1990) however reported no difference of hide weights in implanted steers compared to non-implanted controls. Internal cavity components as a % of EBW was greater for CON (16.3 %) compared to REV (15.5 %). Hutcheson et al. (1997) reports similar findings that implanted animals exhibit a 1% decrease in ICC as a % of EBW. The change in animal energy expenditure as a result of reduction in ICC and gastrointestinal tract in implanted steers may be attributed to the increase in protein synthesis (Loy et al., 1988; Solis et al., 1989; Rumsey et al., 1992).

5.5.4 Composition of empty body components

A TRT x DOF interaction tended to occur (Table 5.4; $P = 0.07$) for ash % of the blood. The author believes this interaction is not real due to small sample percentages and the biological significance is troublesome to explain. Investigating the changes occurring in the empty body components sampled, all proximate analysis components (moisture, protein, fat, and ash) changed ($P < 0.05$) across DOF except for ash content of the hide ($P = 0.93$). Ash content of ICC tended to be affected ($P = 0.06$) by DOF, as well as protein content of bone ($P = 0.09$). In ICC, moisture and protein decreased ($P < 0.01$) in a quadratic fashion while fat increased ($P < 0.01$) in a quadratic fashion. This reflected in

CST with moisture and protein decreasing while fat increased ($P < 0.01$) in a quadratic fashion. These observations follow the reported growth of these particular animals as protein in the body increases at a decreasing rate and fat increases at an increasing rate (NRC, 1996). Fat content of the hide, protein and ash content of ICC, and ash content of bone were different ($P \leq 02$) when comparing CON and REV. Protein content of the blood, protein content of the hide, moisture content of ICC, and protein and fat content of bone tended ($P = 0.10$) to be affected by TRT. Control steers contained 1.3 % less ($P < 0.01$) fat in the hide. Implanted steers contained more ($P < 0.01$) protein and ash (+0.5 and +0.16 %) in ICC and 1.9 % more ash in bone. The higher ash content in bone exhibited from REV may be due to the estrogenic component of the implant. Estrogen accelerates the programmed aging of epiphyseal plates, thus decreasing the ability of chondrocytes to proliferate, leading to early growth plate fusion (Weisse et al., 2001). Implanted steers tended ($P = 0.10$) to contain 0.7, 1.3, and 0.8 % more protein in blood, hide, and bone. This increased protein % in empty body components may attribute to REV steers ability to increase protein accretion discussed previously (Kirkpatrick, 2020). Implanted steers contained more protein in all components than CON, and in contrast, CON contained more fat in all components; however, not all measurements were different. Summarizing the effect of REV implantation, this study indicated that increased yield exhibited by REV steers may be explained by increased protein accretion throughout the body.

5.5.7 *Evaluation of power trends*

Upon evaluating linear and quadratic trends for variables in this study, and especially when comparing empty body weights to Simpfendorfer (1974) data (Figure

5.1), it was brought to the attention of the author that other trends may be a more ideal fit. In regards to EBMW, EBPW, and EBFW a power trend may be a better fit than quadratic. The power curve equations are as follows:

$$EBMW = 2.2816(\text{moisture weight})^{0.7541} \quad R^2 = 0.9585$$

$$EBPW = 0.3879(\text{protein weight})^{0.8634} \quad R^2 = 0.9574$$

$$EBFW = 0.0029(\text{fat weight})^{1.7234} \quad R^2 = 0.9542$$

In regards to fat increasing at an increasing rate, its trend seems to follow an exponential trend visually, however upon applying linear, quadratic, exponential, and power equations, power became the best fit for these empty body weight measurements.

5.5.8 Relationship of quality grade to EBF

Compared to previous literature, Perry and Fox (1997) developed an equation for prediction of EBF which included variables EBW and calculated USDA yield grade that had a calculated R^2 of 0.82. This model utilized the Hankins and Howe (1946) method of carcass composition estimation. This method may not be representative of carcasses of the current fed beef population. Guiroy et al. (2001) developed a composite equation from nine studies evaluating the relationship of carcass and empty body fat to USDA quality grades of 1355 animals. These studies utilized either specific gravity or the Hankins and Howe (1946) method to estimate carcass composition. Guiroy et al. (2001) estimated that for animals to reach low choice quality grade, an animal must contain an EBF% of 28.61. Animals in this current study reached low choice quality grade at a lower percentage (27.1%; Figure 5.2) than previously reported by Guiroy et al. (2001)

and the NRC (2000) (28.61 and 27.8, respectively.) Prediction equations are needed in the current study to further compare and contrast to previous literature.

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Table 5.1 Body weights, carcass yield, and chemical composition of steers (n = 80) implanted with Revalor XS[1] (REV; n = 40) or control (CON; n = 40) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

			DOF[2]											*P* - value				
Item			0	42	84	126	168	210	252	294	336	378	SEM	DOF	TRT	TRT x DOF	Linear	Quadratic
	CON	REV																
n	40	40	8	8	8	8	8	8	8	8	8	8	-	-	-	-	-	-
SBW, kg[3]	540.3	573.9	269.0^{h}	365.8^{g}	426.3^{f}	494.4^{e}	568.3^{d}	636.7^{c}	638.3^{c}	672.6^{c}	711.4^{b}	787.7^{a}	13.7	<0.01	<0.01	0.64	<0.01	<0.01
Fill, kg[4]	52.3	57.2	30.8^{c}	52.4^{ab}	53.6^{ab}	59.8^{ab}	59.9^{ab}	50.4^{b}	51.7^{ab}	53.7^{ab}	66.6^{ab}	68.8^{a}	6.2	<0.01	0.22	0.51	<0.01	0.54
EBW, kg[5]	496.5	524.3	241.7^{h}	325.5^{g}	378.2^{f}	443.5^{e}	513.6^{d}	593.0^{c}	595.1^{c}	627.6^{bc}	656.1^{b}	729.4^{a}	13.1	<0.01	<0.01	0.78	<0.01	<0.01
HCW, kg[6]	362.9	385.0	161.3^{g}	214.0^{f}	295.4^{e}	325.1^{e}	381.2^{d}	436.0^{c}	425.5^{c}	476.7^{b}	484.2^{b}	539.6^{a}	11.3	<0.01	<0.01	0.76	<0.01	<0.01
DYEBW, %[7]	74.1	74.0	67.7^{d}	68.3^{cd}	70.1^{a}	74.8^{ab}	75.0^{ab}	74.5^{abc}	72.5^{bcd}	77.3^{ab}	75.1^{ab}	75.2^{ab}	2.0	0.01	0.97	0.66	0.02	0.02
DYSBW,%[8]	66.4	66.4	59.8^{b}	58.4^{b}	60.0^{a}	65.7^{a}	67.0^{a}	68.4^{a}	66.6^{a}	71.3^{a}	68.0^{a}	68.6^{a}	1.8	<0.01	0.94	0.96	<0.01	<0.01
EBM, %[9]	50.7	51.6	61.9^{a}	57.8^{b}	54.4^{c}	51.2^{d}	49.8^{de}	49.9^{de}	46.4^{fg}	45.5^{g}	46.8^{fg}	47.8^{ef}	0.8	<0.01	0.07	0.17	<0.01	<0.01
EBP, %[10]	16.7	17.4	18.7^{a}	18.0^{ab}	18.1^{ab}	17.3^{b}	17.7^{b}	16.3^{c}	16.2^{c}	15.9^{c}	16.2^{c}	16.0^{c}	0.3	<0.01	<0.01	0.86	<0.01	0.15
EBF, %[11]	27.3	25.3	14.0^{f}	18.4^{e}	22.2^{d}	26.2^{c}	26.7^{c}	28.4^{bc}	31.6^{ab}	33.5^{a}	31.5^{ab}	30.5^{ab}	1.0	<0.01	<0.01	0.50	<0.01	<0.01
EBA, %[12]	5.4	5.7	5.5	5.9	5.3	5.3	5.9	5.4	5.8	5.1	5.5	5.8	0.2	0.52	0.01	0.31	0.91	0.68

a, b, c, d, e, f g, h, Least squares means within a column lacking a common superscript letter differ ($P < 0.05$)

[1]Revalor-XS (Merck Animal Health, Madison, NJ).

[2]Days on feed.

[3]Body weight after calculated 4% shrink

[4]Digesta removed from gastrointestinal tract

[5]Empty body weight

[6]Hot carcass weight

[7]Dressed yield as a percentage of empty body weight

[8]Dressed yield as a percentage of shrunk body weight

[9]Empty body moisture

[10]Empty body protein

[11]Empty body fat

[12]Empty body ash

Table 5.2 Body composition and energy characteristics of steers (n = 80) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

			DOF[2]											*P* - value				
Item			0	42	84	126	168	210	252	294	336	378	SEM	DOF	TRT	TRT x DOF	Linear	Quadratic
	CON	REV																
n	40	40	8	8	8	8	8	8	8	8	8	8	-	-	-	-	-	-
EBWG[3]	1456.7	1695.5	-	2128.6	1744.7	1705.1	1670.1	1648.1	1485.0	1328.1	1294.4	1184.6	150.3	0.06	<0.01	0.11	<0.01	0.46
HCWG[4]	1169.1	1359.2	-	1478.6^{ab}	1688.5^{a}	1373.0^{abc}	1352.1^{abc}	1316.1^{abc}	1102.2^{bc}	1095.9^{bc}	1008.2^{c}	962.4^{c}	126.0	0.04	<0.01	0.57	<0.01	0.80
HCWG: EBWG[5]	0.8170	0.8096	-	0.67	0.72	0.83	0.81	0.79	0.75	0.83	0.79	0.79	0.07	0.14	0.85	0.99	0.44	0.55
EBMW[6]	238.9	259.6	145.3^{g}	180.7^{f}	202.1^{ef}	222.9^{e}	252.8^{d}	292.0^{bc}	272.6^{cd}	281.64^{bc}	301.8^{b}	340.7^{a}	7.7	<0.01	<0.01	0.49	<0.01	<0.01
EBPW[7]	79.8	88.3	44.1^{f}	56.5^{e}	67.5^{d}	75.1^{d}	90.1^{c}	95.2^{c}	95.3^{c}	98.2^{bc}	104.2^{b}	114.5^{a}	2.9	<0.01	<0.01	0.80	<0.01	<0.01
EBFW[8]	143.0	139.2	35.7^{h}	58.0^{g}	83.4^{f}	113.4^{e}	135.5^{d}	167.2^{c}	184.9^{bc}	207.3^{a}	203.5^{ab}	222.1^{a}	6.9	<0.01	0.39	0.94	<0.01	0.01
EBAW[9]	26.3	29.4	13.1^{f}	18.2^{e}	19.8^{de}	23.3^{d}	30.0^{c}	31.8^{bc}	33.8^{bc}	31.7^{bc}	35.3^{b}	41.6^{a}	1.5	<0.01	<0.01	0.45	<0.01	<0.01
DMC[10]	13.17	13.22	-	12.7^{c}	12.8^{bc}	13.5^{abc}	14.0^{ab}	14.7^{a}	12.8^{bc}	13.0^{bc}	12.7^{c}	12.6^{c}	0.4	0.04	0.86	<0.01	0.83	0.05
Total Energy[11]	1793.3	1806.3	585^{h}	865^{g}	1164^{f}	1489^{e}	1781^{d}	2107^{c}	2274^{c}	2500^{b}	2498^{b}	2731^{a}	67.3	<0.01	0.76	0.93	<0.01	<0.01
RE[12]	6.9	7.2	-	8.3	7.6	7.7	7.4	7.3	7.1	6.7	6.0	5.4	0.6	0.27	0.26	0.40	0.02	0.81
MR[13]	0.52	0.54	-	0.60	0.58	0.58	0.53	0.49	0.56	0.52	0.48	0.43	0.04	0.34	0.27	0.73	0.02	0.94
PA[14]	211.3	278.6	-	343.4^{a}	298.6^{ab}	269.0^{abcd}	282.5^{abc}	240.8^{bcd}	218.7^{bcd}	188.5^{cd}	191.5^{cd}	172.1^{d}	30.1	<0.01	<0.01	0.10	<0.01	0.41
FA[15]	609.2	601.2	-	674.2	626.6	669.8	620.4	627.1	631.4	598.2	531.8	463.0	52.3	0.41	0.76	0.92	0.09	0.59
PA:FA[16]	0.35	0.48	-	0.54^{a}	0.51^{ab}	0.39^{bcd}	0.46^{abc}	0.40^{bcd}	0.35^{cd}	0.32^{d}	0.37^{cd}	0.39^{cd}	0.04	<0.01	<0.01	0.11	<0.01	0.06
MA[17]	557.3	719.8	-	977.8^{a}	733.4^{ab}	671.8^{b}	665.0^{b}	696.4^{ab}	542.6^{b}	477.2^{b}	498.8^{b}	484.1^{b}	101.0	0.03	<0.01	0.23	<0.01	0.16
AA[18]	78.4	97.5	-	135.0^{a}	85.3^{bc}	85.8^{bc}	103.4^{b}	89.5^{bc}	85.7^{bc}	64.7^{c}	69.2^{c}	72.8^{c}	7.8	<0.01	<0.01	0.05	<0.01	0.09

[a, b, c, d, e, f, g.] Least squares means within a column lacking a common superscript letter differ ($P < 0.05$)

[1]Revalor-XS (Merck Animal Health, Madison, NJ).

[2]Days on feed.

[3]Empty body weight gain, g/d

[4]Hot carcass weight gain, g/d

[5]HCWG to EBWG ratio

[6]Empty body moisture weight, kg

[7]Empty body protein weight, kg

[8]Empty body fat weight, kg

[9]Empty body ash weight, kg

[10]Daily Mcal consumption

[11]Total energy retained within the empty body, Mcal

[12]Retained energy, Mcal/d

[13]Metabolic ratio (retained energy, Mcal/d ÷Daily Mcal intake)

[14]Protein accretion of the empty body, g/d

[15]Fat accretion of the empty body, g/d

[16]Ratio of protein accretion to fat accretion of the empty body

[17]Moisture accretion of the empty body, g/d

[18]Ash accretion of the empty body, g/d

Table 5.3 Absolute weights and proportionality of carcass and non-carcass components of steers (n = 80) implanted with Revalor XS[1] (REV; n = 40) or control (CON; n = 40) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

Item			DOF[2]										*P*-values					
	CON	REV	0	42	84	126	168	210	252	294	336	378	SEM	DOF	TRT	DOF X TRT	Linear	Quadratic
n	40	40	8	8	8	8	8	8	8	8	8	8	-	-	-	-	-	-
Absolute Weights of Empty Body Components																		
EBW[3], kg	496.5	524.3	241.7^{h}	325.5^{g}	378.2^{f}	443.5^{e}	513.6^{d}	593.0^{c}	595.1^{c}	627.6^{bc}	656.1^{b}	729.4^{a}	13.3	<0.01	<0.01	0.82	<0.01	<0.01
Blood[4], kg	16.2	17.8	10.4^{d}	14.5^{c}	14.2^{cd}	14.4^{c}	16.1^{bc}	19.3^{ab}	19.1^{ab}	19.7^{ab}	20.2^{a}	22.2^{a}	1.3	<0.01	0.06	0.91	<0.01	0.50
Hide[5], kg	42.3	45.9	25.0^{g}	35.0^{f}	34.5^{f}	40.6^{e}	44.2^{de}	52.8^{b}	46.8^{cd}	51.4^{bc}	51.4^{bc}	58.7^{a}	1.8	<0.01	<0.01	0.65	<0.01	0.02
ICC[6], kg	81.4	81.5	35.8^{g}	48.6^{f}	61.1^{e}	68.1^{e}	83.5^{d}	97.8^{c}	95.2^{c}	100.6^{bc}	107.7^{ab}	115.5^{a}	3.3	<0.01	0.96	0.99	<0.01	<0.01
Bone[7], kg	88.0	91.5	50.2^{g}	65.2^{f}	71.8^{ef}	78.6^{e}	91.5^{d}	102.9^{c}	104.0^{bc}	100.9^{c}	111.4^{b}	121.2^{a}	2.8	<0.01	0.06	0.99	<0.01	<0.01
CST[8], kg	268.7	287.6	120.2^{h}	162.2^{g}	196.6^{f}	241.7^{e}	278.3^{d}	320.1^{c}	330.0^{c}	355.1^{b}	365.3^{b}	411.7^{a}	7.5	<0.01	<0.01	0.24	<0.01	<0.01
Percentage of Empty Body Composition																		
Blood, %	3.4	3.6	4.4^{a}	4.5^{a}	3.8^{ab}	3.2^{b}	3.1^{b}	3.3^{b}	3.2^{b}	3.1^{b}	3.1^{b}	3.1^{b}	0.3	<0.01	0.15	0.68	<0.01	<0.01
Hide, %	8.8	9.0	10.0^{a}	10.1^{a}	9.1^{b}	9.1^{b}	8.6^{bcd}	8.9^{cb}	7.8^{d}	8.1^{cd}	7.8^{d}	8.1^{d}	0.3	<0.01	0.26	0.73	<0.01	<0.01
ICC, %	16.3	15.5	14.9	15.0	16.2	15.4	16.3	16.5	16.0	16.1	16.4	15.8	0.4	0.08	<0.01	0.72	0.02	0.03
Bone, %	18.1	18.0	20.9^{a}	20.1^{ab}	19.1^{bc}	17.7^{d}	17.8^{cd}	17.4^{de}	17.5^{d}	16.1^{e}	17.0^{de}	16.7^{de}	0.4	<0.01	0.66	0.18	<0.01	<0.01
CST, %	53.5	54.0	49.3^{f}	49.8^{f}	51.9^{e}	54.5^{bcd}	54.2^{cd}	53.8^{d}	55.4^{abc}	56.5^{a}	55.7^{ab}	56.3^{a}	0.4	<0.01	0.12	<0.01	<0.01	<0.01

$^{a, b, c, d, e, f, g,}$ Least squares means within a column lacking a common superscript letter differ ($P < 0.05$)

[1]Revalor-XS (Merck Animal Health, Madison, NJ)

[2]Days on feed

[3]Empty body weight, kg

[4]Stunned animal weighed 3 min immediately after exsanguination to determine blood weight

[5]Hide weighed during harvest procedure

[6]Internal Cavity Components (heart, lungs, trachea, esophagus, empty gastrointestinal tract, bladder, kidneys, liver, gallbladder, spleen, thymus, and internal fat)

[7]Bone including skull, metacarpals, metatarsals, oxtail, and carcass bone

[8]Carcass Soft Tissue removed during carcass fabrication

Table 5.4 Chemical composition of carcass and non-carcass components of steers (n = 80) implanted with Revalor XS[1] (REV; n = 40) or control (CON; n = 40) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

Item	Treatment			DOF[2]										*P*-values					
	CON	REV	SEM	0	42	84	126	168	210	252	294	336	378	SEM	DOF	TRT	DOF X TRT	Linear	Quadratic
n	40	40	-	8	8	8	8	8	8	8	8	8	8	-	-	-	-	-	-
Blood[3]																			
Moisture, %	76.3	75.7	0.3	80.1^{a}	79.1^{ab}	77.6^{bc}	77.3^{bc}	75.2^{d}	72.9^{e}	69.6^{f}	75.8^{cd}	75.4^{d}	76.7^{cd}	0.7	<0.01	0.14	0.89	<0.01	<0.01
Protein, %	22.6	23.3	0.3	18.6^{f}	20.0^{fg}	20.9^{ef}	21.5^{def}	23.6^{c}	25.9^{b}	29.5^{a}	23.3^{cd}	23.5^{c}	22.4^{cde}	0.7	<0.01	0.10	0.82	<0.01	<0.01
Fat, %	0.26	0.24	0.01	0.26^{bc}	0.23^{cd}	0.33^{ab}	0.25^{c}	0.36^{a}	0.37^{a}	0.22^{cde}	0.15^{de}	0.22^{cde}	0.15^{e}	0.03	<0.01	0.36	0.26	<0.01	<0.01
Ash, %	0.59	0.60	0.01	0.61^{bc}	0.48^{e}	0.56^{cd}	0.52^{de}	0.57^{cd}	0.66^{ab}	0.57^{cd}	0.56^{cd}	0.72^{a}	0.67^{ab}	0.02	<0.01	0.76	0.07	<0.01	<0.01
Hide[4]																			
Moisture, %	63.5	63.5	0.6	66.5^{a}	65.7^{ab}	65.0^{ab}	66.4^{a}	59.0^{d}	64.4^{ab}	62.2^{bcd}	59.8^{cd}	62.8^{bc}	63.3^{abc}	1.3	<0.01	0.94	0.30	<0.01	0.03
Protein, %	32.0	33.3	0.5	30.0^{c}	30.3^{c}	31.7^{bc}	30.2^{c}	34.5^{ab}	31.7^{bc}	33.7^{ab}	36.1^{a}	34.2^{ab}	33.7^{ab}	1.2	<0.01	0.06	0.55	<0.01	0.29
Fat, %	4.7	3.4	0.3	2.3^{d}	3.0^{bcd}	2.2^{d}	2.6^{cd}	5.3^{a}	5.3^{a}	5.3^{a}	5.3^{a}	4.4^{abc}	4.6^{ab}	0.7	<0.01	<0.01	0.15	<0.01	0.03
Ash, %	0.64	0.61	0.02	0.63	0.68	0.60	0.58	0.63	0.56	0.66	0.62	0.62	0.65	0.06	0.93	0.28	0.27	0.9	0.39
Internal Cavity Components[5]																			
Moisture, %	40.9	42.4	0.6	62.1^{a}	55.1^{b}	45.5^{c}	42.6^{cd}	39.8^{de}	36.8^{ef}	33.4^{f}	33.6^{f}	33.9^{f}	33.7^{f}	1.4	<0.01	0.06	0.33	<0.01	<0.01
Protein, %	7.5	8.0	0.15	11.0^{a}	10.2^{a}	8.6^{b}	7.5^{cd}	7.9^{bc}	6.8^{de}	6.3^{e}	6.2^{e}	6.6^{de}	6.5^{e}	0.3	<0.01	0.02	0.75	<0.01	<0.01
Fat, %	48.2	46.6	0.8	24.0	30.9	43.1	47.3	50.0	51.7	58.0	56.9	55.9	55.7	1.7	<0.01	0.09	0.53	<0.01	<0.01
Ash, %	0.57	0.73	0.04	0.71	0.88	0.57	0.44	0.71	0.69	0.54	0.61	0.66	0.68	0.08	0.06	<0.01	0.62	0.35	0.08
Bone[6]																			
Moisture, %	28.5	27.2	0.7	32.4^{a}	32.2^{a}	28.9^{abc}	23.4^{d}	22.9^{d}	29.2^{ab}	24.7^{cd}	28.1^{abc}	27.7^{bc}	29.0^{abc}	1.6	<0.01	0.14	0.39	0.04	<0.01
Protein, %	16.1	16.9	0.3	16.7	14.6	17.4	17.8	17.5	17.0	16.3	16.1	16.3	16.3	0.7	0.09	0.06	0.38	0.56	0.01
Fat, %	26.3	24.5	0.7	26.9^{ab}	23.9^{bc}	27.1^{ab}	29.7^{a}	29.4^{a}	24.4^{bc}	24.9^{bc}	24.4^{bc}	23.0^{bc}	20.8^{c}	1.5	<0.01	0.06	0.55	<0.01	<0.01
Ash, %	26.6	28.5	0.5	23.0^{e}	25.5^{cde}	24.9^{de}	26.8^{bcd}	29.4^{ab}	28.3^{abc}	29.9^{ab}	28.3^{abc}	28.8^{abc}	30.5^{a}	1.2	<0.01	<0.01	0.52	<0.01	0.07
Carcass Soft Tissues[7]																			
Moisture, %	51.7	52.4	0.4	70.1^{a}	63.1^{b}	61.5^{b}	56.9^{c}	57.7^{c}	44.1^{d}	41.9^{de}	41.0^{e}	41.9^{de}	42.2^{de}	0.8	<0.01	0.14	0.35	<0.01	<0.01
Protein, %	15.0	15.2	0.1	19.3^{a}	18.4^{b}	18.3^{b}	16.9^{c}	17.4^{c}	11.9^{d}	12.1^{d}	12.1^{d}	12.5^{d}	12.1^{d}	0.3	<0.01	0.38	0.94	<0.01	<0.01
Fat, %	31.4	30.5	0.4	8.7^{d}	15.8^{c}	18.1^{c}	23.3^{b}	23.2^{b}	42.7^{a}	44.5^{a}	45.4^{a}	43.9^{a}	44.2^{a}	1.0	<0.01	0.18	0.76	<0.01	<0.01
Ash, %	0.57	0.58	0.01	0.74^{a}	0.65^{bc}	0.66^{ab}	0.67^{ab}	0.74^{a}	0.35^{g}	0.42^{fg}	0.47^{ef}	0.52^{de}	0.57^{cd}	0.03	<0.01	0.62	0.14	<0.01	<0.01

$^{a, b, c, d, e, f g,}$Least squares means within a column lacking a common superscript letter differ ($P < 0.05$)

[1]Revalor-XS (Merck Animal Health, Madison, NJ).

[2]Days on feed.

[3]Chemical analysis of blood collected at exsanguination.

[4]Chemical analysis of 100^{2} cm sample of hide.

[5]Chemical analysis of ground internal cavity sample including abdominal and thoracic contents and all internal fat.

[6]Chemcial analysis of the femur and scapula from the right side of each carcass.

[7]Chemcial analysis of lean and fat removed from each carcass.

Table 5.5 Linear and quadratic regression equations of empty body and retained energy parameters of steers (n = 80) during a serial harvest study (0-378 d on feed) with 10 slaughter dates.

Item	*n*	Linear	Quadratic	Adjusted R^2	Root MSE
Fill, kg	80	= 0.0977x + 41.056	-	0.1303	18.19
DYEBW, %	80	-	= -0.0001x^2 + 0.0562x + 69.196	0.0957	5.93
DYSBW, %	80	-	= -0.0001x^2 + 0.0686x + 59.625	0.2470	5.24
EBM,%	80	-	= 0.000002x^2 – 0.0010x + 0.619	0.8116	0.02
EBP,%	80	= -0.0001x + 0.188	-	0.4647	0.01
EBF,%	80	-	= -0.000002x^2 + 0.0011x + 0.138	0.7798	0.03
HCWG, g/d	72	= -2.3390x + 1686.091	-	0.1645	418.88
EBMW, kg	80	-	= -0.0005x^2 + 0.6812x + 148.110	0.7837	30.33
EBPW, kg	80	-	= -0.0003x^2 + 0.2899x + 44.460	0.8045	10.67
EBFW, kg	80	-	= -0.0007x^2 + 0.7815x + 27.190	0.8788	23.95
EBAW, kg	80	-	= -0.00007x^2 + 0.0965x + 13.268	0.7560	4.77
DMC	72	-	= -0.00004x^2 + 0.0155x + 12.048	0.0248	1.71
Total energy, Mcal	80	-	= -0.0080x^2 + 8.9684x + 507.492	0.8961	247.65
PA, g/d	72	= -0.8714x + 372.078	-	0.1595	107.78
PA:FA	72	= -0.0016x + 0.612	-	0.1404	0.61
MA, g/d	72	= -3.1759x + 1039.023	-	0.1618	291.45
AA, g/d	72	= -0.3541x + 132.94	-	0.1900	30.32

x = DOF

Table 5.6 Linear and quadratic regression equations of empty body and retained energy parameters of steers (n = 80) implanted with Revalor XS (REV; n = 40) or control (CON; n = 40) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

Item	*n*	Linear	Quadratic	Adjusted R^2	Root MSE
SBW, kg					
CON	40	-	$= -0.0012x^2 + 1.7148x + 275.314$	0.8847	56.38
REV	40	-	$= -0.0022x^2 + 2.1789x + 272.855$	0.8840	59.99
EBW, kg					
CON	40	-	$= -0.0013x^2 + 1.7070x + 228.979$	0.8982	50.90
REV	40	-	$= -0.0019x^2 + 1.9911x + 237.077$	0.8791	57.56
HCW, kg					
CON	40	-	$= -0.0010x^2 + 1.3229x + 161.089$	0.8995	39.46
REV	40	-	$= -0.0019x^2 + 1.6998 + 160.067$	0.8859	43.39
EBP,%					
CON	40	$= -0.0001x + 0.185$	-	0.5159	0.01
REV	40	$= -0.0001x + 0.190$	-	0.4649	0.01
EBF,%					
CON	40	-	$= -0.000002x^2 + 0.0013x + 0.132$	0.8600	0.03
REV	40	-	$= -0.000002x^2 + 0.0010x + 0.143$	0.7287	0.03
EBWG, g/d					
CON	36	$= -1.3317x + 1746.680$	-	0.0326	500.47
REV	36	$= -7.1808x + 2637.069$	-	0.2019	613.09
HCWG, g/d					
CON	36	$= -0.8772x + 1398.410$	-	0.0706	360.08
REV	36	$= -3.8008x + 1973.772$	-	0.2278	455.82
EBMW, kg					
CON	40	-	$= -0.0003x^2 + 0.5658x + 147.979$	0.7888	28.17
REV	40	-	$= -0.0007x^2 + 0.7967x + 148.241$	0.8152	29.32
EBPW, kg					
CON	40	-	$= -0.0002x^2 + 0.2610x + 42.980$	0.7832	10.86
REV	40	-	$= -0.0004x^2 + 0.3187x + 45.941$	0.8682	8.89
EBAW, kg					
CON	40	-	$= -0.00009x^2 + 0.0984x + 12.266$	0.7879	4.07
REV	40	-	$= -0.00005x^2 + 0.0946x + 14.270$	0.7671	4.95
PA, g/d					
CON	36	$= -0.0263x + 247.122$	-	0.0202	99.62
REV	36	$= - 1.7176 + 497.035$	-	0.3367	102.03
PA:FA					
CON	36	$= -0.00006x + 0.377$	-	-0.0044	0.10
REV	36	$= -0.0033x + 0.846$	-	0.3714	0.14
MA, g/d					
CON	36	$= -1.5850x + 778.919$	-	0.0471	254.75
REV	36	$= -4.7668x + 1299.126$	-	0.2588	303.87
AA, g/d					
CON	36	$= -0.1873x + 106.901$	-	0.1506	24.03
REV	36	$= - 0.5209x + 158.982$	-	0.2322	33.29

x = DOF

Table 5.7 Linear and quadratic regression equations of absolute weights and proportionality of carcass and non-carcass components of steers (n = 80)) implanted with Revalor XS[1] (REV; n = 40) or control (CON; n = 40) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

Item	*n*	Linear	Quadratic	Adjusted R^2	Root MSE
Absolute Weights of Empty Body Components					
Blood, kg	80	= 0.0365x + 11.232	-	0.4578	3.67
Hide, kg	80	-	= $-0.0001x^2$ + 0.1269x + 26.448	0.6867	6.53
ICC, kg	80	-	= $-0.0003x^2$ + 0.3328x + 34.808	0.8581	10.50
Bone, kg	80	-	= $-0.0002x^2$ + 0.2676x + 51.181	0.8203	10.16
CST, kg	80	-	= $-0.0008x^2$ + 1.0824x + 116.078	0.8886	32.95
Percentage of Empty Body Composition					
Blood, %	80	-	= $0.0000002x^2$ – 0.0001x + 0.046	0.3228	0.01
Hide, %	80	-	= $0.0000002x^2$ -0.0002x + 0.107	0.5455	0.01
Bone, %	80	-	= $-0.0000002x^2$ + 0.0001x + 0.148	0.1006	0.01
CST, %	80	-	= $0.0000004x^2$ – 0.0002x + 0.209	0.6057	0.01
Equations for treatment effects					
EBW, kg					
CON	40	-	= $-0.0013x^2$ + 1.7070x + 228.979	0.8982	50.90
REV	40	-	= $-0.0019x^2$ + 1.9911x + 237.077	0.8791	57.56
Hide, kg					
CON	40	-	= $-0.0012x^2$ + 1.6945x + 237.511	0.8949	52.03
REV	40	-	= $-0.0019x^2$ + 1.9978x + 241.984	0.8812	57.73
CST, kg					
CON	40	-	= $-0.00007x^2$ + 0.1055x + 26.078	0.7593	5.32
REV	40	-	= $-0.0002x^2$ + 0.1484x + 26.818	0.6523	7.26

x = DOF

Table 5.8 Linear and quadratic regression equations of chemical composition of carcass and non-carcass components of steers (n = 80) implanted with Revalor XS[1] (REV; n = 40) or control (CON; n = 40) during a serial harvest study (0-378 d on feed) with 10 slaughter dates

Item	*n*	Linear	Quadratic	Adjusted R^2	Root MSE
Hide					
Fat, %	80	-	$= -0.00004x^2 + 0.0221x + 1.677$	0.1993	2.09
Internal Cavity Components					
Protein, %	80	-	$= 0.00005x^2 – 0.0312x + 11.139$	0.7342	0.97
Bone					
Ash, %	80	$= 0.0364x + 23.311$	-	0.2678	3.38

x = DOF

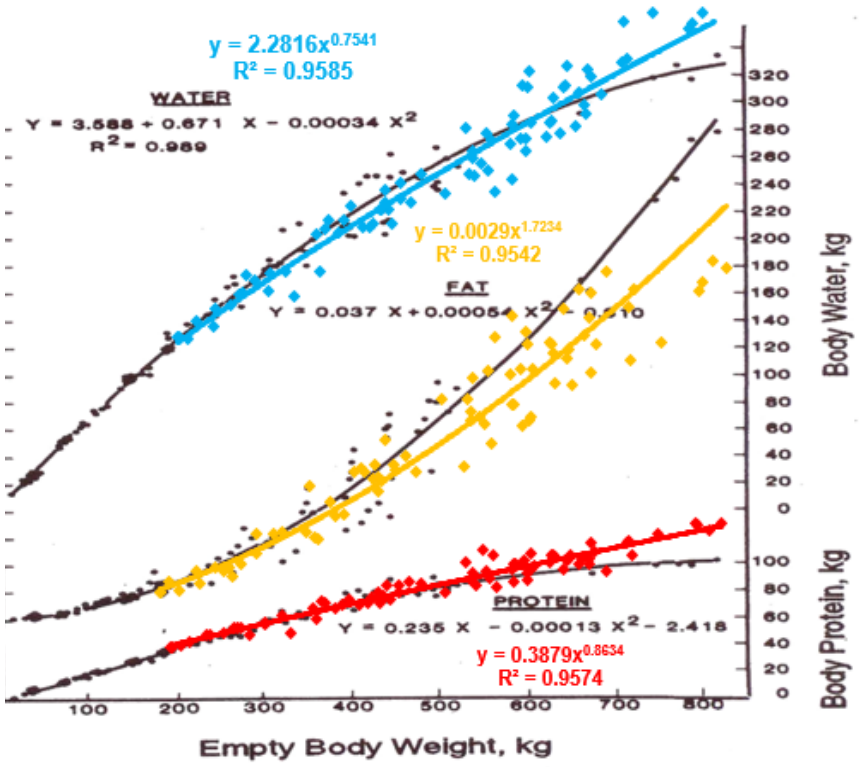

Figure 5.1. Current study empty body weights overlaid with Simpfendorfer (1974) graph with trend lines and power equations.

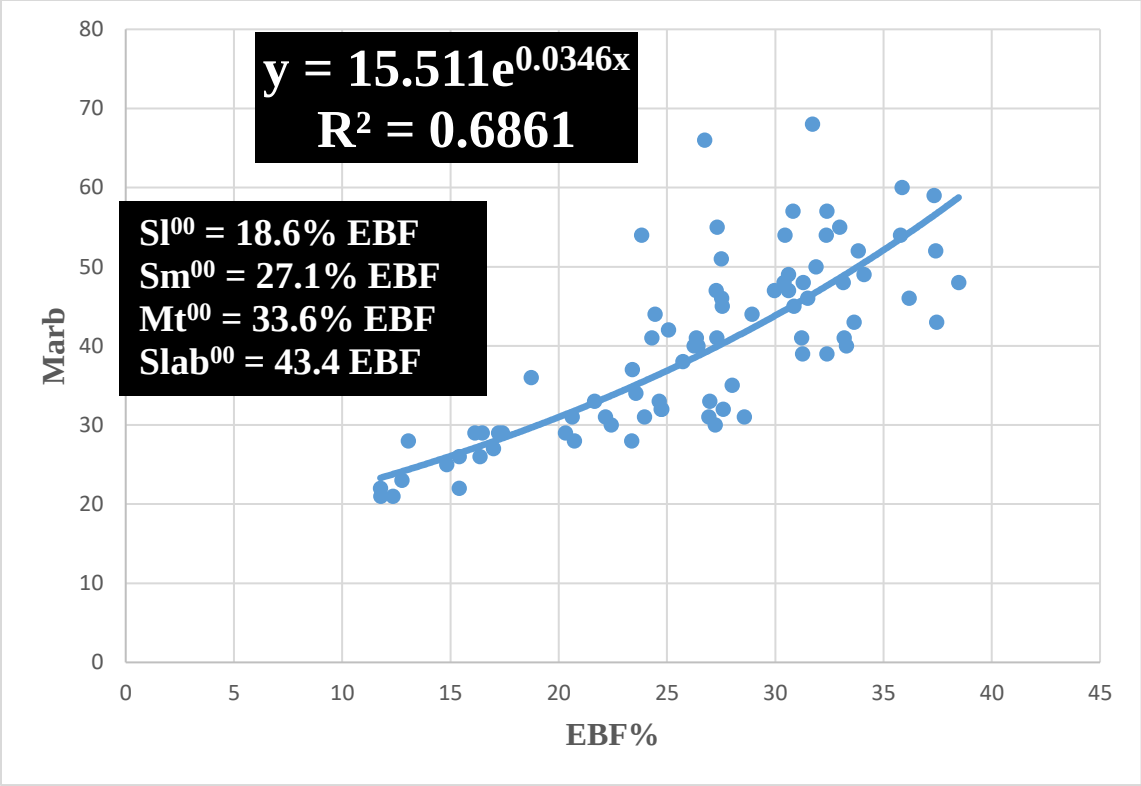

Figure 5.2. Empty body fat in relation to marbling with exponential equation