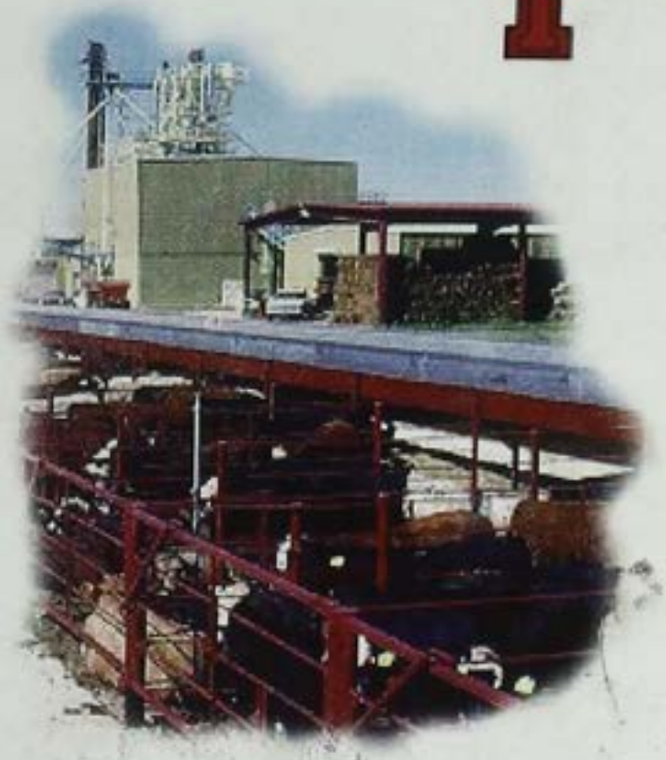
The Composition of Growth in Beef Cattle in honor of Rodney L. Preston, Ph.D.



Texas Tech University
Department of Animal Science and Food Technology

August 2, 1996

Rodney L. Preston

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R.L. Preston received the B.S. degree in Animal Nutrition with High Distinction from Colorado State University in 1953 and the Master and Ph.D. degrees in Animal Nutrition and Veterinary Physiology from Iowa State University in 1955 and 1957. He has served on the Animal Science faculty at the University of Missouri and Ohio State University and was Chairman of the Animal Science Department at Washington State University. He now holds the Thornton Chair and Horn Professorship in Animal Science at Texas Tech University and is the Director of the Burnett Center for Beef Cattle Research and Teaching.

Dr. Preston received the Outstanding Junior Faculty Member Award at the University of Missouri in 1964, an NIH Special Fellowship for research in the Netherlands in 1964-1965, the Texas Tech University, College of Agricultural Sciences Research Award in 1989 and the Texas Tech Dads and Moms Association Barnie E. Rushing Faculty Distinguished Research Award in 1990. He holds honorary memberships in Alpha Zeta, Gamma Sigma Delta, Phi Kappa Phi and Sigma Xi and is listed in American Men of Science. He is a member of the American Society of Animal Science, American Institute of Nutrition, Society for Experimental Biology and Medicine and the Plains Nutrition Council. He was Editor for the Applied Section of the Journal of Animal Science and is a Past-President of the American Society of Animal Science. He served on the NAS-NRC Committee on Animal Nutrition.

Dr. Preston's major research areas area nutrition, body composition and anabolic agents in beef cattle and sheep. He is author/co-author of 101 journal articles, 154 abstracts of papers presented at professional meetings, 11 book chapters and 366 technical/extension reports and popular articles. He has been the major advisor for 19 Masters and 15 Ph.D. students. He served on two AID design or study teams in the countries of Lesotho and Egypt and has lectured in several European countries, the Republic of South Africa, Zimbabwe, Japan, Mexico and Brazil.

The Composition of Growth in Beef Cattle
List of Presentations

Introduction to "The Composition of Growth in Beef Cattle
in honor of Rodney L. Preston".

S. J. Bartle

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I would like to open the symposium with a quote, and a picture. The quote is by a noted Texas Philosopher and goes like this:

> "It's the people that you share life's experiences with and not the experiences that make life special."

I am very honored to share this special experience with Dr. Preston and with the speakers, several of whom are close friends.

The picture (Figure 1, courtesy of the American Hereford Association) is of a champion bull of some time ago. The picture is significant to this symposium for two reasons. First, the gentleman with the pipe is Dan Thornton, noted Hereford breeder, governor of Colorado, and benefactor of the Thornton Endowment at Texas Tech University, and the Chair held by Dr. Preston. The second reason is that the picture was taken in 1952, about the time that Dr. Preston started the road that leads us here today.

Please not the bull; it is obviously very different than the cattle raised today. The next slide is not of a modern bull but I would like you to create in your mind an image of a modern beef bull, compare your image to the bull in the picture, and then please remember that image for later.

I'd like to lughlight some of Dr. Preston's publications. His first scientific publication was entitled "Growth and other physiological responses to diethylstilbestrol in diet of rats and guinea pigs" by Preston, R. L. E. Cheng and W. Burroughs. It was published in 1956. I think that the title of this article illustrates some signature characteristics of Dr. Preston's research throughout his career. These include:

Dr. Preston's pension for statistical designs such as the 2 X 2 X 2 + 2 in the paper to be presented at the upcoming Animal Science meetings probably developed later.

The need to objectively measure the responses to growth promoters and the drive to use simpler tools lead to the development of the urea dilution technique to determine body composition. Prior to urea dilution, determining body composition involved either sacrificing the animal, or the use of expensive and tedious water markers. The first publication on this topic in 1973 (In vivo prediction of body composition in cattle from urea space measurements, Preston and Kock) led to a series of articles seeking to improve and validate urea dilution, and to this speaker running thousand of plasma urea nitrogen's, better know in our lab as PUN's.

One of Dr. Preston's most recent publications (1995) is entitled "Comparative effectiveness of somatotropin and anabolic steroids in feedlot steers." This article and Dr. Preston's 1956 article surround almost 30 years of research in cattle growth. Our understanding of the mechanisms and use of growth promoters has changed as much during Dr. Preston's career as the cattle type (remember your image of the modern bull). I think that it would be fair to say that Dr. Preston's research contribution have been central to the advancement in our understand of cattle growth during the las 30 years and that his work indirectly influenced the change in cattle type too. Today's symposium is a fitting tribute to Dr. Preston's research career.

1. It is straight forward and clear
2. The focus is an applied problem and the underlying biology
3. He used whatever tool was appropriate to answer the question
4. He worked to make complicated questions, simple, not simple questions complicated

I'd like to now move to an area where Dr. Preston takes true pride, his students. Dr. Preston has been the major advisor for 36 Master's and Ph.D. students, served on numerous graduate committees, hosted several visiting scientists, and touched hundreds of graduates and undergraduate students through his teaching. I think that it is significant that when the leaders in the field are gathered to resent a symposium on growth in beef cattle, five o the eleven speakers are former student's of Dr. Preston.

We all learned personal and scientific integrity, to be creative, to work hard (but have fun) and to be individual with our own ideas and approaches. I know that the expectations I have for myself, the way I approach challenges, and the way I relate to other people have all been shaped, in part, by my good fortune of working with Dr. Preston.

Now remember how much cattle have changed during Dr. Preston's career and then try to imagine how much cattle are going to change in the next 30 years. The work of Dr. Preston's students will be instrumental in changing the beef industry and the work of his students will be Preston's true and best legacy.

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[1]Troy Aikman, Dallas Cowboy quarterback after Superbowl win.

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Clinical Trials for the Treatment of Secondary Wasting and Cachexia

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A product largely of the current century, modern body composition techniques provide for the partition of the human body, in a non-traumatic way, into various components; in a manner of speaking, a bloodless dissection. However, the foundation for their use was established earlier, as an offshoot of the 19th century chemists' inquiries into the nature of living things. It was early recognized that young organisms had a higher water content and a lower ash content than the adult. Then Claude Bernard was to announce the concept of "la fixitie du milieu interieur" as a necessary feature for a free and independent life. By the end of the 19th century a number of fetuses and newborns had been analyzed for Na, K, Cl, Ca, P and N, as well as for water and fat. Similar analysis in adults did not come until much later. Figure 1 shows the sequence of events in schematic form.

An important conceptual advance came from Adolf Magnus-Levy, who announced in 1906 that tissue composition is best expressed on a fat-free basis, and so was borne the concept of the fat-free body mass, on which several of the modern body composition techniques are based.

The passing years have witnessed a proliferation of body composition techniques, with the result that we now have a lot of information on its various aspects from infancy through old age. In the tables to follow these will be considered under several categories.

We begin with the two component model, in which the body is divided into lean and fat. The assumption is that the lean body mass, also known as the fat-free mass, has a rather constant composition in mature subjects. Hence by determining the amount of a given constituent, such as water, potassium, or nitrogen present in the body, the magnitude of the fat-free mass (FFM) can easily be calculated. Total body water is determined by isotope dilution (D_2O, tritium, or ^{18}O), total body potassium by assay of ^{40}K, a natural isotope, and total body nitrogen by neutron activation. Body fat is then the difference between body weight and FFM. It has been empirically determined that urinary creatinine excretion and the resistance of the body to a very weak alternating current (bioelectrical impedance) both bear a relationship to the FFM.

Measurement of body density—either by underwater weighing or on land by applying Boyle's law—provides an estimate of both FFM and body fat,

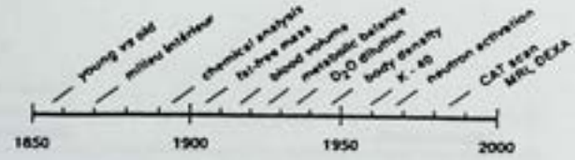

FIGURE 1 Schema of progress in body composition principles and techniques during the last century and a half.

the assumption being that the FFM in mature subjects has a constant density.

Nitrogen balance, by which is meant the intake of N via diet or infusion minus excretion in urine or feces, can be used to estimate changes in FFM. Anthropometry uses a different approach in aiming a an estimate of body fat, where FFM is gotten by subtraction. It principally involves the measurement of the thickness of skin plus subcutaneous fat by means of special calipers (or even by ultrasound). The assumption is that the amount of subcutaneous fat, in the sites chosen for measurement, is proportional to total body fat. Combining skin fold measurements with body weight and certain body circumferences leads to a better estimate of total body fat. Table 1 lists the advantages and disadvantages of each of the above techniques.

We next consider multi-component models of body composition (Table 2). These have been developed in recent years in order to provide estimates of the various components of the fat-free mass, as well as the distribution of the adipose organ. They can be useful in situations where it is likely that the composition of the fat-free mass is altered, so that the simple two-component model cannot be applied.

Of the items listed in Table 2, dual-energy x-ray absorptiometry (DEXA) has found the widest use. While expensive, it is much less so than either the CAT scan or MRI, and the radiation dose is very small, actually less than one receives from a high altitude transcontinental air flight.

The most cumbersome procedure is the last one in Table 2. Various combinations have been used: total body water, total body nitrogen, and total body calcium is one example. It is obvious that this technique is very demanding of equipment and talent,

TABLE 1

Two component models

Technique	Advantages	Disadvantages
Total body water	Little cooperation needed	^{18}O isotope expensive, tritium is radioactive
Body density	Land-based technique Easy and quick *	Underwater weighing difficult in some subjects
Total body potassium	Almost all body K is in ICF	Apparatus expensive, proper calibration required
Total body nitrogen	Almost all body N is in ICF	Apparatus expensive, proper calibration required, some radiation exposure
Nitrogen balance	Small changes detectable	High degree of cooperation, many laboratory analyses needed
Urinary creatinine excretion		Cooperation needed, influenced by diet
Bioelectrical impedance	Easy, quick	Many formulas, poor precision for estimating changes in FFM**
Anthropometry	Easy, inexpensive	Uncertainty ratio s.c. fat/total body fat

* McCrory et al. (1995); Dempster and Aitkens (1995)
** Forbes et al. (1992); Yanovski et al. (1996)

TABLE 2

Multi-component models

Techniques	Advantages	Disadvantages
Dual-energy x-ray absorptiometry (DEXA)*	Estimate of soft tissue, lean tissue, bone and fat	Apparatus expensive radiation exposure
CAT scan	Delineates organ size, fat and muscle distribution, bone size	Instrument expensive radiation exposure
Magnetic Resonance Imaging (MRI)	Delineates organ size, muscle, fat, fat distribution, total body water	Apparatus very expensive
Seratim application of several techniques**	Provides values for total body fat, water, protein and minerals	Much apparatus needed

* Pietrobelli, et al. (1996)
** Heymsfield, et al. (1996)

and there are only a few research laboratories capable of carrying out such an array of prodecures.

Table 3 lists some additional techniques of interest. Body fluid volumes are relatively easy to measure, as is total erythrocyte mass. Total exchangeable sodium and potassium require that radioactive isotopes be given, while total body chloride can be approximated by bromide dilution.

Elemental analysis is performed by total body neutron activation, a procedure requiring elaborate instrumentation and a small amount of radiation.

Metabolic balance can detect *changes* in body content of a number of elements. It cannot estimate total body content per se. It consists of measuring input (food, drink) and output (urine, feces) of the element in question; and while the procedure is very demanding of both investigator and subject (the latter must be both cooperative and compliant) it is capable of estimating changes in body composition with much better precision than any of the other techniques listed here. Moreover, it can be used to study elements such as Se, Pb, and Hg, which cannot be measured by other techniques.

Recently I had occasion to be measured by several techniques over a rather brief span of time, and the resultant estimates of my lean body mass (LBM) are listed in Table 4. Incidentally, I am 81 years old, weighing 80 kg, and am 178 cm tall. As can readily be seen, the first eight assays listed produced almost the same result, the mean being 49.3 kg, SD 0.6 kg (c.v. 1.2%). This sort of variability is what would be expected from repeated assays on a single subject by any one of these techniques. The one aberrant value was generated by bioelectrical impedence (BIA) (arm-leg configuration, single frequency). Although this technique is widely used, it does not accurately reflect changes in body composition induced by diet or exercise (Forbes et al. 1992), and a disturbing feature is that the theoretical basis for the procedure is unclear (Yanovski et al. 1996).

There are a number of other techniques (see Forbes 1987, Roche et al. 1996) which have found very limited use. These books should be consulted for details and fuller exposition of the various techniques listed in the tables. It is obvious that the investigator now has a number of techniques at his/her disposal for making estimates of body composition in living subjects.

TABLE 3

Other techniques

Body fluid compartments—plasma volume, ECF volume, total body water, ICF volume (by difference), erythrocyte mass
Total exchangeable Na, K; total body Cl
Elemental analysis by neutron activation: Na, Cl, P, Ca, N
Metabolic balance—many elements (change in body content only)

TABLE 4

Author's LBM by various techniques

Assay	LBM, kg	Location
K-40	49.7	Rochester
K-40	48.8	N.Y.C.
THO Dilution	50.5	N.Y.C.
Density (under-water weighing)	49.4	N.Y.C.
Density ("Bod-Pod")	49.5	Buffalo*
DEXA	49.1	N.Y.C.
DEXA	49.1	Rochester
Skinfolds, circumferences	48.6	N.Y.C.
BIA	59.2	Rochester
BIA	56.4	N.Y.C.

N.Y.C. refers to St. Luke's Hospital Obesity Research Center, Drs. Richard Pierson, Jack Wang, and Steven Heymsfield.

* Courtesy Mr. John Torine, trainer Buffalo Bills team. The "Bod-Pod" is a new device for measuring body volume on land, by application of Boyle's law.

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Use of Ultrasound to Estimate Body composition

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The Composition of Growth in Beef Cattle
Lubbock, Texas, August 2, 1996

Ultrasound technology may provide a very usable tool to estimate body composition, especially where this information is needed by cattle producers. Particular advantages are that this method is non invasive and can be used on the live animal at any stage of growth. It is rapid, especially when interfaced with computer image analysis techniques for automated measurement so that readings are obtained in near real time. It is not expensive because suitable low-cost ultrasound systems are pervasive in most science departments and a cadre of independent sonographers is emerging.

It is serendipitous that the single measure of subcutaneous fat over the longissimus between the 12th and 13th rib provides and excellent estimate of the fat: lean ration in cattle. There are four elements in the USDA cutability grade equation for predicting retail yield of carcasses: fat thickness; longissimus area; percent kidney, heart and pelvic fat; and carcass weight. Statistical partitioning of variance from those four sources show that at least 70% of the yield grade assignment is from back fat thickness alone. Fat thickness is the attribute that is most accurately measured with ultrasound and least affected by variation among different sonographers. The fat measurement on the live animal with ultrasound is probably much more accurate that that obtained on the carcass in the packing plant because of various disturbances that occur in the slaughtering process – especially in commercial facilities (trimming, mutilation by mechanical hide p8llers, glacier like flow of fat from the thicker deposits over the loin and rump on the hanging carcass during chilling, and expansion of fat after hide removal). Figure 1 presesents the correspondence of ultrasound backfat thickness and that measured on the carcass. While the R squared value is high, it is misleading because of the extreme diversity of the sample. A better measure is the average error; which ought to be smaller than in this set and is usually less among modern cattle that seldom exceed 18mm backfat. The solid line in this figure is the isopleth (one:one) line and the error is calculated as average distace from this line.

A data set that evaluated the utility of ultrasonic backfat measurements was collected in 1992 on 214 steers at the USDA Meat Animal Research Center iat Clay Center, Nebraska. Live animal estimated of subcutaneous fat between the 12th and 13th rib and also over the rump were obtained within a week of slaughter. Eleven diverse sire breeds were represented in this Cycle IV of the MARC gemplasm program. Components of USDA Yield Grade were obtained after a 24 hour chill in a commercial packing plant. The right side of each carcass was transported to the MARC meat laboratory and fabricated into boneless retail cuts trimmed free of fat. Chemical analysis was not performed, but should coincide with the percents fat, lean and bone that were reported.

In Figure 2 is a comparison of models to predict the proportion of trimmed fat on each carcass from elements of the yield grade equation or the ultrasound measures. There was little improvement in model efficiency from adding indicators other than backfat. That is partially attributed to using proportion, rather that total component weight, as the independent variable. Models that predict total weight of a component have R squared values because spurious measures of weight (such as rib eye area) are often used as model elements. The calibration model relating ultrasonic rib fat to percent trimmable fat was
Y= 17.74 + .5584 * backfat (mm).

Predictions from ultrasound rib fat were less accurate than those from carcass backfat. However, adding an ultrasound rump fat measurement to the equation significantly improved prediction accuracy Than may have been affected by the diverse collection of breeds among these steers because there may be differences among breeds in ratio of rib fat to rump fat thickness. Prediction models for proportions of trimmed, boneless lean (Figure 3) had similar R squared values to those for fat (this should be expected because the auto correlation between fat and lean was –0.975). Figure 4 shows individual animal projection in a scatter chart so that the reader can quickly grasp the amount of error in the estimates. The

calibration model used in generating this chart was percent trimmable fat = 13.09 + .8620 * rib fat (mm) - .0157*rib fat^2 + .3072 *rump fat (mm).

Body composition if of interest of the cattle feeder because USDA yield grade, and estimate of body composition, is a dimension in the price matrix for formula pricing. The above discussion documents that backfat thickness is a powerful estimator of yield grade. In addition, feed efficiency is related to composition of gain and feed conversion declined after an animal transfers from a growing to a fattening mode.

Our primary interest has been to predict future body composition, i.e. yield grade, from a single ultrasonic backfat measure upstream in the finishing process. Serial measures of backfat have indicated that and exponential mode ($Y = A * e^{(k * t)}$) best explains the increase in backfat thickness as a function of time during the finishing period. In that model, Y is time in days. This model is easily explained to producers by considering than .7 (logn 2 = .693) divided by the rate coefficient is the doubling time for instantaneous growth.

A difficulty in applying this model is the wide variation in the rate coefficients among individual cattle. Age of maturity as indicated by breed type (frame score ?) has the most apparent relationship to the rate coefficient as shown in figures 5 to 7. In these figures, the sets of serial measures of individual animals were standardized by shifting them on the abscissa to their appropriate location on the curve. Steers (origin was unknown) were partitioned into the three groups by multivariate factor analysis with estimated breed, weight, and visual frame score as some of the vectors. The figures show how early maturing cattle fatten at a much faster rate and reach a compositional end point much sooner than late maturing cattle.

The rate equations are functions of chronological days. The charts would tend to coincide and differences in rate coefficients become smaller if time were scaled to physiological age of each animal. This is apparent in Figure 8. This figure synthesizes the relationships of ultrasonic backfat thickness and live weight, but that may be valid only for those cattle that have enjoyed a lifetime of unrestricted feed intake. More information is neeed about allometric growth of fat tissues after nutritional restriction.

A component of body composition very important to producers is intramuscular fat (marbling). There is little information on the development of this depot because of the enormous expense of serial slaughter, which yields only one estimate per animal. Our laboratory has developed a system to estimate intramuscular fat in live animals which may have sufficient accuracy to enable tracking marbling in live animals. Figure 9 shows that the method can project marbling scores with an average error of .4 marbling score unit (probably slightly greater than variation among graders who call marbling scores from subjective visual assessments). We made serial measures at about 30 day intervals in a sample of 338 steers that were fed a finishing ration. That allowed 3 or 4 estimates per animal so that individual marbling rates could be generated. Figure 10 shows the distribution at slaughter in marbling classes among the steers used in the tracking study and confirms that there was diversity in this study comparable to that function of time. The average of 100 days to increase marbling one step – much slower than most feeders would have anticipated.

There was a large amount of variation in the individual rate coefficients (Figure 11) in that a few steers made a step increase in 40 or 50 days, while others barely increased marbling during the course of the experiment. About half the variation in rate coefficients was related to the mean marbling level of each steer; animals with more marbling increased at a faster rate. The results suggest that extended feeding does little to enhance marbling and improve quality grade. Figure 13 shows that there was little correlation between carcass marbling score and sequential filling of fat depots so that intramuscular fat follows intermuscular and subcutaneous fat and also fails to support contentions that there are strong genetic and phenotypic correlations between backfat thickness and marbling.

In conclusion the correlations between ultrasonic backfat measures and carcass compositions appear high enough to favor exploiting this technology. Where a high number and frequency of estimates are needed and low cost is an important consideration, ultrasound may be the most feasible method. It

appears likely that ultrasound will be especially cost effective in those commercial applications where knowledge of present and future carcass composition of the live animal is important.

USE OF DILUTION TECHNIQUES TO ESTIMATE BODY COMPOSITION IN CATTLE

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A manuscript prepared for the Rodney L. Preston

retirement symposium:

The Composition of Growth in Beef Cattle

INTRODUCTION

Understanding the compositional changes that occur in growing beef cattle is important to nutrition, production, and marketing of beef animals, and represents an important concern in beef cattle growth research. Indirect methods to estimate body composition have included measurement of specific gravity (Kraybill et al., 1952), as well as body water. It was reported early on that total body water and total body nitrogen are highly correlated with fat-free body weight in guinea pigs (r^2=.99, n=50; Pace and Rathbun, 1945). These authors also concluded that the water content of the lean body mass is 73.2%, and should be a reasonable estimate for most species of mammals. Several simple equations for calculating percentage of fat and water were reported from this work (Pace and Rathbun, 1945):

$$\% \text{ fat} = 100 - (\% \text{ water}/.732),$$

$$\% \text{ fat} = 100 ((5.548/ \text{ sp.gr.}) - 5.044),$$

and

$$\% \text{ water} = 100 (4.42 - (4.061/\text{sp.gr.})).$$

Thus, the mathematical concept of the relationship between body water, fat, and body specific gravity has been within the literature for over 50 years.

Determination of body water allows for calculation of protein and of fat, the latter component being negatively associated with water because fat acts to dilute body water (Pace and Rathbun, 1945). Desiccation of the entire body was the earliest method of determining body water (Mitchell et al., 1945). This method has obvious disadvantages. Use of dilution techniques to estimate the volume of body water compartments was first reported by Gaudino

(1949). This technique involved intravenous injection of a single bolus of a known amount of substance, and then analyzing a blood plasma sample taken before injection and after the substance has been uniformly distributed within the body water. An early review of this subject was published by Levitt and Gaudino (1950). The simple nature of this concept is illustrated by the equation for calculating body water (Levitt and Gaudino, 1950):

$$V = Z/C$$

where

"V" is the volume of the compartment,

"Z" is the amount of substance injected,

and

"C" is the concentration of substance in blood after distribution.

This simple mathematical representation has been the basis for most attempts to use dilution techniques to estimate body composition in cattle. With current availability of statistical software, more rigorous computations than the formula above have been introduced to this field.

This review will include discussion of several substances including deuterium, tritium, antipyrine, and urea. Much of the recent literature (last 23 years) on urea dilution in beef cattle has been published by R.L. Preston and his co-workers, as well as by students of Dr. Preston. Most of this review will be dedicated to discussion of urea space and its use and validation for estimation of body composition in cattle.

USE OF LABELLED WATER TO MEASURE BODY WATER

Several substances were evaluated for use in dilution experiments. It was recognized that

appropriate materials must fulfill certain criteria (Levitt and Gaudino, 1950). The substance must be: 1) rapidly and uniformly distributed; 2) non-destructive and non-formative; 3) without influence on body water distribution; 4) slowly eliminated; 5) non-toxic; and 6) accurately and easily determined. Several materials were indicated as appropriate for body water determination by dilution. Deuterium oxide was recognized as a suitable substance because it is biologically and chemically similar with water, and non-toxic (Hevesy and Hofer 1934). Deuterium dilution was investigated in humans (Moore, 1946), guinea pigs (Flexner et al., 1942), and the rabbit (Hevesy and Jacobsen, 1940). Tritiated water also fit these criteria, and had also been evaluated for use in determining body water (Pace et al., 1947). McManus et al. (1969) reported tritium space and total body water in rabbits to agree to within 2.3% during normal growth and nutrititon. However, during rapid growth, induced by compensatory gain that followed under nutrition, tritium space overestimated total body water by 12%.

A number of studies on use of deuterium oxide to estimate body composition in cattle have been published recently (Byers, 1979; Robelin, 1982; Odwongo et al., 1984; Arnold et al., 1985; Andrew et al., 1995). The work of Byers (1979) expanded the simple dilution model to develop a two pool model wherein the distribution curve of deuterium oxide was used to estimate both water of the gastrointestinal tract as well as empty body water of beef cattle. This model involves extrapolation of the rapidly equilibrating pool to estimate the intercept, which is considered the empty body water. Total body water is then calculated from the intercept of the slowly equilibrating pool. Estimates of water loss through feces, urine, and milk (if animals are in lactation) are also included. Gut water is calculated as the difference between total and empty body water. Arnold et al. (1985) evaluated this model as well as a three compartment model

(the third compartment was extracellular water) using 30 crossbred beef steers, 15 large- and 15 small-frame, with five each slaughtered at 6, 12, or 18 mo of age. These authors reported that the two pool model did not improve estimation of body water over the one pool model. Accounting for gastrointestinal tract water apparently was quite difficult, and incorporating further regression equations to compensate for errors introduced even more error into the estimations. Mathematical representation of water content of the gastrointestinal tract are subject to numerous errors because of gut fill differences due to diet composition, which influence rate of passage and water intake. Also, the interaction of diet with ambient conditions and possibly breed of cattle would influence this estimation.

Dunshea et al. (1990) suggested that gut fill in growing beef cattle would be small and proportionate to body weight which would limit the usefulness of the two pool model under the conditions reported by Arnold et al. (1985). These authors also indicated that lactation causes greater variation in feed intake which increases the usefulness of the two pool model. By using a two pool tritium dilution model, Dunshea et al. (1990) were able to account for body fat losses during lactation in goats which also coincided with increased dry matter intake and gut fill. Andrew et al. (1995), however, were unable to determine gut fill from the two compartment model, even when variation in dry matter intake and gut fill were acounted for by their direct measurement.

An important observation reported by Arnold et al. (1985) was that the one pool model accurately predicted differences between cattle types in empty body protein, water, and ether extract. For example, these authors reported 67.9% water for large-frame steers at 6 mo of age, and 63.8% water for the small-frame, 6 mo old steers when water was measured directly.

Water predicted by the one compartment model resulted in 67.6% and 62.0% water for the large- and small-frame steers, respectively. The similarity in difference between large- and small-frame steers with respect to water was also the case for protein and ether extract.

Predicting body water by using a dilution technique has been the primary objective of these studies. However, accurately predicting a difference in composition or a change in composition over time is an extremely important research tool. Validation of equations developed from dilution studies also must be done if their usefulness is to be established. As indicated above, Arnold et al. (1985) were unable to validate results of other studies when similar models were applied to a different population of cattle. Odwongo et al. (1984) developed prediction equations from deuterium dilution of dairy cows that included some cows that were growing, as well as some in lactation. Total body water estimates were influenced by growth in young animals, and by lactation in older animals. Brown et al. (1989) overestimated empty body fat in a separate group of dairy cows when equations of Odwongo et al. (1984) were used. Andrew et al. (1995) validated prediction equations from deuterium dilution of dairy cows when equations were tested by using cows from the same population. Similar deuterium dilution validation studies with dairy cows were recently reported (Crooker et al., 1996; Weber et al., 1996).

Tritium dilution has likewise undergone evaluation for estimation of body water in cattle. A number of studies have been published that report regression equations for prediction of body components (for example, Little and Morris, 1972; Little and McClean, 1981; Sheng and Huggins, 1979; Bird et al., 1982; Meissner et al., 1980a,b,c). Panaretto (1963) used tritium space to accurately predict composition of sheep and goats after previous observations that

tritium space was unbiased compared with antipyrine space (Panaretto and Till, 1963). Searle (1970) later determined that tritium space could be used to predict composition of sheep from 3 d of age through adult animals. Turnover of water and tritium-hydrogen exchange before equilibration would cause an overestimation of body water (because tritium concentration is the denominator in a one pool model); however, regression equations, for example, those reported by Bird et al. (1982), corrected for tritium loss. This may suggest that tritium turnover and exchange are reasonably constant. As indicated above, Dunshea et al. (1990) sucessfully used tritium dilution to account for losses in body fat in goats during lactation.

Although deuterium oxide and tritium oxide space provide accurate estimates of body water, they offer several important disadvantages. First, routine use would be expensive, especially in serial trials with large numbers of cattle. Second, equipment required for water recovery and analysis can be extensive, and prohibitive under most budgetary constraints. Finally, tritium waste disposal would make this compound even more difficult to justify using, especially with large numbers of animals. Alternatives to deuterium and tritium oxide include several solutes that have been shown to be effective in estimating body water.

USE OF ANTIPYRINE TO ESTIMATE BODY WATER

Several solutes were considered for use in dilution experiments, including urea, thiourea, sulfanilamide (Levitt and Gaudino, 1950) and antipyrine (Kraybill et al., 1951; Panaretto, 1963b). The latter compound was used by Soberman et al. (1947) in dilution studies to estimate body water in humans, and later by Kraybill et al. (1951) to estimate body water in cattle. Antipyrine (1,5-dimethyl-2-phenyl-3-pyrozolone) is an analgesic and antipyretic drug. In the study of Kraybill et al. (1951), 30 cattle, made up of 24 yearling Hereford steers and six

crossbred cows and heifers, were used. Cattle ranged in body weight from 227 kg to 555 kg; differences in body fat content were produced by feeding low- and high-plains of nutrition. Antipyrine space was used to estimate body water and the chemical composition of the 9-10-11 rib section. Complete distribution of antipyrine in body water occurred in 2.5 h (straight line of log of antipyrine concentration (x) vs. h after injection (y)). The ratio of tissue water to serum water was nearly 1:1 (tissues analyzed were liver, spleen, muscle, heart, lung, and serum). Specific gravity of the viscera, carcass, and whole animal was determined and the body water calculated from specific gravity by the procedure described by Rathbun and Pace (1945). Body fat was then calculated from body water. Results of this early study indicated that body water calculated from specific gravity or by antipyrine dilution (respectively) were in close agreement: 51.9% and 52.2% (± 2.1%, SE) for the six crossbreds, and 54.1% and 54.4% (± 1.2%) for 24 Hereford steers. Carcass fat determined by ether extract or calculation from body water data also were in close agreement, but this should not be surprising because antipyrine space and specific gravity estimates of body water were in close agreement. However, when separable fat percentage was plotted against percentage body fat calculated from body water determined by antipyrine space, a slope near unity with a zero intercept was apparent.

Panaretto and Till (1963) evaluated antipyrine, N-acetyl-4-aminoantipyrine and tritiated water dilution in goats. Fat-free empty body water of their goats (73.8 %) was similar to other species. Antipyrine space underestimated body water of the goats by 4.4% of the live weight whereas tritiated water overestimated total body water by .8%. N-acetyl-4-aminoantipyrine underestimated total body water by 6.3%. These authors concluded that antipyrine space and N-acetyl-4-aminoantipyrine space biased estimates of total body water, but the nature of the bias

was not discussed. Moreover, Reid et al. (1963) concluded that antipyrine space was not an accurate enough predictor of body water to warrant further use. Although these two compounds meet most of the criteria for a dilution marker, they also represent a foreign substance to the animal, and metabolism of the drug can be rapid in cattle (Kraybill et al., 1951).

USE OF UREA TO ESTIMATE BODY COMPOSITION

Urea was considered a potential marker for dilution studies, but it was dismissed early (Levitt and Gaudino, 1950) because of the Ralls (1943) conclusion that urea did not diffuse evenly within plasma water and intracellular water of blood cells. Ralls (1943) reported a 1.14:1 ratio of urea in red blood cells to urea in plasma water of 66 human blood samples. At the time, no mechanism was known, but the author suggested that a urea-hemoglobin complex was possible, which at steady state, could result in a slightly higher concentration of urea in the red blood cells. If this is the case, then the conclusion of unequal distribution becomes tenuous because development of such a complex could occur during equal distribution of non-complexed urea. Moreover no suggestion of such complexes in cells of other tissues was given.

As pointed out by Preston and Kock (1973), urea dilutes and equilibrates in blood and tissue, and could be used to estimate body water. Furthermore, urea meets the criteria established for appropriate marker substances indicated by Levitt and Gaudino (1950), including not being a foreign substance to the body. Also, urea analysis is accurate, convenient, and economical. San Pietro and Rittenberg (1953) calculated similar body water values in humans when urea space and deuterium oxide space were used indicating the potential of urea as a body water marker. In sheep, urea space and tritium space predicted body water and body fat with similar accuracy (Meissner, 1976). However, urea space and deuterium space did not agree

when applied to dariy cows (Andrew et al., 1995).

Preston and Kock (1973) compared urea space calculated from plasma urea concentrations of blood samples taken 9, 12, and 15 min post infusion of 130 mg urea/kg body weight of 12 steers. Empty body fat was accurately predicted by urea space (percentage of live weight) as indicated by the correlation coefficient of -.96. Live weight was highly correlated with empty body fat for the 12 steers, but urea space was more highly correlated than live weight when the heavy weight steers were evaluated. In this study, empty body water was underestimated by urea space. However, empty body water and fat were calculated from carcass specific gravity, and not by direct chemical analysis. Error in estimation of body water could be reflected in the error in urea space estimation in body water. On the other hand, the underestimation of body water might also suggest that urea had not completely distributed into the body water.

In subsequent work by Kock and Preston (1979), urea space, calculated from urea concentration measured in plasma from blood sampled at various times post infusion, was determined in 113 beef steers, and the relationship to rib soft tissue composition and carcass specific gravity evaluated. Plasma urea nitrogen from 12 min samples resulted in urea space estimates that were the most highly correlated with rib composition and carcass specific gravity. Correlation coefficients of .84, .73, and -.84 were observed for regression of urea space (12 min) on water, protein, and fat, respectively, of the rib. It was also determined in this study that carcass specific gravity was less accurate a predictor of composition than urea space in thin or very lean cattle.

The time from infusion to sampling used by Koch and Preston (1979; 12 min) was similar to that used by Meissner et al. (1980a; 10 min). In the latter study, urea space

regressed on empty body water resulted in a slope of 1.07 and a zero intercept. However, including body mass in a multiple regression equation decreased the standard error of the estimate and the 95% confidence limits by nearly half. The same response to inclusion of body weight occurred for prediction of protein and fat. Also, neither urea space or tritium space were reliable predictors unless body weight was included. These authors concluded that more than one measurement of body water should be done to improve estimation of body composition.

Live weight alone was shown to be an effective predictor of body composition in cattle (Meissner et al., 1980a). This also was the case in a study reported by Jones et al. (1982). Also in the study by Jones et al. (1972) urea space (mass) was not highly correlated with half carcass lean weight in cows (r=.74). Live weight was correlated a little higher than urea space (mass) with lean weight (r=.79); however no improvement in regression coefficient was observed when live weight and urea space were combined.

As pointed out by Bartle et al. (1983) body weight in mature cows is not an appropriate indicator of body composition because of pregnancy and lactation. However, Waltner et al. (1994) found body weight to be a better predictor of fat than deuterium space in lactating dairy cows. Bartle et al. (1983) evaluated urea space as a marker for estimating composition of mature cows. Urea space (percentage of live weight or empty body weight) was used to develop prediction equations based on 9-10-11 rib section composition and carcass specific gravity. Urea space as a percentage of empty body weight was correlated to a higher extent than when urea space was expressed as a percentage of live weight, indicating that gut fill contributed significantly to error. Greater accuracy in prediction of fat in beef cows compared with dairy cows was observed; greater internal fat was thought to contribute to this error. Bartle et al.

(1983) concluded that groups of cows, rather than individuals, be used to determine comparisons in body composition in cows.

A hallmark investigation into urea space as a predictor of body composition in beef cattle was published by Hammond et al. (1984). In this study, 68 mixed-breed and 50 Angus steers (210 to 517 kg live weight) were used to determine urea space, and then slaughtered and carcass chemical composition determined. Urea space, both as mass and percentage of live weight, were highly correlated with empty body water. Moreover, slopes and intercepts reported by Hammond et al. (1984) were similar to those reported by Preston and Kock (1973). Live weight also was highly correlated with empty body water (Hammond et al., 1984), but this observation would not be unexpected because of the numbers of animals used and the range in body weights represented. In Holstein steers, however, urea space was far less correlated with body water, and little benefit of urea space over body weight was observed (J.L. Morrill, personal communication).

The potential for urea to distribute into the rumen would result in over estimation of empty body water and underestimate total body water. Bartle and Preston (1986) reported no increase in rumen NH_3-N for 120 min. post infusion of urea in the blood, and the ratio of rumen fluid ^{15}N to plasma ^{15}N increased from 0 to .08 in 30 min. This indicated that negligible urea entered the rumen fluid pool during the short equilibration time into the empty body water. On the other hand, the urea concentration of urine increased and then equilibrated at nearly the same time as the plasma pool after urea infusion. These authors concluded that urea dilution at 12 min overestimates empty body water by the volume of urine produced in this 12 min period.

Numerous prediction equations have been developed for estimation of body composition

using urea space. The equations published by Hammond et al. (1984) and Kock and Preston (1979) were in good agreement. However, validation of published equations is needed to establish their utility in the same or different populations of cattle. Rule et al. (1986) reported results of a detailed statistical evaluation of numerous prediction equations in which urea space was expressed as a percentage of body weight or as mass. To accomplish the evaluation, 28 crossbred beef steers were slaughtered at either 6, 12, or 18 mo of age, and empty body water determined directly. Prediction equations published by Preston and Kock (1973), Meissner et al. (1980a), and Hammond et al. (1984) were evaluated. By using urea space as a percentage of live weight determined in the 28 test animals, prediction of percentage empty body water was from .3% to 4.4% for the 6 mo old steers for three of four equations. For the same three equations empty body water was estimated from .4% to 5.2%, and 2.4% to 8.0% of directly measured values for the 12 and 18 mo old steers, respectively. The equations published by Preston and Kock (1973) resulted in 1.5% overestimation, 2.2% underestimation, and 6.4% overestimation for the 6, 12, and 18 mo old steers, respectively. It is interesting to note that this equation was determined as urea space regressed on empty body water that was calculated from specific gravity, and not direct chemical determination.

Seven equations were evaluated for prediction of mass of empty body water. Calculated values nearest the directly measured values were from equations in which live weight was included with urea space in a multiple regression equation. A substantial effect of live weight is not uncommon in studies where rapidly growing cattle are used to develop equations. Further evaluation of slopes and intercepts of estimated vs. directly measured empty body water (MacNeil, 1983) revealed that all four equations predicting percentage empty body water from

urea space were valid, but only three of seven equations predicting mass of empty body were valid according to this approach.

A subsequent validation study was reported by Bartle et al. (1987) in which Hereford x Angus steers and heifers, and fullblood Chianina steers and heifers were used. In this study, a similar approach to that taken by Rule et al. (1986) was reported except that carcass specific gravity was measured and composition calculated. Good agreement was observed when urea space values were used in several published equations. For example, when empty body water of the cattle (calculated from specific gravity) was plotted against empty body water calculated from an equation published by Hammond et al. (1984), a slope of .98 and an intercept of 1.5 was observed (r^2 = .67). The work of Bartle et al. (1987) did not demonstrate a consistent influence of live weight on empty body water. In contrast to data reported by Rule et al. (1986) and Hammond et al. (1984), who reported r^2 values of .84 and .68, respectively, for regression of live weight on percentage empty body water, Bartle et al. (1987) observed r^2 values of .07 for all cattle, .70 for Hereford x Angus cattle, and .35 for the Chianina cattle. Bartle et al. (1987) indicated several important points regarding this observation. The mass of body components increases during growth, but not in direct proportion, and, depending on breed or mature size of cattle, not in the same proportions as in other populations of cattle. Thus, calculating amounts of body water, fat, or protein from percentage values would be the most appropriate approach (Bartle et al., 1987).

The study of Bartle et al. (1987) also attempted to relate urea space to lean composition of the round. On a fat-free basis, urea space values predicted empty body water at 75% and protein at 22%. Combined with previously reported ash values of 5%, urea space accounted

for, and therefore, was related to lean body percentage.

These authors also discussed problems associated with variation in gastrointestinal tract fill. Regression equations can be influenced by gastrointestinal tract fill because live weight is included in calculation of urea space: in the numerator because the amount of urea infused is dependent on live weight, and in the denominator if urea space is expressed as a percentage of live weight. Thus, if serial dilutions are to be done on the same animals, standard procedures for shrunk weight or consistent full weights should be implemented. If terminal dilutions are to be done, then some means of estimating gut fill in the slaughtered cattle should be implemented to reduce this variation.

CONCLUSIONS AND FUTURE DIRECTIONS

Dilution techniques for estimation of body water have been developed to calculate lean tissue mass and carcass fat in meat animals. Use of water in the form of deuterium oxide or tritiated water was shown early on to represent body water with a high degree of accuracy, but rapid growth and lactation were shown to influence estimation of body water. The length of time needed for equilibration and the equipment needed for analysis has made these techniques less desirable than techniques that employed the distribution of a solute, for example antipyrine or urea. A substantial body of literature has emerged on use of urea dilution to estimate body water, as well as to relate mathematically to fat and protein. The early work on urea dilution with cattle established the potential of this solute for use in dilution studies. Later work established relationships with larger numbers of cattle and composition measured directly. The most recent work has validated the technique by evaluating equations established in these trials. Not all studies have reported high correlations between empty body water and urea space.

Potential problems include breed, gut fill, and urinary losses of infused urea.

Subsequent to the aforementioned validation studies, investigation into the accuracy with which urea space can predict differences in composition are needed. Recently, a phenotypic mutation in sheep was discovered, the callipyge, which is characterized by heavy posterior muscle (Jackson et al., 1992; Cockett et al., 1993). At growth rates similar to normal lambs, the callipyge are capable of markedly different composition. For example, Khoomarie et al. (1995) observed callipyge carcasses to contain 27% more total muscle and 29% less fat thickness than normal lambs of similar breeding but with the callipyge gene. The callipyge lambs contained 4% less mass of internal organs and viscera. Thus these lambs differ from normal lambs primarily in fat and lean. Fed similar dietary regimens, normal and callipyge lambs may be a useful tool to determine if urea dilution accurately predicts changes and differences in body water and body composition. A final suggestion on utility of urea dilution is in its potential to determine changes in composition when the animals are losing body condition, for example, cows or ewes living on range conditions.

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Compensatory Growth

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Introduction

Several excellent papers summarize observations on compensatory growth and its relationship with body composition. A general overview of compensatory growth in ruminants by Hogg (1991) is valuable reading. Symposium proceedings by Reeds and Fiorotto (1990) and Jackson (1990) provide important perspective by scientists studying the similar concept of catch-up growth in man. Reid et al. (1968) provided the basis for my own biases regarding concepts of growth as did the benchmark studies in cattle by Fox et al. (1972) and in rats by Ferrell and Koong (1986). The reader new to this subject should be reminded of earlier publications by Moulton (1923) and Winchester and Howe (1955) that were the foundation for more current research.

Considering the wealth of noteworthy information already in print, an attempt at providing new knowledge becomes humbling. A more achievable goal would be to make an effort to meld existing information into a compatible description of growth and its manipulation. In doing so, some excellent publications on this subject will be beyond the scope of this essay. My apologies to those authors and to the researchers that will yet need to ferret out those publications.

Rest assured this is not a cop out. In the context of this symposium, it seemed more appropriate to take some liberties with the subject. If you have spent any time in discussions with Dr. Preston, you are aware of his keen interest in the relationships between growth patterns and body composition. Spend a little more time with him and you are impressed that this interest has spanned decades and that he can draw upon a wealth of observations throughout the entire time. Some of the results are published, some are only notebooks, much is of his own doing but always the respected works by others come into the conversation. Spend a few years with him and you will become deeply intrigued by the subject and will formulate your own insights. The seeds of those insights were planted and cultivated by Rod. It seems fitting to reflect the results of his mentoring in this essay.

A Definition for Growth

Before we can delve into compensatory growth, we need to establish the criteria that relate to normal growth. The definition and measurement of growth are interpreted variously in the literature. I propose the definition of growth as being the increase in dimensions or accumulation of mass over time as an organism proceeds toward chemical and cellular maturity. It seems fair to assume that the growth process (i.e., typical growth and development of an individual) is set at conception by the incorporated genetic code. Within this genetic coding,

there is an inherent timeline for development. Jackson (1990) refers to a growth channel which infers some allowable variation in growth and development. Benchmarks of physiological development such as puberty are dependent upon age, mass, and chemical composition of the body.

Apparently there is some form of inherent chronometer that makes time an undeniable factor in the growth process. Most likely the time component comes from the cell maturation processes within the organism. This is compatible with existing information if we allow that the rate of cell maturation is influenced by the plane of nutrition but cannot be accelerated by excessive caloric intake. As part of this timeline, there is a prioritization of tissue development and preservation. The highest priority goes to the central nervous system followed in order of priority by skeletal and connective tissue, visceral organs, skeletal muscle, and adipose (Wilson and Osbourn, 1960). Besides the prioritization of nutrient partitioning, there are differences in the coefficients of allometric growth assigned to the various tissue systems.

Skeletal muscle represents the greatest mass change associated with growth and coincidentally is our primary economic concern. Miller (1969) pointed out that in rats skeletal muscle increases from 23% of body mass at birth to 45% of body mass at maturity. Similar changes occur in cattle and growth coefficients for lean tissue have been established. The allometric rate of protein accretion is relatively constant across varying caloric intakes (Fortin et al., 1980) or among frame sizes of cattle (McCarthy et al., 1983).

The flexibility in growth and development by mammals is provided by adipose tissue. Generally, fat is overlooked as an essential component of growth, but Preston (1971) argued that fat should be considered a part of true growth. Indeed, body fat levels necessary to attain puberty and to maintain reproductive function are indicative that adipose tissue growth is required and must be accommodated in normal growth.

Normal growth is probably better characterized in unselected species. By selecting for appetite and a propensity to fatten, the nature of the normal growth curve for cattle becomes obscured. Wild ruminants tend not to fatten prematurely and are not willing (or able) to achieve excessively high body fat content once mature size is achieved. Normal growth rate seems like a simple concept but upon consideration becomes extremely difficult to define. There are some benchmarks we can use. Body fatness as a proportion of body weight begins at 4 to 6% at birth, reaches 14 to 16% at puberty, and approaches 28 to 30% in Choice steers. Postweaning lean gain can achieve 1.0 to 1.15 kg/d (Fox and Black, 1984) but will plateau as animals approach their mature lean body mass (Moulton, 1923). Bone growth continues at a steady rate until puberty is attained but will continue for years in cattle castrated prior to closure of the epiphysis. As long as nutrient and caloric intake are available sufficient to meet the needs of each of these anatomical components, growth proceeds in an orchestrated harmony. In these normal conditions, body composition and production efficiencies are similar among individuals once corrections are made for relative mature size.

Discontinuous Growth

If the nutrient or especially the energy intake of a mammal is insufficient to support normal growth, mechanisms are engaged to conserve life. The influence on tissue accretion works in reverse of priorities for growth. Adipose gains are influenced first, then skeletal muscle, and eventually visceral organs. Influences beyond this threshold will result in the permanent stunting of growth. Ferrell and Koong (1986) demonstrated tissue prioritization in young rats (Table 1). The moderate caloric intake group continued to deposit lean tissue while depositing no additional fat. When caloric intake was below maintenance, the gram daily loss of fat was nearly twofold the loss of protein. Organ mass (liver, heart, kidney, and gut) was lower in low caloric intake rats even after realimentation. Ferrell et al. (1986) demonstrated similar results in sheep. In both studies energy expenditures for maintenance were reduced by restricted feeding.

Table 1. Empty body gains by male rats with varied caloric intake[a]

	Level of caloric intake		
	H	M	L
Empty body gain, g/d[b]	4.50	1.62	-.97
Fat gain, g/d[b]	.49	.00	-.16
Protein gain, g/d[d]	1.12	.52	-.09

[a]From Ferrell and Koong (1986).
[b]$P<.01$.

At this point, I should identify generalizations I have drawn from the collective literature on changes in body composition during discontinuous growth. Foremost is the idea that shifts (positive or negative) in accretion rates by skeletal muscle and adipose tissues include considerable overlap. One tissue is not mobilized or conserved exclusive of the other. This makes sense if the affinities for nutrients by cells of various tissues are not too dissimilar, if blood chemistry is maintained within normal physiological ranges, and nutrient uptake is the limiting factor for tissue growth. Insulin sensitivity and hexokinase system differences between tissue types could account for much of the priority that exists in the tissue beds being considered and excludes any, all, or none relationships.

The impact of discontinuous growth on the body will be impacted by the magnitude of the deviation from normal and the duration of the malnourished experience. When reviewing the literature, it is necessary to make a critical evaluation of the control and treatments and how they relate to a theoretical growth channel for the test subject. Since cattle are willing to consume a great deal of ME in some forms of feed, control groups may be growing at the upper limits of normal. Caloric intake restrictions imposed upon treated subjects may cause significant differences in production rates without creating truly discontinuous growth. In these circumstances, time would not impose any additional influence and true compensatory growth would not be expressed. Hogg (1991) points out this situation will create a recovery of weight-for-age that is not compensatory growth.

Compensatory Growth

Compensatory growth includes two primary production characteristics. The DMI of compensating animals is greater than for normal animals of the same BW. There is a concurrent reduction in the feed required per unit of gain. From the scientist's perspective, fasting heat production is lowered following discontinuous growth by virtue of the reduced mass of high metabolic rate organs and possibly other metabolic adjustments to low caloric intake. The reduced ME required for maintenance and the heightened DMI would cause a dramatic increase in ME available for gain.

The apparent efficiency of ME use for gain is improved. This is generally related to chemical and consequently caloric content of gain in compensating mammals. The heat of combustion for lean tissue and adipose tissue of 1.62 and 9.50 kcal/g, respectively (derived from Reid et al., 1968), make it clear that, if the composition of gain is altered by discontinuous growth, the ME required for gain would be altered.

At this point evaluations of compensatory growth become a messy affair. Mammals exhibiting normal or discontinuous growth vary in age or weight. When refeeding, DMI (g/kg $W^{3/4}$) is typically different. These confounding factors can lead to misunderstandings and create a confusion of information. The situation becomes even more clouded since the window of observations used relative to when compensatory growth actually occurred can markedly influence interpretations. If observations are concluded prematurely, it appears that body composition has been altered. If observations are averaged over too great a time window, the true compensatory growth phase can be lost in averages.

Fox et al. (1972) observed an increased percentage of gain as protein in compensating steers up to 341 kg BW. From 341 kg through 454 kg BW, composition of gain and final empty body composition converged. Turgeon (1986) described a similar phenomenon in sheep and pointed out how crucial BW was when making observations on the various aspects of compensatory growth. Rompala et al. (1985) observed elevated rates of protein deposition in compensating steers at 200 and 250 kg BW but noted no differences at heavier body weights. Carstens et al. (1991) observed accelerated protein gains and unchanged rates of fat gain during compensatory growth. Fat components of the empty body were altered at 450 kg BW from 32% in normal to 24% in compensating steers. A mechanism for increased protein accretion with limited fat accretion was provided by Yambayamba et al. (1996) in an evaluation of the hormonal changes associated with compensatory growth. They noted that 10 d following realimentation compensating steers continued to have elevated serum levels of somatotropin. Elevated somatotropin in the presence of adequate energy is generally recognized as a heightened anabolic state.

In our effort to evaluate compensatory growth, Alderson (1994) observed that the proportion of carcass weight gained as fat was lower due to discontinuous growth. On a time constant basis for 97 d from the onset of realimentation , 60% of carcass weight gain was fat in control heifers, while only 43% of carcass weight gain was fat in compensating heifers. During this same time frame, DMI was 88 g/kg $W^{3/4}$ and 97 g/kg $W^{3/4}$ for normal and compensatory

heifers, respectively. The combined influences of increased ME intake per unit of metabolic body size and lower caloric content of gain resulted in a 15% increase in ADG and an 11% increase in gain/feed by compensating heifers.

During compensatory growth, fractional protein accretion remained constant (Table 2) rather than increasing as described by others (Rompala et al., 1985; Carstens et al., 1991). Fractional increases in body fat gains were dramatic in compensating heifers. The discrepancy between this and previously published research may lie merely in the timing of sampling. In the Alderson (1994) observations, the normal growth subjects demonstrated a diminished ability to deposit protein or fat over time. The compensating heifers either sustained growth (of protein) or increased growth (of fat) such that body composition converged at 500 kg BW.

Table 2. Fractional accretion of protein and fat at time constant end points[a]

Phase	I			II			
Growth	Restricted		Normal	Restricted		Normal	SEM
				Accretion rates			
Protein accretion							
Period	.34	*	.51	.32	*	.11	.02
Cumulative				.33	*	.29	.01
Fat accretion							
Period	.43	*	..92	.81	*	.52	.02
Cumulative				.58	*	.63	.02

[a]From Alderson (1994).

*Adjacent means differ (P<.10).

Summary

Mammals are born with a genetic code that sets a normal channel for growth and development. During discontinuous growth due to caloric restriction, the first tissue to be affected is adipose. The impact of inadequate caloric intake is to lower daily adipose accretion rates. Further calorie restrictions will begin to influence skeletal muscle growth but to a lesser extent than the impact on fat accretion. Theoretically, a prolonged episode at this level of discontinuous growth would have a much greater impact on body fatness than on lean mass relative to a time constant norm. In beef production this may be demonstrated by the steer coming off range at 18 to 20 mo of age. These subjects demonstrate what Lepkovsky (1973) referred to as compensatory appetite. The result is elevated DMI and very poor gain/feed.

For a mammal to demonstrate true compensatory growth, protein mass accumulated in the body during the discontinuous growth phase must have been lowered from the intrinsic time constant norm. One can expect reduced visceral organ mass and lowered fasting heat production in these cases. During realimentation the rate of accumulation of protein and fat in the body is relatively higher than in normal subjects of the same age. It is unclear to me as to whether these rates are elevated above physiological norms or are simply not reduced as begins to occur during normal growth and maturation. It is clear that the degree of change in fat and protein accretion

rates is driven by a need to achieve the set point of mass and composition relative to the subject's age and genetic code. Given ample time to truly re-equilibrate their systems, subjects managed by either pattern of growth appear to achieve a similar homeostatic state.

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Predicting Optimum endpoints for finishing cattle

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Introduction

The optimum endpoint for finishing cattle can be defined as the point in growth when each feedlot steer, heifer or bull is the most profitable. Presently in the United States, that point is determined by predicting incremental cost of gain, carcass quality and yield grade, and avoiding discounts for under or oversized carcasses, and excess carcass fat depth. A high proportion of cattle in feedlots are either over or under fed in relation to their genetic potential and are thus not sold at their most profitable endpoint. The major problem is that whole pens are sold at once, based on the manager's prediction of average quality grade for the pen. The beef industry is developing programs to minimize excess fat produced, increase consistency of product and to identify and reward individual owners for superior performance in the feedlot. These programs must be successful if the industry is to remain competitive and profitable as food producers. The National Cattlemen's Beef Association have been promoting the development of Strategic Alliances between cow-calf, feedlot and packer segments of the industry to accomplish this goal. However, a major stumbling block has been the lack of a system for sorting cattle into optimum feeding and marketing groups, which requires co-mingling of cattle from different owners in a pen and marketing them as individuals when they have reached their most profitable sale point. Systems are being developed that can overcome this problem and allow Strategic Alliances to work. Their objective is to market animals at their optimum economic endpoint, considering live and carcass incremental cost of gain and carcass prices, carcass quality grade, and avoiding discounts for too much fat (typically a maximum of .5 inches or yield grade 3A or better) and outsized carcasses (typically below 550 or above 950 lb.). Once cattle are slaughtered, the proportion of feed fed to a pen apparently consumed by each individual to support the actual weight gain must be allocated.

These systems require being able to predict composition of the gain and net energy requirements of individuals based on environmental conditions, weight at the target carcass composition endpoint, and carcass weight and composition changes during growth so that cattle can be marketed at the optimum time. The objective of this paper will be to discuss (1) predicting energy requirements for maintenance and growth for cattle varying in breed type and body size fed in widely varying environmental conditions, (2) predicting carcass weight, body fat percent, quality and yield grade in live cattle during growth, and (3) an example system for electronically tracking cattle to predict their optimum endpoint. For details, see Perry and Fox (1996). The intent was to aggregate knowledge at a level and form that can be applied in feedlots. The authors recognize that the approach and equations presented do not account for all of the variation and our knowledge of the biology of growth extends beyond that presented here. A glossary of terms used in this paper is presented in table 1; all units are in metric.

Table 1. Glossary of terms.

ADG	= shrunk weight average daily gain, kg/d
AFBW	= final shrunk body weight adjusted to 28% fat
BRY	= boneless retail yield
BW	= body weight
CF	= carcass fat
CW	= carcass weight
CWP	= predicted carcass weight proportion
EBF	= empty body fat
EBG	= empty body weigh gain, and is .956 ADG
EBW	= empty body weight
EQSW	= equivalent shrunk weight
EQCW	= equivalent carcass weight
EQEBW	= equivalent empty body weight, and is .891 SBW
FFG	= feed for gain
FFM	= feed for maintenance
FSBW	= final shrunk body weight
FT	= fat thickness, cm
FTU	= FT predicted with ultrasound
LMA	= longissimus muscle area
LMAkg	= LMA/ (FSBW/100)
LMAU	= LMA predicted with ultrasound
MBW	= metabolic body size; $SBW^{.75}$
NEg	= net energy for gain
NEm	= net energy for maintenance
NEFG	= net energy available for gain
QG	= quality grade
RE	= retained energy, Mcal/day
SBW	= shrunk body weight
YG	= yield grade

Predicting incremental cost of gain

Equations to predict incremental cost of gain must be able to account for differences in basal NEm requirement, the effect of environment on NEm requirement, differences in body size, implant program and feeding system. These effects are accounted for by Fox et al. (1992) and in the 1996 NRC model. The effects of breed type are accounted for by adjusting the base NEm requirement of 77 kcal/kg MBW for Bos indicus and dairy types (-10 and +20% compared to Bos taurus). The effects of previous nutrition are accounted for by relating body condition score to NEm requirement. On a 1 to 9 scale, maintenance requirement is reduced 5% for each condition score below 5 and is increased 5% for each score above 5. The effects of acclimatization are

accounted for by adjusting for previous month's average temperature (ranges from 70 kcal/kg MBW at 30C to 105 kcal/kg MBW at -20C). This adjustment is continuous, with no effect at 20C. Current environmental effects are accounted for by computing heat lost vs heat produced, based on current temperature, internal and external insulation, wind, and hair coat depth and condition. This becomes important when the animal is below the computed lower critical temperature, and can range from no effect at 20C to twice as high (thin, dirty hide at -12C and 16 kph wind). In a validation of this system, apparent NEm requirements agreed with model predicted values, but the standard error of the Y estimate was 14 kcal/ MBW and only 33% of the variation in apparent NEm requirement was accounted for (Fox et al., 1992). The variation accounted for might have improved if all of the variables needed had been available in the data set used. Some of the variables such as hair coat depth and condition are difficult to establish under feedlot conditions, particularly for individual animals in a pen. More research is needed on how to more accurately predict maintenance requirements under feedlot conditions.

Equations to predict requirements for growth must be able to account for the effects of mature body size, implant program, and feeding system. The 1996 NRC presents a system to accomplish this objective. The system relies on feedlot personnel to determine the expected weight at the target grade endpoint, based on their experience with similar cattle under their management conditions. Then the 1984 medium frame steer equation is used to describe the growth curve of cattle, and the weight equivalent to this standard reference animal is computed. Three data sets were used to test this system. With two of the data sets (82 pen observations of Bos taurus implanted steers and heifers varying in breed type, body size and diet type and 142 serially slaughtered nonimplanted steers, heifers and bulls varying in body size aggregated into "pens" by slaughter groups), this system accounted for 94% of the variation in energy retained with only a 2% underprediction bias. It cannot be assumed that this accuracy will apply to individual animals at a particular point in time during growth, since these results are computed from pen averages and total energy retained. Data set 3 included ADG predicted, using the Cornell Net Carbohydrate and Protein System (Fox et al., 1992; Russell et al., 1992 and Sniffen et al., 1992, which is similar to the 1996 NRC model level 2) from 96 different diets fed to a total of 943 Bos indicus (Nellore breed) steers and bulls (Lanna et al., 1996). For NRC 1984 and the Cornell systems, the variation accounted for was 58 and 72 %, and the bias was -20% and -2% respectively. Data set 3 was independent from a set of 120 serially slaughtered Nellore bulls and steers (whole body chemical analysis by component; Boin et al., 1994) used to develop model parameters FSBW, metabolizable energy intake, NEm and NEg requirements. This analysis shows this approach is an improvement over the 1984 NRC. It also shows that when the prediction of dietary energy supply was included, the variation accounted for was lower. Many factors can alter estimates of finished weight of individuals, such as previous nutrition, implant programs, level of intake and energy derived from the diet, limits in daily protein and fat synthesis, and daily energy retained. The problem is to be able to predict those effects in individual animals based on information that will be available and is practical to apply. Accuracy will likely be best on individual animals when predictions are made toward the end of the feeding period, using accumulated predicted feed requirements and FSBW that has been adjusted based on ADG and FT measurements.

Predicting carcass weight, body fat, quality and yield grade

Equations to predict carcass weight and composition in live cattle during growth must rely on estimates of AFBW, and data that can be obtained on individuals during growth, such as current weight, ADG and ultrasound estimates of fat depth. Fox and Perry (1996) developed equations to predict carcass weight and composition from body composition data with 192 steers of 5 breeds slaughtered at 3 different endpoints (CU1). These equations were validated with data from individually fed cattle varying widely in cattle type and body size from two independent Cornell experiments (CU2; 129 individually fed steers) described by Perry et al. (1991) and a series of experiments at Michigan State (MSU; 96 pens) described by Tylutki et al. (1994). All 3 data sets were used for validating equations not developed from CU1. When tested on the three data sets, equations to predict carcass weight during growth accounted for 84, 83 and 88% of the variation with 0, 1 and 3% bias. An equation to predict carcass fat percentage (CF%) from fat thickness (FT) and EQSW accounted for 96% of the variation. When validated on the CU and MSU data sets, this equation accounted for 95 and 91% of the variation with a bias of 3 and 3%, respectively. Predicting CF% from ultrasound FT and EQSW accounted for 95% of the variation with a 3% bias when tested on the CU data set. An equation to predict yield grade from LMAkg, FT, and EQSW accounted for 93% of the variation. When validated on the CU and MSU data sets, this equation accounted for 94 and 86% of the variation with a 3 and 6% bias, respectively. Using the equation developed to predict yield grade from ultrasound FT, ultrasound LMAkg and EQSW accounted for 71% of the variation with no bias when tested on the CU data set. The relatively high R^2 achieved with ultrasound compared to that observed by others was possible because values taken before slaughter were not accepted until duplicate measurements were within 5% of each other.

Table 2 shows a summary of the data that relates body fat to quality grade. Where measured, ultrasound attenuation correctly identified quality grade in 82% of the steers.

Table 2. Relationship of carcass and empty body fat to quality grade[a]

Number pens	USDA quality grade[b]	Marbling score[c]	Carcass fat	Empty body fat(EBF)	EBF SD
4	3.5	4.2	21.0	18.8	0.52
32	4.5	4.9	26.5	23.8	0.74
47	5.5	5.9	31.1	28.1	1.29
14	6.5	6.1	33.7	30.5	1.30

[a]Data from trials described by Perry and Fox (1996).
[b]Standard = 3 to 4; Select = 4 to 5; Low choice = 5 to 6; Mid choice = 6 to 7.
[c]3 = Traces; 4 = Slight; 5 = Small; 6 = Modest; 7 = Moderate; 8 = Slightly abundant; 9 = Abundant.

In a summary of taste panel data collected with part of these studies, means for overall taste panel acceptability scores were 5.3, 5.5, 5,7, 5,8 and 6.2 for standard, low select, high select, low choice and mid choice, respectively. These results suggest that prediction of carcass fat during growth is useful in predicting carcass grade. Smith et al. (1995) reported the percent of steaks with low eating quality for the prime, choice, select, and standard grades were 5.6, 10.8, 26,4, and 59.1 percent, respectively. This 1995 National Beef Quality Audit reported that up to 20% of all beef does not pass consumer satisfaction in eating quality and recommends that the percentage of cattle grading low choice and above be increased. Although the optimum composition may change in the future, these results suggest beef is a product that contains some optimum combination of fat and muscle tissue, and that considering the proportion of fat in the carcass to predict optimum endpoints is necessary.

An example system to predict optimum endpoints

A computerized Electronic Cattle Management sorting and tracking system (ACCU TRAC™ ; Microchemicals, Inc., Amarillo, TX) is being marketed to predict the most profitable endpoint in feedlot cattle. The objective of the ACCU TRAC™ system is to predict carcass and empty body weight and composition so that incremental live and carcass cost of gain, quality and yield grade can be predicted as cattle progress during the feeding period to determine optimum profitability sale point.

The key components of the ACCU TRAC™ system are:

1. Cattle are processed on arrival through a series of low stress stations in a processing snake where they are measured for frame size by video imaging to predict body size, are weighed, vaccinated, implanted and given an electronic ear tag, and ultrasound backfat depth between the 12th and 13th rib measurements are taken. Cattle are measured again at re-implanting and are re-sorted based on new predicted finished dates. This data is processed and stored in a computer data base, then automatically places them in one of seven pens according to their projected optimum finish date. The computer analyzes the animal, opens the gate to the destination pen, senses when the animal passes the gate and automatically closes it.

2. A formula is used to determine each animal's share of pen feed consumption, based on predicted shrunk body weight at 28% empty body fat to determine composition of gain, and actual body weight and daily gain.

3. In complimentary technology under development, cattle weigh themselves daily in pens equipped with in-pen automatic sorting gates to allow easy sorting as animals near their ideal market weights. Projected market dates in the data base consider drug withdrawal time limits and other critical marketing considerations such as value compared to incremental cost of gain.

The ACCU TRAC™ system contains two key components to predict optimum endpoints. The Cornell Net Carbohydrate and Protein System predicts energy requirements as described by Fox et

al.(1992) and carcass weight and chemical composition as described by Perry and Fox (1996). Ultrasound technology developed at Cornell University and backfat deposition rates developed at Kansas State University is used to predict carcass fat depth during growth. The system used to predict optimum endpoints is summarized below as described by Perry and Fox (1996), except the NRC (1996) is substituted where appropriate since it predicts requirements similarly to the Cornell Model.

1. Predict EQSW (NRC, 1996);
   AFBW =(EBW + ((28 - EBF%)*19))/.891; EQSW = SBW(478/AFBW). An AFBW that has an empty body fat of 28% was chosen as the target endpoint, since table 2 shows that it is related to the low choice grade, and is the target most feedlot managers are familiar with and is most commonly used as the average target grade.

2. Predict NEg required and FFG from ADG, EQSW and diet NEg (NRC, 1996);
   RE = .0635 $EQEBW^{.75}$ $EBG^{1.097}$; EQEBW is .891 EQSW.
   FFG = RE/diet NEg.

3. Predict NEm required and FFM (NRC, 1996).

The NEm and NEg values to use in the system to predict FFM and FFG should be developed in each feedlot with well described historical data. This is accomplished by using this system to predict gains on the historical data set, using actual DMI. The apparent feed NEm and NEg values are those resulting when adjusted until predicted and observed ADG agree. These apparent net energy values will reflect feedlot feed processing, environmental and seasonal effects not accounted for in the system or any tabular values.

4. Individual DMI required is FFM + FFG.

5. Adjusted individual DM required = Predicted Individual DMI required * (actual pen DMI /predicted pen DM required).

6. Equivalent carcass weight (EQCW) = (EQEBW-30.3)/1.36; Garrett and Hinman, 1969.

7. CW proportion (CWP) = EQCW/EQSW.

8. Predicted CW = CWP*SBW; this equation is used to predict minimum and maximum CW thresholds and incremental cost of gain on a CW basis.

9. Predict FT from ultrasound; FT = .0351 + (.904 FTU). All ultrasound measurement equations should be developed for each individual operator to help minimize differences between operators and equipment which will reduce the errors associated with ultrasound measurements.

10. Predict LMAkg from ultrasound;
    LMAkg = (6.83 +(.908LMAkgU)). Develop your own if possible.

11. Predict YG; YG = 4.38 + .991 FT - .2 LMAkg + .000639 EQSW.

12. Predict CF%; CF% = - 4.93 + .781 FT + .0935 EQSW - .000045 $EQSW^2$.

13. Predict quality grade (QG), using table 2. Alternatively, use ultrasound to identify marbling score.

To predict AFBW from carcass data for retrospectively computing cost of gain from actual carcass data;

1. Predict EBW; EBW = 1.316CW + 32.29 (Garrett et al., 1978).

2. Predict EBF%;
EBF% = ((.351EBW + 21.6YG - 80.8)/EBW)*100; R^2 = .82.

3. Predict AFBW; AFBW =(EBW + ((28 - EBF%)*19))/.891.

Application and evaluation of the system

Table 3 shows an example of these calculations applied to the data of 8 (two each of Angus, Holstein, Simmental, and Angus x Simmental) of the individually fed steers in CU1. The predicted average daily DM required is a function of maintenance (FFM; actual average body weight, breed type) and growth requirement (FFG; average EQSBW and ADG). The second Angus has a higher 28% EBF weight (508 Vs 469 AFBW) and has a 14% higher daily feed requirement because of a larger average weight and higher ADG. However, these two Angus steers were at the same stage of growth because of nearly identical average EQSBW. The second steer is predicted to be in the choice grade, while the first is predicted to be select. Despite differences in body size, the two Holstein steers have the same ADG and daily feed requirement; the higher SBW of the first Holstein and higher FFM is offset by the lower average EQSBW and FFG. The first Holstein is predicted to be low choice grade, while the second must be fed longer to reach the choice grade. The first Simmental has a higher DM requirement, because of both a higher body size and ADG, despite being at an earlier stage of growth (EQSBW of 317 Vs 366). This steer must be fed to 670 kg to reach low choice grade; the second Simmental is predicted to be at choice grade. The two crossbred steers have the highest daily feed requirements because they have the highest ADG. This group of 8 steers consumed 14,971 kg of feed to date; the predicted DM required is 15,155, or 98.79% of the actual. This percentage multiplied times the predicted feed requirement gives the correct amount to charge against each steer.

Table 3. Demonstration of system to predict optimum endpoint

Breed	Angus		Holstein		Simmental		AngusxSimmental crossbred	
IWT,kg	225	241	180	181	241	289	191	246
SBW,kg	451	580	595	493	596	549	455	533
Days on feed	185	234	318	234	234	185	157	178
ADG,kg	1.22	1.45	1.31	1.33	1.52	1.41	1.68	1.61
AFBW[a]	469	508	545	498	670	511	464	560
Avg. ASBW,kg	347	374	362	339	456	400	328	403
Avg. EQSW,kg[a]	345	344	311	318	317	366	330	336
FFG,kg/d[b]	4.38	5.26	4.94	5.14	5.21	5.32	5.98	5.79
FFM,kg/d[c]	3.25	3.44	3.75	3.57	3.98	3.61	3.11	3.63
DM required,kg/d[d]	7.63	8.70	8.69	8.71	9.19	8.93	9.09	9.42
Total kg required[e]	1412	2036	2763	2038	2150	1652	1427	1677
Share of DM fed[f]	1395	2011	2730	2013	2124	1632	1410	1657
EQCW,kg[g]	272	327	312	280	250	306	277	269
CW,kg[h]	273	356	364	299	359	335	276	322
FT,cm[i]	1.64	1.39	.48	.49	.57	.39	.57	.75
LMAkg[j]	15.3	15.9	13.2	14.4	14.5	16.2	18.2	17.8
YG[k]	3.2	2.9	2.5	2.3	2.3	1.9	1.6	1.8
CF%[l]	29.3	33.2	31.4	29.1	26.6	31.0	28.9	28.3
QG[m,n]	4	5	5	4	4	5	4	4

[a]Predicted as shown in equation 1.
[b]Predicted as shown in equation 2.
[c]Predicted as shown in equation 3.
[d]Predicted as shown in equation 4.
[e]Predicted DMI required to date.
[f]Predicted with equation 5, using 14,971kg actual DMI and 15,155kg predicted DM required by the 8 steers.
[g]Computed as shown in equation 6.
[h]Computed as shown in equations 7 and 8.
[i]Predicted as shown in equation 9.
[j]Predicted as shown in equation 10.
[k]Predicted as shown in equation 11.
[l]Predicted as shown in equation 12.
[m]Predicted as shown in equation 13.
[n]4=Select; 5=Choice-.

The group and individually fed animals in the CU1 study, which were fed the same diet in the same environment at the same time, were used to test the system. The group fed cattle were used to determine apparent diet NEm and NEg values, which were then used to predict DM required in those individually fed. The system accounted for 48% of the variation in actual DMI, with a 3% overprediction bias. The variation not accounted for was likely due to individual animal variations that the system cannot fully account for, including maintenance requirements, diet digestibility and metabolizability, and body composition. Predicted DM requirements contain all of the accumulated errors in predicting each component. However, all of the feed is allocated by multiplying the actual pen DMI times each animal's proportional share. Therefore this system provides a method for allocating feed to individuals fed in a group on a biological basis, considering differences known to affect requirements (breed type, body size, stage and rate of growth).

The predicted carcass as a percent of shrunk weight can be adjusted for local conditions by adding or subracting the difference between predicted and observed values based on historical data. Using a constant of EBW/SBW of .891 based on NRC (1984), the equations presented to predict CW from EBW result in a range of carcass as a percent of shrunk body weight from 54.1 at 218 kg to 60.7% at 523 kg at 28% EBF, which allow for adjustment for the increasing proportion of EBW that is CW as an animal approaches 28% EBF. This relationship between EBW and CW was similar in 5 different published studies compared by Fox et al. (1976). In the equations presented in this paper, a constant of .891 for EBW/SBW is used for all stages of growth, based on NRC (1984). However, in the studies of Fox et al. (1976) and Abdalla et al.(1988) EBW/SBW varied from 86 to 94% at an EBF of 10% to 92 to 96% at 28% EBF. Therefore further adjustment of the prediction of EBW/SBW is needed for variations in gut fill, and historical data base can be used for this purpose as described above.

However, we do not recommend changing the .891 factor to compute EBW from SBW and .956 * ADG to compute EBG in the equation used to to predict RE. Predicted RE was substituted for NEFG (net energy for gain) in the equation used to predict ADG to test for errors in interconversions between shrunk and empty body weight and shrunk and empty body ADG in predicting RE or ADG. The equation to predict ADG uses EQSBW and (DMI-FFM) * diet NEg to predict NEFG. When this is done, predicted and observed ADG agreed for each group in the CU data set. Therefore these two equations are internally consistent when .891 is used to interconvert between SBW and EBW and .956 is used to interconvert between ADG and EBG.

An evaluation of the ACCU TRAC™ system was conducted under commercial feedlot conditions with 735 steers (unpublished data supplied by Drs. Thomas Eck and Max Garrison; test sponsored by Micro Chemical, Inc., Allflex USA, Inc. and Integrated Beef Technology). The cattle were allowed to continue on feed until the maximum carcass weight or the maximum back fat thickness reached 0.5 inches as predicted by the ACCU TRAC™ system. As a result, the cattle finished at an average predicted 29.4 (SD of 2.3) percent body fat, which was above the target of 28% body fat. Actual backfat depth averaged .47 (SD of .15) inches. Ninety three percent of the Cattle achieved the targeted yield grade of 3A or better, 73% of the cattle were YG 2B or better;

99% of the cattle had a YG of less than 3.99. The cattle graded 73% choice or better and 98.5% of the carcasses were within the targeted hot carcass range (550 to 950 lb). The carcass discounts ($/cwt) were $7 for select, $12 for yield grade 4, $10 for carcasses under 550 lb., $5 for carcasses 950 to 1000 lb. and $25 for carcasses over 1000 lb. The economic benefit was $23.69/head for using the ACCU TRAC™ system to avoid these discounts.

This data was used to demonstrate how a historical data base can be used to establish diet NEm and NEg values for a particular feedlot. The diet contained 79.7% flaked corn, 2.3% cottonseed meal, 2.5% cottonseed hulls, 6.5% alfalfa hay, 4% cane molasses and 5% supplement. Diet ME was used to predict NEm and NEg (NRC, 1996), and was adjusted until actual and predicted ADG agreed, using actual DMI. The apparent feed NEm and NEg values resulting were .927 and .628, compared to initial calculated values of .961 and .624. These apparent net energy values reflect feedlot feed processing, environmental and seasonal effects not accounted for in the system or any tabular values.

Summary

A system is presented that provides a method for allocating feed to individuals fed in a group on a biological basis, considering differences known to affect requirements (breed type, body size, stage and rate of growth). This along with equations developed to predict carcass weight and compositional changes during growth can be used to market cattle on an individual basis at the optimum time, considering incremental cost of gain and carcass weight and composition discounts.

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New Management Approaches to Alter Mature Body Size and Body Composition[1]

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Abstract. The "equivalent weight" concept advanced by NRC (1996) indicates that body composition can be calculated from current weight and an index of market or mature body weight. Brody's growth equations indicate that body weight at any specified animal age can be calculated from a growth retardation factor and mature body weight. Taken together, these two concepts dictate that body composition of an animal at a given weight is fixed. Certainly, as animals mature, protein accretion increases until fat reaches 32 to 36% of empty body weight. At this point, protein accretion slows or stops. Presumably, continued accretion of protein, a time dependent factor, is retarded when body fat deposition, which is maximized by high energy intake, reaches a specific point. But exogenous and endogenous hormone concentrations, gender, frame size, and pre-and post-natal supply of energy and nutrients all can influence fat content of the body at a given body weight. Consequently, mature body weight must not be fixed. Indeed, alterations in mature size may explain why hormonal and nutritional manipulation alter body composition at a given weight. Research studies have been summarized to examine the degree to which growth stimulants, nutrient restriction, and background impact mature size.
(Key words: Growth, Fat, Protein, Deposition, Feedlot, Cattle)

Introduction

Growth and development have been reviewed in classic texts cited in articles by Preston (1971), Lindsay et al (1993) and Owens et al. (1993; 1995). The "equivalent weight" concept advanced by the NRC (1996) for beef cattle proposes that body composition at a specified percentage of slaughter or mature weight is fixed. This indicates that body composition and nutrient requirements are driven by maturity, not by energy or nutrient intake. The basic mathematical equations often used to describe growth and maturation were devised by Brody (1945). Those equations indicate that animal weight at any given time can be calculated from animal age, mature weight, and percentage of the monthly decline in rate of growth, i.e., the deceleration factor. Taken together, these two concepts indicate that body composition at a specified fraction of maturity is fixed. Yet, numerous studies with growth stimulants, hormonal implants, and compensatory growth indicate that body composition at a specified weight can be altered and must not be fixed. Whether this means that totally different equations are required to simulate growth of such animals or that some factor in the Brody equation can be altered to predict growth, maturation, and development of such animals is not known. Although Brody's deceleration factor certainly may be altered, a simpler approach is to consider that mature size can be altered. The objective of this paper is to explore the research base behind the potential to alter mature size of animals.

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Growth Patterns

Theoretical growth curves for normal, retarded, compensatory, and, for lack of a better term, hypercompensatory growth are presented in Figure 1. Deficiencies of protein and certain minerals in utero can stunt animals so that their rate of weight gain and mature weight are less than normal. Runt pigs are an example of such retardation. Also, limiting oxygen supply to the egg or

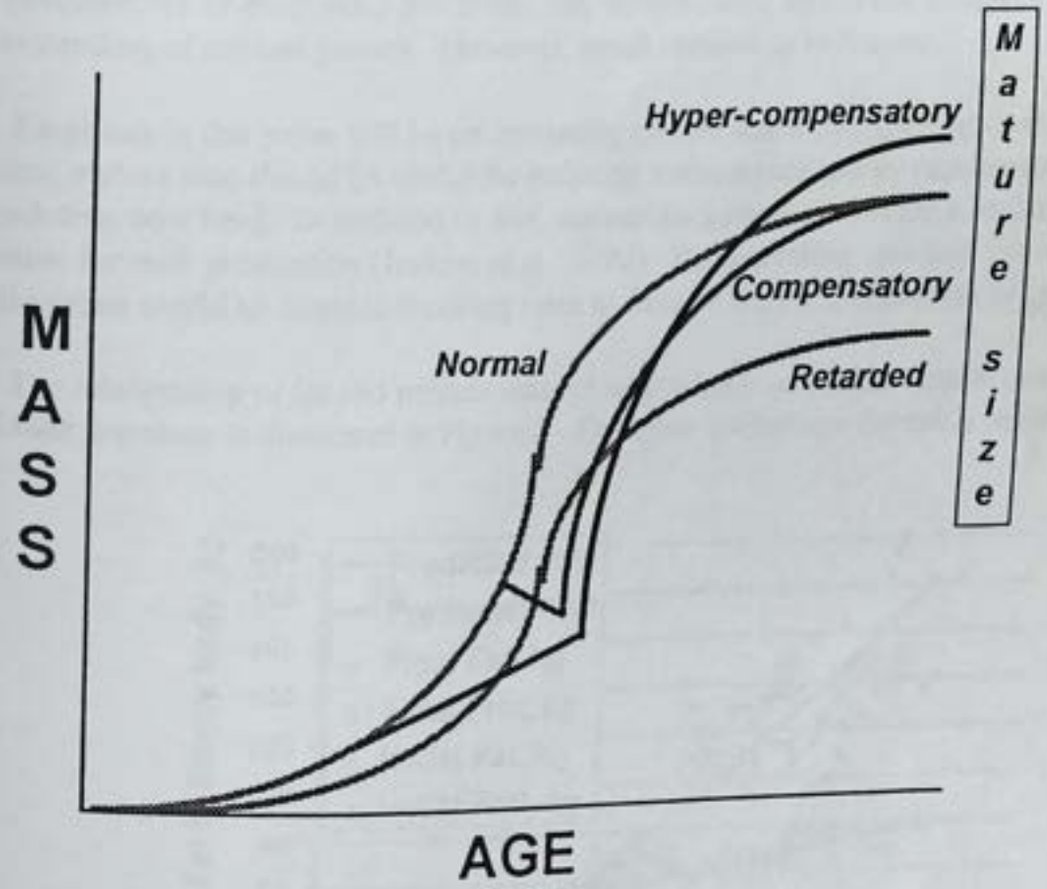

Figure 1. Schematic representation of body weight versus age for animals with normal growth, retarded growth, compensatory growth, and hypercompensatory growth.

cold stress of poults can permanently reduce mature size (R. Teeter, personal communication). In contrast to permanent stunting, an energy deficiency during growth will cause growth to be retarded only temporarily provided bone growth and cell replication are not retarded. In this case, when energy intake is restored, rate of weight gain is more rapid than normal so that weight compensates as a result of "compensatory gain." In this case, the weight-age relationship of the growth curve returns to normal and mature weight returns to those of animals that have never been restricted. An increase in visceral mass, an increase in the protein:DNA ratio, or cessation of proteolysis during realimentation of restricted animals may be responsible for the compensatory weight gain (Trenkle, 1974). The potential for compensatory gain depends on the extent and degree of restriction. Bergen (1974) reported that protein synthesis rate of rat muscle tended to be increase with moderate restriction but to be depressed with severe feed restriction. The third modification of normal, that of hypercompensatory growth, can follow a restriction period or be produced simply by hormonal modification. In this case, protein accretion is stimulated or fat

accretion is retarded. By reducing the negative feedback of fat mass on protein accretion, protein mass and thereby size at maturity may increase beyond that of animals that have not been restricted. Both the degree and the timing of nutrient or hormonal alteration determine the potential extent of hypercompensatory growth. From a body composition standpoint, information about controlling fat and protein synthesis and degradation and thereby accretion are not well defined, probably because many factors are involved and interacting (Trenkle, 1974). Certainly the development of exogenous hormones and repartitioning agents has enhanced our understanding of normal growth. However, much remains to be learned.

Emphasis in this paper will be on increasing mature size even though growth retardation and reduced mature size should be useful for reducing maintenance energy requirements of the reproducing cow herd. In addition to size, maintenance requirements are correlated with the potential for milk production (Jenkins et al., 1986). By decreasing cow size, growth inhibitors should prove useful to increase stocking rates and return from a specific area of grazing land.

The relationship of fat and protein mass to empty body weight for feedlot cattle from the published literature is illustrated in Figure 2. The open symbols are for cattle before being fed

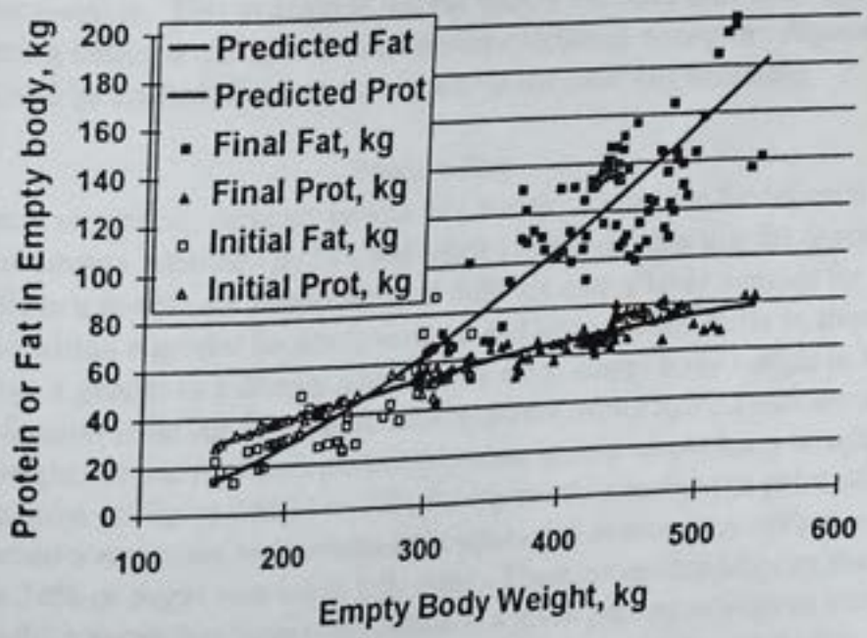

Figure 2. Weights in kilograms of protein (triangles) and fat (squares) for feedlot cattle at entry into (open symbols) or exit from (solid symbols) from the feedlot at various empty body weights. Data are from the literature compiled by Owens et al. (1995).

high concentrate diets whereas closed symbols are for cattle after being finished or fattened. With weight gain and maturation, both protein and fat mass increase curvilinearly, especially for cattle fed high concentrate diets. Normally, cattle are marketed at about 85% of mature weight, much later on the growth curve than broilers which are marketed at a point where fat and protein

content of the carcass are approximately equal. This maturity difference can explain much of the inter-species difference in feed costs per unit of product.

Site of fat deposition also may change over time although information about the time at which various fat depots mature is sketchy. One of the last sites of fat deposition in many breeds of cattle is intramuscular fat or marbling. In this conference, John Brethour detected only a low correlation between subcutaneous fat thickness and intramuscular fat. This could reflect differences in temporal accretion at these two sites, which matches observations of differences between breeds in potential for marbling based on genetics with some calves at weaning time already grading choice, or these two depots may differ in their inertia or potential for mobilization.

Altering Body Composition

Many nutrition studies have attempted to alter body composition at a given empty body weight by slightly altering rate of gain of feedlot cattle; in general, such studies have not been successful. This has led to the conclusion that body composition at a given weight is fixed genetically and not changeable. In contrast, cattle producers typically "grow" cattle prior to placing them on high concentrate diets to increase slaughter weight and avoid the price discount from light carcass weights. This increase in market weight indicates that body composition can be altered by subjecting cattle to different environmental conditions during development. Both points of view could be correct if indeed mature size is not fixed but malleable.

Mature Size

From a genetic viewpoint, certainly mature size varies. Values for fat deposition calculated from energy requirements published by Fox and Black (1984) indicate that fat deposition during growth changes from a lower to a steeper slope at different empty body weights for heifers than for steers and also within a gender for small, medium and large framed cattle as shown in Figure 3. The switch from a gentler to a steeper slope occurs when empty body weight is 34 to 37% fat, far beyond the inflection point for fat accumulation apparent from Figure 2 that occurs at about 40% of mature weight. If one regresses protein accretion against empty body weight, one finds that the inflection point of Figure 3 at 34 to 37% fat apparently matches the point where protein accretion has reached a maximum and animals have achieved a mature size. Whether this value should be 32% or 34% or might vary is not fully clear. These curves are basic to the "equivalent weight" concept which states that body composition at a given percent of mature size (or market weight) is constant for all genders and frame sizes of cattle. A change in mature size automatically alters composition at a specified weight. By corollary, if body composition at a specific weight is altered, this must reflect an alteration in mature weight. For calculations in this paper, when body composition was used to project mature weight, fat content was assumed to equal 32% of empty body weight when mature weight was reached.

heifers, respectively. The combined influences of increased ME intake per unit of metabolic body size and lower caloric content of gain resulted in a 15% increase in ADG and an 11% increase in gain/feed by compensating heifers.

During compensatory growth, fractional protein accretion remained constant (Table 2) rather than increasing as described by others (Rompala et al., 1985; Carstens et al., 1991). Fractional increases in body fat gains were dramatic in compensating heifers. The discrepancy between this and previously published research may lie merely in the timing of sampling. In the Alderson (1994) observations, the normal growth subjects demonstrated a diminished ability to deposit protein or fat over time. The compensating heifers either sustained growth (of protein) or increased growth (of fat) such that body composition converged at 500 kg BW.

Table 2. Fractional accretion of protein and fat at time constant end points[a]

Phase	I			II			
Growth	Restricted		Normal	Restricted		Normal	SEM
				Accretion rates			
Protein accretion							
Period	.34	*	.51	.32	*	.11	.02
Cumulative				.33	*	.29	.01
Fat accretion							
Period	.43	*	..92	.81	*	.52	.02
Cumulative				.58	*	.63	.02

[a]From Alderson (1994).
*Adjacent means differ (P<.10).

Summary

Mammals are born with a genetic code that sets a normal channel for growth and development. During discontinuous growth due to caloric restriction, the first tissue to be affected is adipose. The impact of inadequate caloric intake is to lower daily adipose accretion rates. Further calorie restrictions will begin to influence skeletal muscle growth but to a lesser extent than the impact on fat accretion. Theoretically, a prolonged episode at this level of discontinuous growth would have a much greater impact on body fatness than on lean mass relative to a time constant norm. In beef production this may be demonstrated by the steer coming off range at 18 to 20 mo of age. These subjects demonstrate what Lepkovsky (1973) referred to as compensatory appetite. The result is elevated DMI and very poor gain/feed.

For a mammal to demonstrate true compensatory growth, protein mass accumulated in the body during the discontinuous growth phase must have been lowered from the intrinsic time constant norm. One can expect reduced visceral organ mass and lowered fasting heat production in these cases. During realimentation the rate of accumulation of protein and fat in the body is relatively higher than in normal subjects of the same age. It is unclear to me as to whether these rates are elevated above physiological norms or are simply not reduced as begins to occur during normal growth and maturation. It is clear that the degree of change in fat and protein accretion

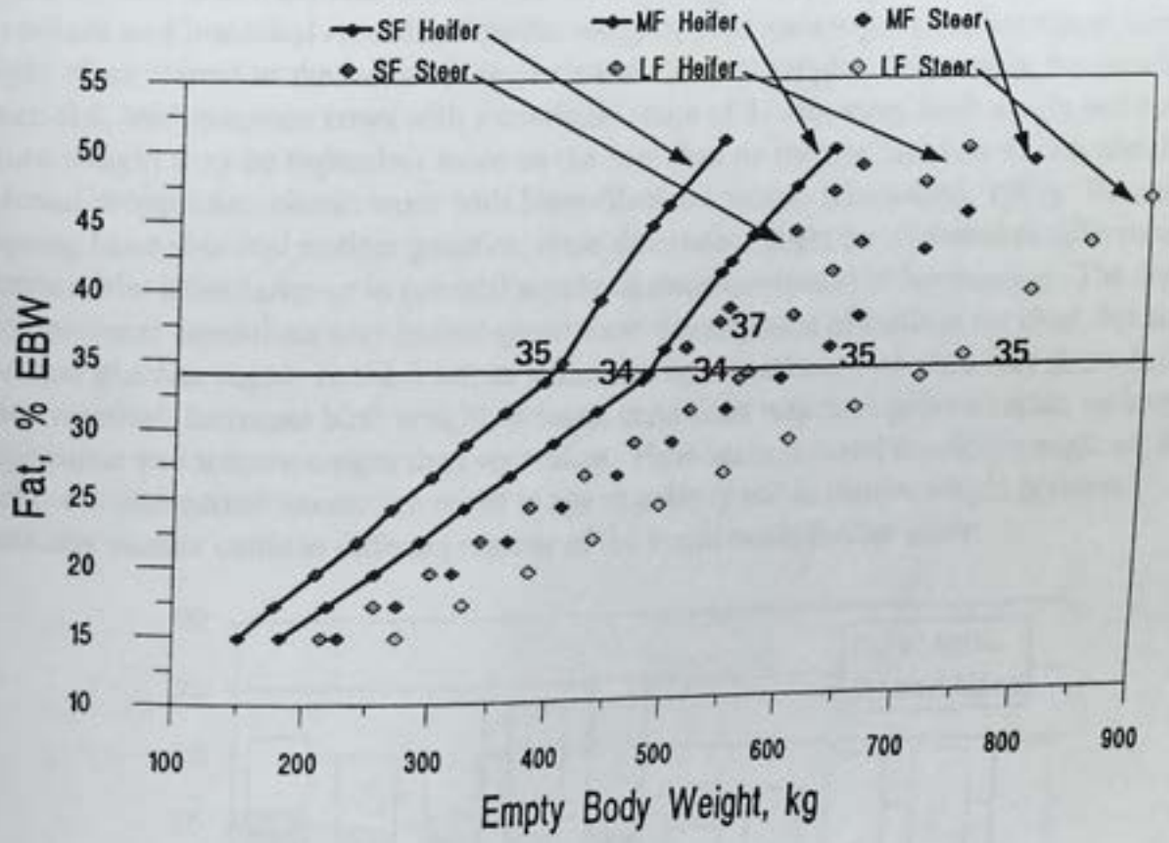

Figure 3. Impact of gender and frame size on fat content of empty body based on NEg requirements for gain of different types of cattle from Fox and Black (1984).

What is mature size? Some species and genders may continue to increase in weight throughout life, especially when given liberal amounts of feed. Observations with aging rats, with sows kept for several gestations, and with cannulated steers indicate that weight and frame size of some animals continues to increase as they age. Dairy and beef cows and bulls generally reach a stable weight and size and even steers appear to plateau in weight and size after 4 to 6 years (Hogan, 1929). In humans, lean body mass tends to decline after age 35 for both men and women even though body weight and fat continue to increase (Durnin and Womersley, 1974) as shown in Figure 4. With very low calorie diets, some 23% of the weight lost by women was fat-free mass (Morgan et al., 1992) indicating that, as with ruminants at lower condition scores (Taylor et al., 1996), a substantial fraction of weight lost during limited energy intake is lean tissue.

The current nutrient requirements for growing cattle (NRC, 1996) require an estimation of maturity or market weight and leaves that estimation up to the producer. Based on NRC (1996), market weight cattle with adequate marbling to grade low choice should have an empty body fat content of 27.8 to 28%. At maturity, values of 32 to 34% fat have been proposed by Fox and Black (1984) with bulls having a mature weight 67% greater than cows. Because feedlot heifers with similar parents as feedlot steers have 18% greater NEg requirements, the market or mature weight probably is about 20% lower for feedlot heifers than feedlot steers. In contrast, heifers

grown at .6 to .8 kg/day presumably have a 10% greater mature weight than steers (NRC, 1996). This indicates that restricting the rate of growth reduces empty body fat content of heifers at a given weight which translates into a larger mature weight. Lacking information on empty body fat content and historical records of market weights, producers might calculate mature size or weight of an animal as the mean of the dam's and the sire's weight. Presumably, this would be for forage-fed, mid-lactation cows with a condition score of 5. However, birth weight and perhaps mature weight may be dependent more on the dam than on the sire based on studies with British-Brahman crosses and classic work with Shire-Shetland crosses (Hammond, 1960). Because such offspring have identical nuclear genetics, these differences might be attributed to differences in mitochondrial inheritance or in prenatal supply of some nutrient(s) or hormone(s). The degree to which prenatal conditions may impact growth and development of cattle is not clear, but since an increased glucose supply to the fetus, as influenced by diabetes or by severe cold stress during winter weather, increases birth weight, prenatal conditions may have greater impact on body composition and mature weight than we realize. How much prenatal conditions might explain the genetic-environmental interaction noted in age at puberty and in mature weight between genetically similar cattle in different regions of the world needs further study.

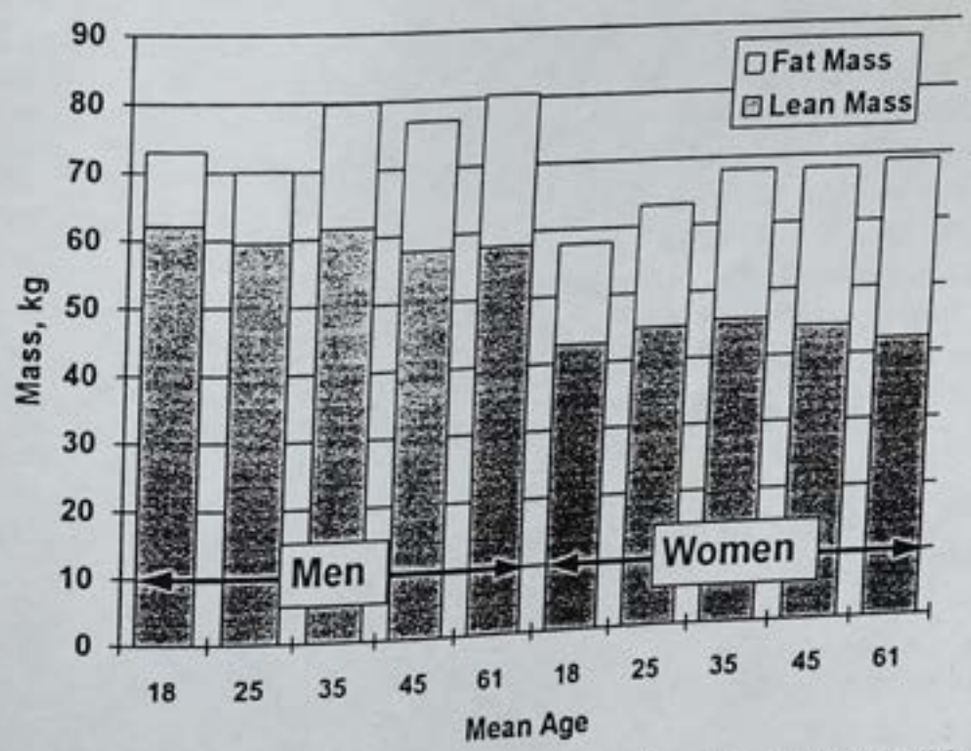

Figure 4. Mass of lean and fat of humans of different age calculated from means published by Durnin and Womersley (1974).

Altering Mature Size

Among the factors that may dictate size at maturity are genetics, gender, and exercise. First, concerning exercise, weight training by humans appears to increase muscle mass markedly, even among mature individuals. In contrast, couch potatoes with unlimited access to Twinkies™ acquire a very predictable shape and size, supporting the theory that "you become what you eat." The impact of exercise may be important for cattle as well, based on greater fat content of cattle

fed tranquilizers. Although the differences between grazing and grain-fed cattle in body composition traditionally have been attributed to differences in nutrient intake, miles traveled and degree of exercise is much greater for grazing than for feedlot animals, especially when grazing conditions are suboptimal. Beef produced in Europe often comes from limit-fed, tethered bulls. How exercise might influence marbling, efficiency, and composition of feedlot cattle needs further study.

Impact of hormonal status may explain differences between genders in body composition. In Australian studies with pigs (Campbell et al., 1989), both rate and composition of gain for barrows and gilts could be made equivalent to that of boars by administering porcine growth hormone. Gilts typically gain protein mass faster when pregnant than when open. In contrast, castrated men have a much larger frame size and mature weight than intact men, based on records of eunuchs from Italy that were castrated to maintain an immature voice quality (Peschel and Peschel, 1987). And the fact that most of the very heavy cattle in the ancient British literature were steers supports the suggestion that castrated cattle continue to grow as they age, at least up to 7 years (Hogan, 1929).

Exogenous hormones also can influence body composition and mature weight. In classic work by Preston (1978), Hereford or Angus and Charolais crossbred steers received no estrogen implants or repeated implants for a period of over 600 days. Implants increased weight at market time by 4 and 10% and at over 600 days by 13 and 18% for British and Charolais steers, respectively. So estrogen implants, in this case diethylstilbestrol, obviously increased mature size; this, in turn, can explain many of the differences in rate and composition of gain obtained with implants. Cattle often are implanted a sufficient number of days prior to marketing so that the hormone release expires in order to avoid adverse effects on marbling scores. Although this may imply that hormonal effects are not permanent, implanted cattle invariably remain heavier and have greater protein mass than non implanted cattle at a specified thickness of fat over the longissimus muscle.

Mature size also might be altered by energy intake at certain stages of growth. Protein restriction in utero may permanently stunt growth of pigs (Pond et al., 1990). In contrast, superalimentation of growing swine by Pekas (1994) increased both protein and fat deposition, suggesting that increased energy intake may have some impact on mature weight of pigs. In humans, rapid growth and maturation during adolescence results in greater obesity in adulthood (van Lenthe et al., 1996).

Restricting energy intake early in life has increased mature weights in several species. Park et al. (1994) stair-stepped feed intake of rats at 40% of normal during weeks 5-7 and 9-11 and at 70% of ad libitum thereafter. Rats that had experienced intake restriction were 5 to 6% heavier late in the study (13 to 25 weeks). Feed efficiency also was improved for rats whose intake had been restricted. Hogan (1929) restricted growth of steers until they reached 39 to 51 months and weighed and measured these steers until their sabbatical at 7 years. Weights are presented in Figure 5. Although intake restriction resulted in lower weights during the restriction period, maximum weights of the restricted steers exceeded those of the steer given more feed early in life.

Few differences in body measurements were detected although body length from the shoulder to the ischium tended to be greater for steers whose growth had been retarded.

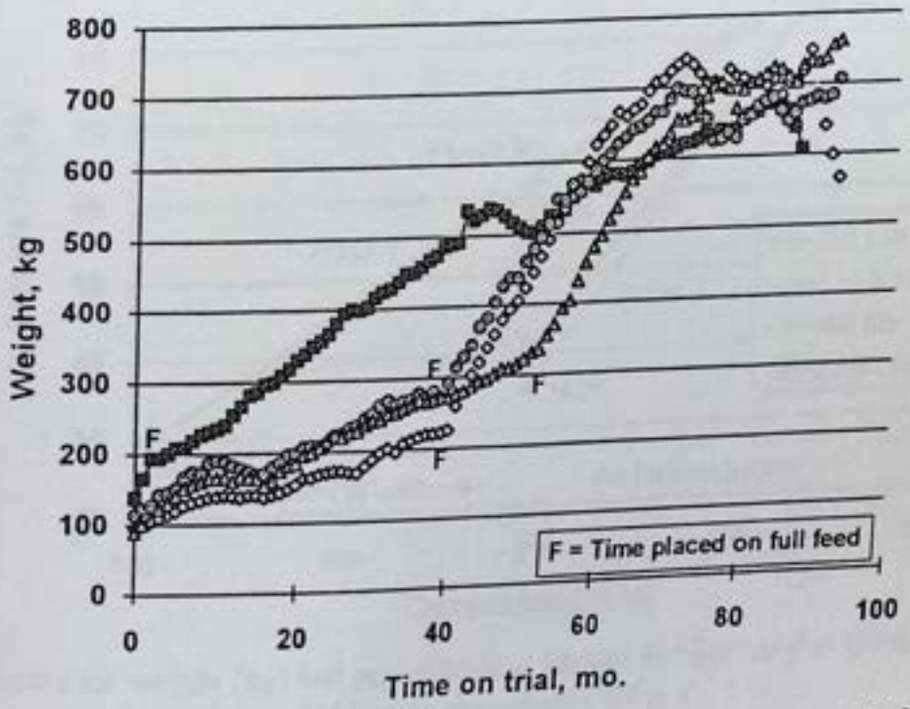

Figure 5. Body weights (kg) of steers placed on feed at various ages (Hogan, 1929).

Generally, restricting feed intake of feedlot cattle by a slight (3 to 10%) amount will increase feed efficiency. Based on measurements with lambs, Murphy et al. (1994) suggested that restricting feed intake results in leaner carcasses which would translate to an increased mature size. Hill et al. (1996) in two trials restricted feed for steers to 85 to 95% of ad libitum intake during the first half of the feeding period (for 140 kg live weight gain) and measured body composition after steers had gained 140 kg in body weight and at market weight. At the end of the period of limited feed intake, those that were limit fed surprisingly tended to be fatter than those given ad libitum access to feed as measured by carcass fat (Figure 6) or fat thickness over the rib. However, after all steers had been given ad libitum access to feed until they reached market weight, carcasses of those that had been limit fed earlier in life tended to contain less fat. No differences in protein content of the carcass were detected. A summary of research trials supports the suggestion that steers that had access to feed restricted typically are less fat at slaughter (Owens et al., 1995).

Gill et al. (1993) placed steers in the feedlot at various ages in order to determine whether differences in nutritional background would influence the live weight at which cattle would reach market weight and grade. These steers were fed high concentrate diet beginning at either 3.5, 7.9, 11.6, 15.4 or 17.4 months of age. This was immediately after weaning (3.5 or 7.9 months of age) of after these calves had grazed winter wheat for 112 days (11.6 months), or been wintered on forage and grazed native range in the spring for either 68 or 122 days (15.4 and 17.4 months of age). Protein and fat contents of the empty body of some of these steers were determined at entry into and exit from the feedlot for these closely related Angus calves as shown in Figure 7.

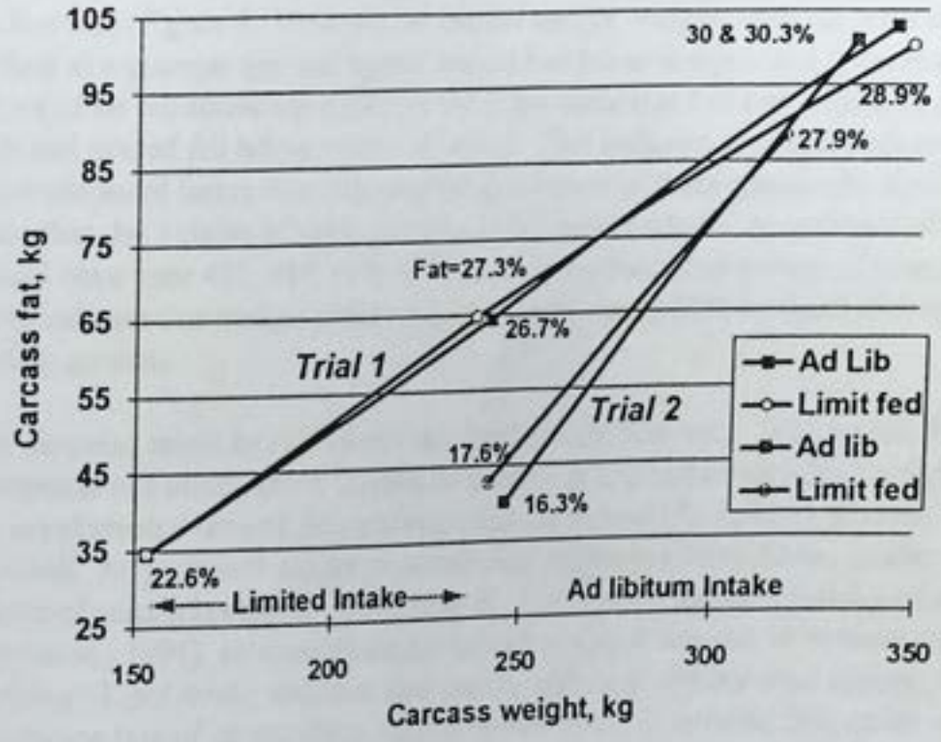

Figure 6. Carcass fat weight (kg) and percentages at various carcass weights for steers receiving restricted amounts of feed below 235 kg carcass weight (Hill et al., 1996).

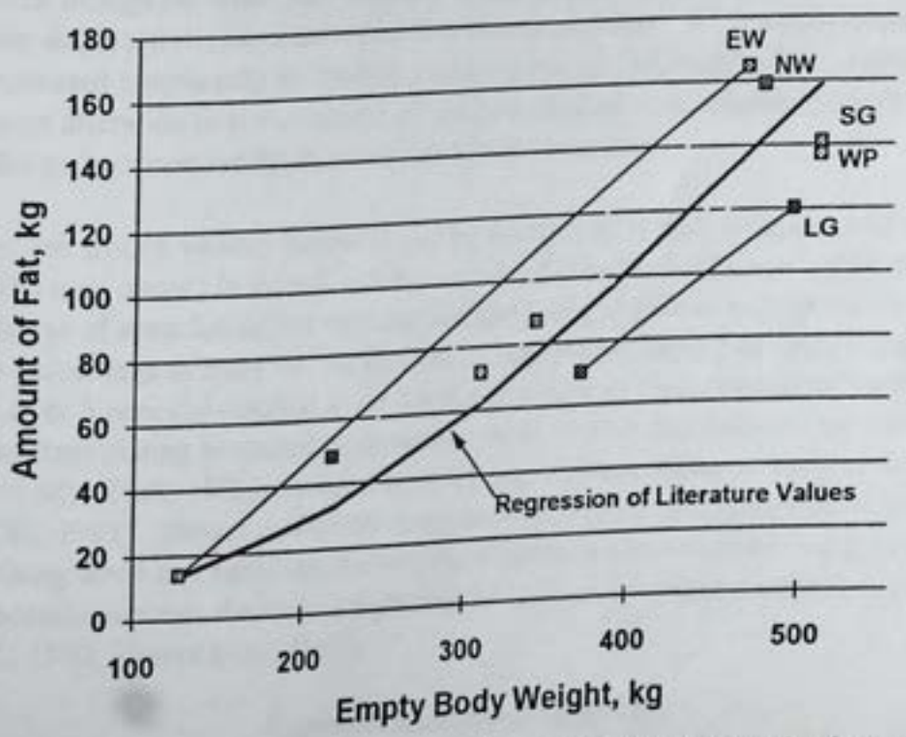

Figure 7. Initial and final fat content (kg) of steers (squares) with different backgrounds and ages at entry into and exit from the feedlot (Gill et al., 1993). Lines are drawn to connect points and are not meant to imply that changes with empty body weight are linear. Abbreviations are EW for early weaned, NW for normal weaned, WP for wheat pasture, SG for short grazed, and LG for season-long grazed steers.

Fat content of these steers at the start of the feeding period generally fell above the regression line from Figure 2. However, at market weight, weights differed markedly; steers placed on feed at a younger age and lighter weight had lower weights at 1.2 cm external fat cover. Also, weights of fat fell above the expected value for cattle that had not grazed forage whereas those which had grazed fell below expected values. This indicates that age, background, exercise, or some environmental factor was reducing the fat content of these genetically similar steers. One can calculate that the weights of these steers at 32% empty body fat, an estimate of mature weight, would have been 422, 456, 604, 587, and 649 for these five groups of steers, respectively. These results indicate that mature weight was altered by nearly 50% by these different backgrounding systems.

Mature size also might be altered by supply of specific nutrients. With swine, higher dietary protein concentrations often reduce carcass fat content at a specified slaughter weight; in contrast, with cattle, supplemental urea usually increases carcass fatness (R. A. Zinn, personal communication). An increased supply of postruminal casein has been shown to alter concentrations of certain hormones (Guerino et al., 1991) and mitogenic activity of serum of steers (Reecy et al., 1994), so some alteration in body composition due to nutrient supply would not be surprising. Lipid intake also may alter mature size, but whether total supply, which in cattle may increase rate of fat accretion, degree of saturation, or specific fatty acids are involved remains to be elucidated. In non-ruminants, amount of carcass fat typically is greater for animals fed unsaturated than those fed saturated fats. This might explain why obesity in humans has increased even though fat intake has declined. Concurrently, unsaturated fats of vegetable origin have partially displaced the more saturated fats of animal origin. With nonruminants, fat accretion has been depressed temporarily by feeding alpha linoleic acid (Albright et al., 1996). Whether this is due to direct alteration in site or extent of lipid metabolism or mediated through alterations in prostaglandin or hormone synthesis or activity is not yet known.

Interactions among various factors including energy restriction, exercise, and exogenous hormones also may occur. In human nutrition, yo-yo dieting has been studied by a number of workers because of speculation that repeated weight loss and gain in mature individuals may increase the percentage of body fat. In one study, intermittent fasting of rats (3 days out of 21 day periods over 5 periods) resulted in no change in weight or composition of the females; but for males, intermittent dieting increased body weight, body protein and body fat by 10.7, 10.2 and 14%, respectively (Turk, 1988). Other studies have found less effect on body composition (Prentice et al., 1992). However, an interaction between hormonal status and weight change may not be surprising when one considers that estrogen implants often increase weight loss while trenbolone acetate implants decrease weight loss of cattle under maintenance feeding conditions (Tudor et al., 1992; Hunter et al., 1993).

Conclusions and Open Questions

As animals mature, they gain fat, both in percentage of body weight and in mass. Physiological maturity normally is calculated as current weight divided by mature body weight. Weight varies with genetic or hormonal, as well as nutritional history, and mature body size may be altered substantially by hormone treatment and nutrition. Many questions about growth and development remain. For example, with maturation, what nutrients or hormones control rates of

fat and protein synthesis, degradation, and accretion? What signals from fat depots might retard protein accretion? What are the maximum rates possible and are ceilings being reached? At a specified physiological maturity (fraction of mature weight), how does body composition differ by gender and genetic type, and does it differ between slowly versus rapidly maturing animals? Which nutrients and hormones, and at what age, will dictate body composition and mature size? How and when might exercise or weight training alter composition and protein mass? Despite extensive publicity about weight training in humans, little is known about body composition and lean mass changes with exercise. How can mature body size be best defined and predicted and can mature animals gain protein mass without administration of hormones or chemicals? Are specific nutrients producing effects directly or exerting their actions through altering hormonal status? These questions about the potential to alter body composition and mature size assure job security for industry and university scientists for many years to come.

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Effects of Steroid Implants on the Composition of Growth in Beef Cattle.

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Estrogenic or androgenic steroids have been used for the last 42 years to enhance the efficiency of beef production. Since 1954 many different combinations (dosages and ratios) have been approved for beef cattle. Steroid implants are the best available non-nutritional management to for a producer to increase the efficiency (biological and economical) of beef cattle (Preston, 1987). Not only have steroid hormones increased the efficiency of the beef industry, they have opened many new avenues of research. Preston (1996) attributed growth physiology research programs of today to the quest of understanding the mechanisms in which steroids increase protein deposition. This manuscript will review some old and new research pertaining to the use of steriods in cattle production and hopefully stimulate some thought for future research.

Feedlot Performance

Estrogenic and androgenic hormones are commonly used to increase growth rates and efficiency. Many excellent reviews have been written concerning the use of steroids in beef production (Trenkle, 1969; Preston, 1975, 1987; Hancock et al., 1991; Roche and Quirke, 1986). Steroids increase average daily gain (Bartle et al., 1992), dry matter intake (Mader, 1994) and gain efficiency (Mader, 1994). Implants increase growth rates even when cattle are at the steepest slope on their growth curve. Thomson et al. (1995) implanted steers (1049 lb.), that had been on feed for 105 d but never implanted, with 120:20 mg TBA:E2 (Revalor-S, Hoechst-Roussel Vet) 5 and 3 weeks prior to slaughter. Implanting these steers increased gains by 186% relative to the non-implanted steers (Table 1). The magnitude of this response was a surprise due to the fact that the steers were very close to slaughter and thought to have decreased their rate of protein deposition.

Composition of Growth and Shift in Mature Body Size

Implants have been found to influence the composition of gain (Hutcheson et al., 1996, Johnson et al., 1996). Johnson et al. (1996) reported that implanted steers had increased protein and bone deposition relative to non-implanted steers. Also, carcass water was higher in implanted steers due to the fact that water is needed to deposit protein. Johnson et al. Observed that implants have no effect on carcass fat accretion. However at the end of the feeding period the non-implanted steers had a decrease in fat deposition indicating that they had reached maturity. This data also suggests that implants affect fat only at the end of the feeding period. This falls in line with two schools of thought: 1) maximum fat accretion (Owens, 1994) and 2) shift in mature body size (Preston, 1978).

Owens (1994) expressed that cattle have a maximum limit in which they can deposit fat. During the finishing phase implanted and non-implanted cattle consume enough energy to

maximize fat accretion rates and therefore implants would not have an effect on fat accretion. Therefore, implants do not have a lipolytic effect on body adipose tissue and decrease the percent of fat in the carcass by increasing the deposition of protein and bone.

Maturity is determined by the amount of fat in the carcass. It has been shown (Preston, 1978; Loy et al., 1988) that steroid implants increase the mature body size of steers. In these studies, steers that were implanted regularly with estrogenic steroids had increased gains, hook heights (Preston, 1978) and weight:height ratios compared to non-implanted steers. Preston found these results to be true for small and large framed cattle. These cattle were fed for up to 486 days and the non-implanted steers never caught up with the hook heights of the implanted steers. These data indicate that implants increase the mature body size of steers.

Plasma Urea Nitrogen

Plasma urea nitrogen (PUN) has been utilized for many years as an indication of anabolic activity. PUN is directly correlated with decreasing urinary nitrogen losses due to increased nitrogen retention (Grebing, 1970). The depression in PUN can be caused by either an increase in protein synthesis or a decrease in protein degradation. A PUN depression has been observed as quickly as 48 h with DES treatment (Grebing, 1970) and 7 d post implantation with TBA and estradiol benzoate (Figure 1, Thomson et al., 1996). It would be interesting to know if the PUN depression is from an increase in protein synthesis or a decrease in protein degradation. As indicated by PUN, steroid implants increase nitrogen retention of intake and absorbed nitrogen. This would indicate that implants would increase the efficiency of converting metabolizable protein to net protein which is not addressed in the NRC (1996).

Carcass Characteristics

If there has been one reason why producers have reservations about using steroid implants it is because of carcass characteristics. Steroid implants increase hot carcass weights and ribeye are (Preston et al., 1996). These two characteristics are increased due to increased mature body size and increased protein deposition. Back fat is not consistently affected by implants. However, marbling is decreased in implanted steers relative to control steers. Therefore, the percentage of steers grading Choice is often times decreased. Bartle and Preston found that trenbolone acetate:estradiol implants decrease marbling scores in finished steers by .15. The greatest decreases in carcasses not grading Choice is when the average marbling score for a group of steers is close the Small 0 and Slight 90 line or if the group of steers is vary uniform. Preston et al. (1991) indicated that implanted heifers and steers need to be fed 4 (37lb.) and 14 (87 lb.) days longer than non-implanted heifers and steers, respectively, to reach the same quality grade.

A question is commonly asked, is why do implants affect marbling but do not affect external back fat? Preston et al. (1996, Table 2) observed that implants had no affect on back fat. If one divides back fat by HCWT you will see that the ratio of back fat to HCWT decreases in implanted steers relative to controls. Ribeye area is larger for implanted steers than controls,

however if you divide REA by HCWT the quotients are similar across all treatments. Owens (1994) reported that there is a maximum amount of fat that can be laid down per day. If this is true and implants increase protein deposition, again at Table 2., implants decreased marbling scores. If the marbling scores are multiplied by the REA the products are similar for all treatments.

Other hypotheses need to be researched to understand the effects of implants on marbling. One concern is at which time of the finishing period is most critical for fat of IGF-I at the muscle level. If this were true , the IGF-I might stimulate localized lipolysis or decrease localized lipogenesis which would decrease marbling and have no affect on external back fat. Miller (1987) showed that the difference in marbling between Angus and Santa Gertrudis steers is due to fat cell hypertrophy and biochemical properties within the fat cells. The number of fat cells was similar across breed types, however the size of the fat cells was larger for the Angus steers which had higher marbling scores. It was concluded that the intramuscular fat cells from the Angus steers were more efficient in converting acetate to lipids and glucose to glyceride-fatty acids. Miller suggested that the Angus steers were able to produce more marbling because of the synergistic effects of the pentose cycle reductatse activities and the availability of glyceride-fatty acids for storage lipid production.

Dark Cutting Beef

Another concern of packers and producers is that TBA products increase the incidence of dark cutting beef, especially if the cattle are implanted to close to the time of slaughter. Thomson and Preston (1995) implanted steers 5 and 3 wk prior to slaughter. There were no dark cutting carcasses regardless of implant treatment. Also, Thomson et al. (1996) implanted steers 24 d prior to slaughter (Table 3). There were no differences observed in Hunter L, a, and b values or pH between implanted and non-implanted steers. Therefore, implants alone have no effect on dark cutting beef.

Composition of growth during the finishing period

Protein Deposition Mechanisms

The question arises as to how implants cause an increase in protein deposition in cattle. A technology in its infancy is cell culture. There are many estrogenic and androgenic receptors in skeletal muscle (Sauerwein and Meyer, 1989). Inactive receptors float unbound in the cytosol. The steroid passes through the plasma membrane and binds to the receptor. The hormone-receptor complex then translocates to the nuclear membrane where it is thought to stimulate protein sythesis. The receptors in skeletal muscle have the same affinity for estrogen as in uterine tissue (Meyer and Rapp, 1985). However, the number of receptors in skeletal muscle are much less than uterine tissue.

Roeder et al. (1986) reported that steroids do not directly stimulate protein synthesis in rat muscle cells. Thomson et al. (1996, Figure 3) found the same to be true for in vitro beef muscle cells treated directly with E2 and TBA alone and in combination. However, cholesterol, which is used as a carrier for steroid implants did stimulate protein synthesis in the bovine muscle cells in

culture. These data clearly show that steroids have no direct effect on muscle cell protein synthesis.

To test the indirect effects of steroid hormones on protein synthesis/degradation and cell proliferation, Thomson et al. (1996) treated cells with serum from steers treated with TBA:E2 and BST alone and in combination. These results indicate that steroids indirectly increase protein synthesis with no effect on protein degradation. This agrees with the in vivo results concerning the effects of E2 and TBA on protein turnover as reported by Hayden et al. (1992). Serum from steers implanted with TBA:E2 increased cell proliferation of rat C2 myoblasts (Figure3, Thomson et al., 1996; Johnson et al., 1996).

Finally, the mechanism which implants increase protein deposition has been debated for some time. Trenkle (1970) reported that steroids increase the size of the pituitary and increase the number of acidophils. There are three types of acidophils located in the anterior pituitary: 1) somatotropes (secrete somatotropin, ST), 2) lactotropes (secrete prolactin, LT) and 3) mammosomatotropes (secrete somatotropin and prolactin, MST). Kineman et al. (1991) reported that bulls contained 9% MST, 45% LT and 21% ST in their anterior pituitary while steers had 22,46 and 8%, respectively. This indicates that the gonadal status of the animal effects the composition of the anterior pituitary.

Thomson et al. (1996) implanted steers 24 d prior to slaughter with 200:20 mg TBA:E2 (Synovex Plus, Fort Dodge Laboratories). At the time of slaghter the anterior pituitaries were harvested and the reverse plaque assay (Kineman, 1991) was performed to examine the composition of the acidophils. Implants increased the percentage of ST while decreasing the percentage of MST relative to control steers (Figure 4). Steroids had no affect on LT. Implants did increase the overall percentage of cells that secrete somototropin by 30% verses non-implanted steers (Figure 5). Therefore implants are working through the growth hormone pathway which had been hypothesized some time ago.

Future Research Needs

Research breeds new research. One thing that is needed in implant structure and technology is an implant with increased sustainability and payout throughout the entire feeding period. Another area of research that has not been exposed is the effects of steroid implants on immune responses in cattle. Also, implant and time of travel to slaughter facility interactions should be investigated for the occurrence of on dark cutting beef. Lastly, anterior pituitary data is needed for steers implanted with E2 and TBA alone and in combination to determine how implants affect growth hormone secretion.

Table 1. Effect of implanting time relative to slaughter on feedlot performance of finishing steers.

	Implanting time, weeks			
Item	Control	3	5	SEM
Weight, kg				
d 0	496	528	530	19.2
d 14	506	534	546	19.5
d 35	521	574	577	20.3
ADG, kg				
d 0 to 14	.69	.46	1.12	.17
d 14 to 35	.73	1.88	1.48	.14
Overall	.71	1.31	1.33	.21

Table 2. Effect of trenbolone acetate and estradiol benzoate on the carcass characteristics of finished beef steers.

	Treatment		
Item	None	Implanted	SEM
Lean color	6.50	6.17	.49
Heat ring	3.83	3.83	.40
Texture	6.50	6.50	.22
Firmness	7.17	6.50	.27
L value	41.0	41.6	.98
A value	25.8	26.3	.97
b value	11.0	11.5	.47
pH	5.41	5.43	.02
Temperature	31.8	31.6	.10

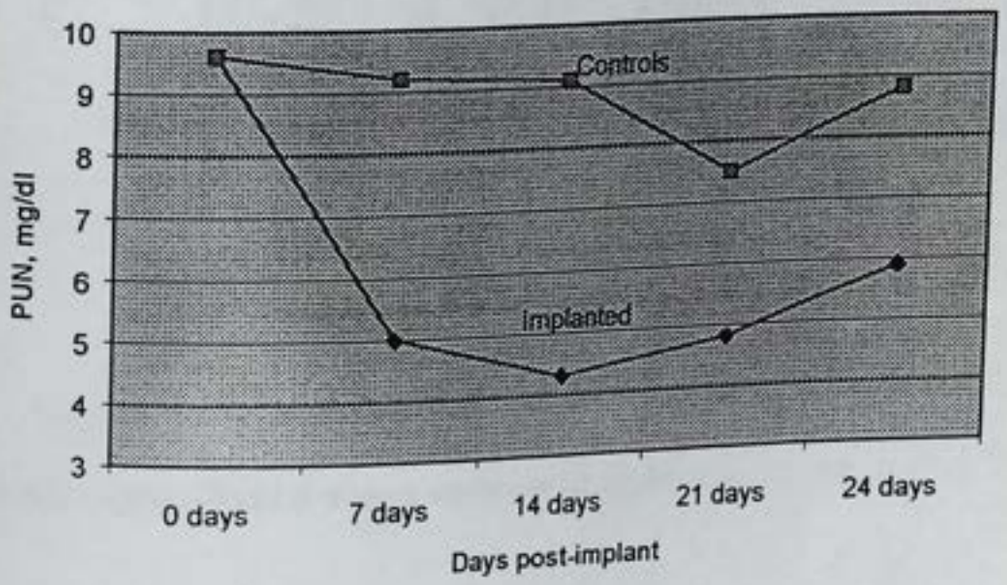

Figure 1. Effect of trenbolone acetate and sestradiol benzoate on plasma urea nitrogen concentrations in finishing beef steers

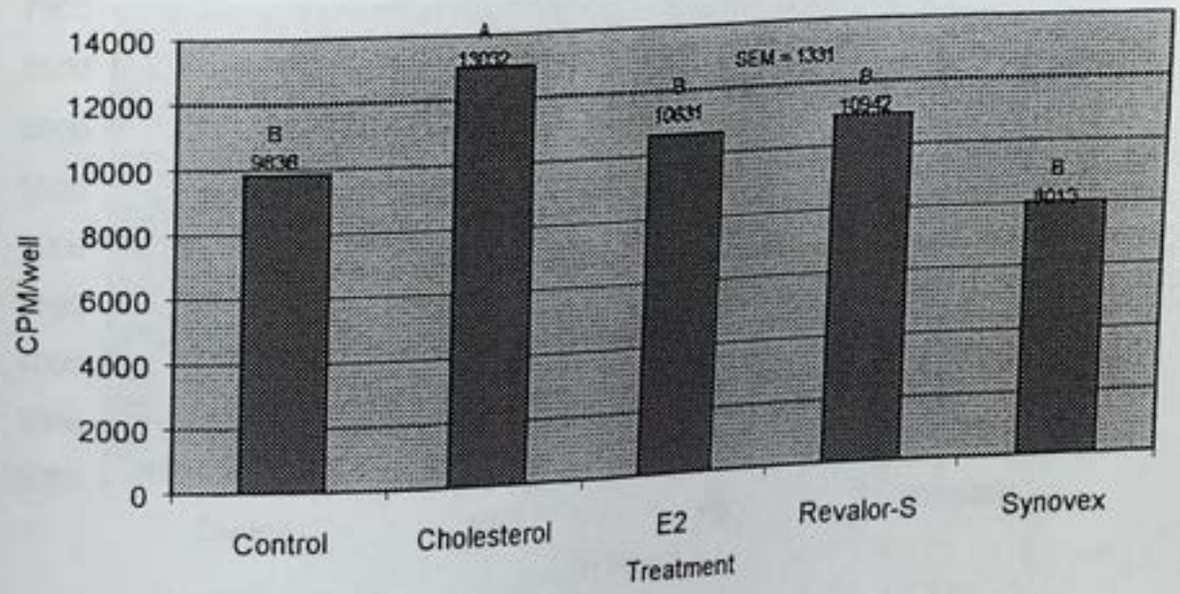

Figure 2. Direct effects of different steroids on protein synthesis in bovine muscle cells in vitro.

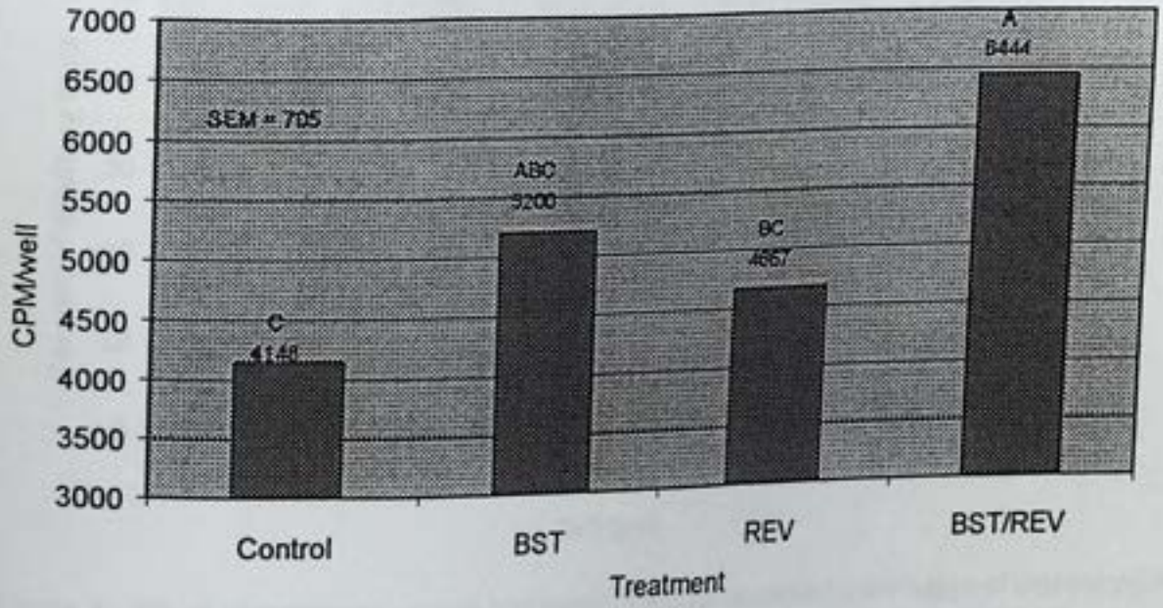

Figure 3. Effect of serum from steers treated with a steroid implant and somatotropin alone and in combination on cell proliferation of rat C2 muscle cells.

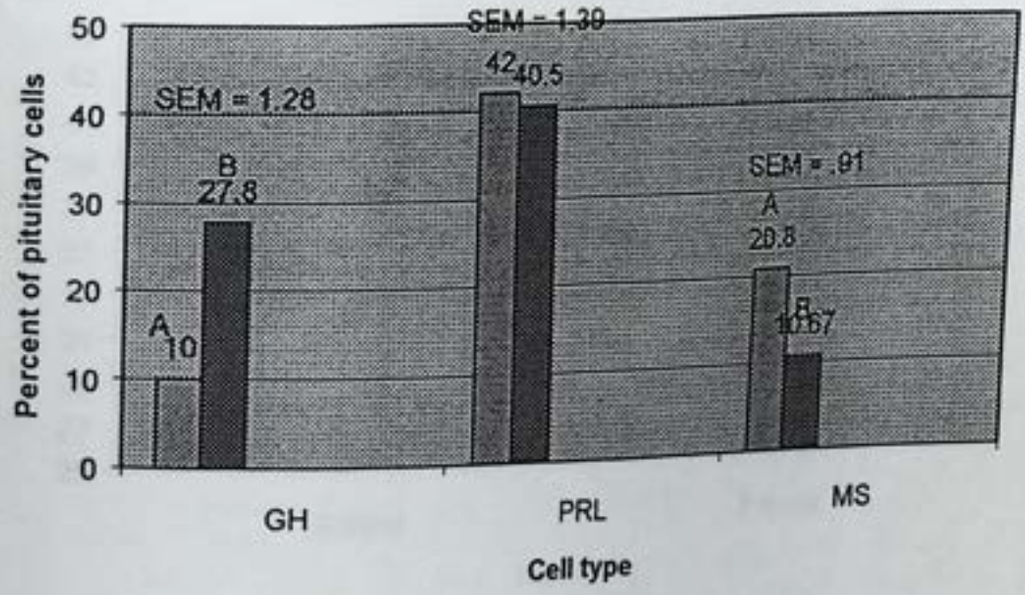

Figure 4. Effect of tenbolone acetate and estradiol benzoate on the percentages of anterior pituitary cells that secrete somatotropin, prolactin or somatotropin and prolactin in finishing beef steers.

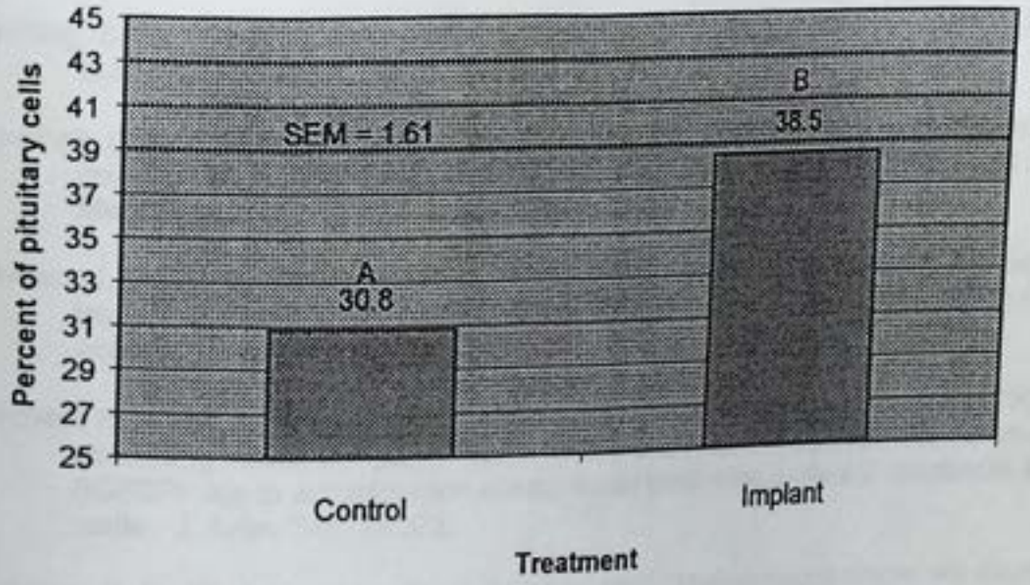

Figure 5. Effect of trenbolone acetate and estradiol benzoate on the percentage of anterior pituitary cells that secrete somatotropin in finishing beef steers.

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Use of Cell Culture to Evaluate Regulation of Muscle Growth

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Cell culture is a powerful tool which can be used to study mechanisms of growth of many animal tissues. Examples of cell culture systems commonly used by animal agricultural researchers to study growth are listed in Table 1. Cell culture systems used to examine the biology of growth must closely simulate what is occurring in the whole animal. Otherwise, observations may be simply peculiar to cell culture. The ability to separate direct and indirect effects of a substance on a particular observation is one of the greatest strengths of the technique. In vivo, cells of one type may secrete compounds which stimulate a second cell type to produce a substance resulting in some effect. An example of this is the growth hormone - insulin-like growth factor axis. Cell culture gives researchers the opportunity to identify what factors are produced by a particular cell which may potentially impact the function or activity of cells of the same or different type either at a distance (hormonal effects) or locally (growth factor effects). To be useful in mechanistic studies of growth, the cellular composition of cultures need to be clearly defined. This can be a problem in primary cultures which may become overgrown with fibroblasts. For this reason, target cells are sometimes cloned or sorted by flow cytometry to obtain pure populations for study.

Embryonic myoblasts are responsible for early prenatal development of skeletal muscle, whereas satellite cells serve this function from the mid-fetal period through adulthood. Satellite cells, which reside between the basement membrane and the plasmalemma of skeletal muscle fibers (Mauro, 1961; Muir, 1970), donate their nuclei to adjacent muscle fibers (Moss and LeBlond, 1971; Stockdale and Holtzer, 1961; Allen et al., 1979), subsequently leading to muscle protein accretion, i.e., muscle growth (Moss, 1978; Moss and LeBlond, 1971). Most satellite cell isolation procedures which have been described are derived from the method described by Bischoff (1974). This entails removal of skeletal muscle in an aseptic manner, grinding or mincing of the tissue and a proteolytic digestion to release satellite cells from the muscle fibers. This is often followed by filtrations and centrifugations to separate the cells from the muscle debris. Following these steps cells may be plated into cell cultureware and administered a growth medium or frozen in the presence of the cryoprotectant DMSO in liquid nitrogen and stored frozen. The ability to store satellite cells in liquid nitrogen allows for greater convenience and eliminates the need to maintain flocks or herds of animals specifically for cell culture purposes.

Many aspects of muscle growth may be modeled using embryonic myoblasts or satellite cells in culture. Cultured muscle cells 1. proliferate in culture in response to growth factor signals, 2. operate biochemical pathways characteristic of muscle tissue, 3. move about on a substratum, and 4. differentiate and fuse to form myotubes and synthesize contractile proteins and other proteins characteristic of the differentiated state. A few examples of the many types of studies which may be conducted with muscle cell culture to understand mechanisms of muscle growth include determining the role and requirements of growth factors and hormones, as well as the numbers and affinities of their receptors on cell surfaces. It is also possible to study the requirements, transport

and metabolism of various nutrients. Additionally, many current efforts utilize muscle cell culture to examine the genetic regulation of specific proteins related to the growth process. In all of these studies it is important to remember that differences may exist between species in terms of their cell physiology and response to administered factors.

Most cell culture systems utilize a media formulation including 10-20% serum. Serum acts as a source of growth factors, micronutrients and other substances which are necessary to support cell proliferation. Lowering of the serum levels will induce satellite cell cultures to initiate differentiation and fuse to form multinucleated myotubes. This process is believed to result from the production of IGF-II by satellite cells and the induction of myogenic regulatory genes in a sequential manner (Florini et al., 1991; Smith et al., 1994). Simulation of the myogenic process in culture allows researchers the ability to follow many of the cellular events which occur during differentiation.

The fact that serum contains a wide array of growth factors and other substances which influence proliferation of cells precludes its use in studies designed to elucidate the role of growth factors and nutrients in cellular proliferation, differentiation and metabolism. For this reason a number of serum-free medium formulations have been developed for cultured satellite cells from different species. These include formulations for human (Ham et al., 1988), rat (Allen et al., 1985), sheep (Dodson and Mathison, 1988), swine (Doumit et al., 1993), turkey (McFarland et al., 1991) and chicken (Dollenmeier et al., 1981) satellite cell. The use of serum-free medium has been a key factor in elucidating the role of growth factors in muscle development. In fact, much of what has been learned about muscle development, including the role of growth factors, stems from the use of appropriate cell culture systems and serum-free media. Among the growth factors demonstrated to have mitogenic effects on satellite cells are fibroblast growth factor (FGF), epidermal growth factor (EGF), platelet-derived growth factor (PDGF) and the IGFs (for review: Dodson et al., 1996). Insulin-like growth factors also stimulate differentiation of some satellite cells (Allen and Boxhorn, 1989; Greene and Allen, 1991) while transforming growth factor-beta (TGF-β) inhibits proliferation and differentiation (Allen and Boxhorn, 1987). Allen and Boxhorn (1989) showed that by altering the levels of IGF-I, FGF and TGF-β cultured mammalian satellite cells may be induced to divide, differentiate, or remain quiescent. Recently, Allen et al. (1995) reported that hepatocyte growth factor shortened the lag phase of cultured quiescent satellite cells derived from old animals.

In addition to allowing researchers to identify which growth factors impact satellite cell physiology, cell culture is ideally suited to study the properties of receptors which interact with growth factors (for examples: Minshall et al., 1990; Sun and McFarland, 1993; Sun et al., 1992). Analyses of receptor binding data allows researchers to determine whether there are more than one type of receptor interacting with the growth factor as well as to calculate the binding affinity and the number of receptors/cell. Receptor numbers and binding affinities are important factors in determining the response of cells to growth factors.

Nutritional and biochemical aspects of muscle development can also be studied with cell culture techniques. During differentiation of satellite cells there are increases in anabolic metabolism including protein synthesis and glucose uptake. Protein synthesis and degradation rates are often determined in myotube cultures by measuring the incorporation (synthesis) or release (degradation) of radiolabeled amino acids such as [^{35}S]methionine from protein. Glucose transport rates can be

measured by determining the uptake of non-metabolizable glucose analogues such as 2-deoxy-[^{3}H]-glucose into cells. In a recent study (McFarland et al., 1996) we compared protein synthesis, protein degradation and glucose uptake in satellite cells derived from the avian pectoralis major (PM), a muscle comprised largely of white fibers, and the biceps femoris (BF), a muscle comprised largely of red fibers. The results showed that protein synthesis, degradation and glucose uptake rates were higher in BF satellite cell cultures ($P<0.05$), correlating with previously reported in vivo measurements using red and white muscle fibers. The sequential pattern of fast myosin isoform expression in vivo can also be demonstrated in cell culture. During embryogenesis and regeneration of skeletal muscle tissue there is a transition in fast twitch myosin isoform expression from embryonic to neonatal and then to adult forms. This same progression in myosin isoform expression can be demonstrated in culture (Hartley and Yablonka-Reuveni, 1990).

Future use of skeletal muscle cell culture in agriculture may take any number of different avenues. For instance, it is quite possible that cell culture may be used in the genetic selection of meat animals. Satellite cells from animals which deposit greater levels of skeletal muscle may have a particular trait which can be detected in culture and used as a screening method for superior animals. In earlier studies we demonstrated that satellite cells derived from a fast growing line of turkeys were more responsive to the mitogenic effects of serum (McFarland et al., 1993) and IGFs (McFarland et al., 1995) than were cells from a slow growing line. In addition to comparing growth characteristics of satellite cells from animals having different growth rates, serum from such animals might be used in bioassays of growth potential. Gerrard and Judge (1993) reported that serum from fetal double-muscled cattle had greater mitogenic activity toward myoblasts in culture than control fetal serum. These findings suggest that there might be great potential for rapid and inexpensive screening of potential breeding lines of meat animals.

Cell culture techniques have permitted researchers to identify many growth factors and other compounds which have growth stimulating effects on muscle. The potential to identify additional factors, both naturally occurring and synthetic is yet another possible application of these techniques. Genetic modification of satellite cells by medical researchers who are seeking to lessen the impact of muscular dystrophy on young children (Gussoni et al, 1992). It is possible that these techniques can be employed to direct satellite cells to proliferate or differentiate faster or secrete growth promoting compounds. Perhaps such modified satellite cells can be added to embryos or postnatal animals to influence growth.

Cell culture will undoubtedly play an important role in future advances in muscle biology. Not only will muscle culture uncover additional mechanisms which regulate skeletal muscle development, but, coupled with advances in molecular techniques, there is great potential to increase meat animal production efficiency and improve genetic selection.

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Table 1. Examples of Cell Culture Systems.

Tissue	Cultured cell type
Skeletal Muscle	Embryonic Myoblasts Satellite Cells
Adipose	Pre-adipocytes Adipocytes
Bone	Osteoblasts Osteoclasts
Cartilage	Chondrocytes

NEW APPROACHES TO PREDICT BEEF TENDERNESS

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The accurate prediction of beef tenderness in a timely fashion has been very elusive for researchers. The National Beef Tenderness Symposium in 1994 showed that one in every four steaks is less than desirable in tenderness. The recommendation from this symposium was to encourage the development of a rapid test for the tenderness of beef carcasses. The National Beef Instrument Assessment Symposium in 1994 concluded that video image analysis, total body electrical conductivity and the Tendertec probe were very promising technologies. The most promising new technologies emerging for the prediction of beef tenderness and body composition will be outlined in this paper.

I. RAPID WARNER-BRATZLER SHEAR FORCE DETERMINATION. The Rapid Warner Bratzler Shear Force Methodology is being investigated by M. Koohmarie, T. L. Wheeler and S. D. Shackleford, USDA MARC, Clay Center, NE.

The technology to remove a steak immediately after ribbing a beef carcass and cooking the steak on a belt grill in less than three minutes and removing Warner-Bratzler shear cores and shearing them for a tenderness value assignment to each carcass is an idea that is being developed by researchers at the U.S. Meat Animal Research Center in Clay Center, NE The method may be applied in a short period of time (less than 20 minutes), is very accurate $R^2 > 90$ % and would be implemented by all packers very soon were it not for the cost of the application. The meat costs on a 4,000 head/day plant would be $6,500/day. Thus, the need for the industry to develop the value of tenderness is very important for the implementation of this technology.

II. TENDERTEC PROBE. The Tendertec probe is being investigated by M. H. George, J. D. Tatum and G. C. Smith at Colorado State University.

The Tendertec probe uses a 14-cm piston with deceleration stops at 3 and 6 cm of carcass insertion. The probe tip of the Tendertec instrument is inserted between the spinous processes of the lumbar vertebrae (L-1 and L-2) through the multifidus dorsi and the longissimus lumborum muscles. The Tendertec measures the force required to penetrate the muscle and relates this force to tenderness.

The Tendertec probe does demonstrate moderate repeatability (precision) in its correlation among carcass sides. Moreover, the Tendertec probe variables correlate more positively, though weakly, with panelist sensory evaluations of steaks than with steak Warner-Bratzler shear values. However, as has been reported for the Tendertec probes predecessors tenderness prediction capabilities (accuracy) appear limited because of its inability to characterize the changes that occur in muscles during the cooking process. In other studies conducted at Colorado State University, the Tendertec probe does show some promise as an indicator of connective tissue effects on beef palatability, particularly in populations of more mature carcasses (i.e., those from cull cows and cull bulls). However, its usefulness as a predictor of beef tenderness in youthful beef is questionable.

III. ELISA CALPASTATIN. ELISA Calpastatin methodology is being investigated by M. Koohmaraie, M. E. Doumit, S. M. Lonergan, J. R. Arbona and J. Killefer, USDA MARC, Clay Center, NE.

Calpastatin is an endogenous inhibitor of the calpain (EC 3.4.22.17, Ca^{2+}-dependent cysteine proteinase) proteolytic system, which has been implicated in a multitude of cellular functions in a variety of tissues. In skeletal muscle, the calpain system has the potential to regulate growth through involvement in myogenic cell differentiation and initiation of myofibrillar protein turnover. It is also well established that calpains are primarily responsible for postmortem proteolysis, which results in meat tenderization. Postrigor calpastatin activity, which is inversely proportional to postmortem tenderization, accounts for a greater proportion of the variation in beef tenderness (~40%) than any other single measure. However, current procedures for quantification of skeletal muscle calpastatin activity are laborious.

Bovine skeletal muscle calpastatin cDNA has been cloned and sequenced. The availability of cDNA clones has made possible the production of recombinant skeletal muscle calpastatin. Production of recombinant calpastatin, which can be readily purified and used for antibody production, circumvents the need to purify significant quantities of calpastatin from skeletal muscle.

An indirect antibody ELISA has been developed for rapid and sensitive quantification of skeletal muscle calpastatin. Polyclonal antibodies were raised in rabbits against recombinant calpastatin, corresponding to domains 2, 3, and 4 of bovine skeletal muscle calpastatin. Western blot analysis revealed that antibodies specifically recognize an immunoreactive calpastatin protein of approximately 130 kDa in prerigor skeletal muscle extracts. The intensity of the immunoreactive bands corresponds qualitatively with assayable calpastatin activity. Calpastatin ELISA results are linearly related to calpastatin activity (calpain inhibitory activity) of heated longissimus muscle homogenates from prerigor lamb (r^2 = .89; n = 40) and beef aged for 24 or 48 h (r^2 = .90; n = 47). Intra-assay CV was < 5% (n = 8) and inter-assay CV was < 6% (n = 5). This assay offers advantages of speed, simplicity and sensitivity over conventional methodology for calpastatin quantification and is a promising method for the segregation of carcasses for tenderness.

IV. DNA GENE PROBES. DNA gene probes are being investigate by Jerry Taylor and Scott Davis, Texas A & M University.

A genetic mapping project is providing important clues to help the beef industry produce the quality and consistency consumers want. The Angleton Project, named for its base of operations at the Angleton Research Center in Angleton, Texas, began 5 years ago with checkoff funding. Its mission was developing a herd that could be used to identify genes responsible for variation in growth and carcass quality traits important to improving beef quality and consistency.

Researchers currently are tracking the location of genes that influence these traits, using DNA samples from animals at weaning. As new groups of cattle are slaughtered, the analysis is updated to reexamine the statistical support for genes already identified. So far, 355 animals have been slaughtered and when this year's spring calves are slaughtered in the fall, 1997, the project will be completed.

Researchers have located 230 DNA markers, or specific locations of DNA on chromosomes. Chromosomes carry the genes that determine genetic traits. Markers are assigned to chromosomes and, by determining the order of the markers and distance between them, scientists can produce what is called a genetic map. So far, Angleton researchers have mapped the breed of origin of DNA at all 230 markers for the herd progeny, and expect to score another 40 markers this year.

But, in the meantime, researchers will use markers to hunt genes. For example, comparing marbling scores of all Angleton herd progeny that inherited two pieces of Angus DNA and the marbling-score of all animals that inherited two pieces of Brahman DNA at that same marker may reveal a gene influencing marbling. If the mean marbling scores of the two groups differ, a gene influencing marbling is close to the marker. At this point, it may be possible to use the marker to identify cattle superior in marbling.

Or, it may be necessary to actually identify the specific DNA differences responsible for the differences in marbling before DNA-marker selection is possible.

Another collaboration with Utah State University led to scoring genotypes for the calpastatin marker. The enzyme calpastatin is involved in the post-mortem breakdown of connective tissue. Angleton researchers integrated this marker into the map of bovine chromosome seven, and tested the whole chromosome for involvement with tenderness factors. Strong evidence was found for a gene on chromosome seven where the amount of calpastatin enzyme produced by cattle with Angus DNA was lower than cattle with Brahman DNA. But no evidence was found that this gene has any effect on Warner-Bratzler shear force measurements of tenderness. These results imply a DNA test for differences in the calpastatin gene may not be a useful predictor of beef tenderness.

This research will lead to production of tests for individual genes that will allow the industry to genotype cattle for breeding and diagnostic purposes, allowing better management of the genetics producers already have. This technology will allow the genes responsible for tenderness to be identified and used to screen seed stock.

(This information was provided by NCBA's "Beef Business Bulletin".)

V. UV-FIBER OPTICS PROBE MEASUREMENTS. UV-fiber optics probe measures are being investigated by H. J. Swatland, University of Guelph, Ontario, Canada.

Recently it has become possible to detect connective tissues in beef using a probe with a single optical fiber to detect the UV fluorescence of collagen and elastin, perhaps also with a contribution from fluorescent pyridinoline cross-links in the collagen molecule (Swatland et al., 1993). Measurements take only a few seconds, can be made in a meat cooler, and cause negligible damage. The UV probe signal may be correlated with panel scores for chewiness.

The UV-Fiber probe utilizes the different photometry of connective tissue vs. muscle to predict meat tenderness. The probe measures fluorescence at the cut surface of muscle and may be very useful.

Meat from animals that are 12, 17 and 24 months, respectively, produced absolute values for the strongest simple correlations of chewiness and numerical indices of $r = .32$ ($P \leq .01$), .32 ($P \leq .01$), and .47 ($P \leq .0005$), for *semitendinosus* muscle, and = .31 ($P \leq .01$), .29 ($P \leq .05$), and .18 (NS), for *longissimus dorsi* muscle. The corresponding multiple correlations derived from stepwise regressions of indices were $R = .64$, .61, and .86 for *semitendinosus*, and .63, .47 and .65 for *Longissimus dorsi* muscle. Therefore, these early data indicates that the UV-Fiber optic probe may be useful in predicting meat tenderness.

VI. ULTRASONIC ELASTOGRAPHY Ultrasonic elastography is being investigated by R. K. Miller and L. L. Moore, Texas A & M University. These data were presented by L. L. Moore at the 1996 Reciprocal Meats Conference in Provo, Utah.

Ultrasonic elastography was used to predict chemical and mechanical measures of beef tenderness. Beef carcasses (n = 30) were obtained from animals of known genetic background of three breed types (3/4 Angus (A) x 1/4 Brahman (B), 1/4 A X 3/4 B, and F_2 A x B crosses). The right side of each carcass was electrically stimulated. Four muscles (*semimembranosus, semitendinosus, biceps femoris* and *triceps brachii*) were obtained from each side. Additionally, the *longissimus* muscle (LD) was obtained from the electrically stimulated side. Warner-Bratzler shear force (kg) of steaks at 2, 14, 28, and 42 days postmortem aging, calpastatin activity (mg/g) sarcomere length (mm), total collagen (mg/g), collagen solubility (%), moisture (%) and lipid (%) were determined. Two gray-scale images, called elastograms, were obtained for each sample using elastography. Stepwise regression was used to determine the ability of textural features extracted from

elastograms ($f1$-$f14$) to predict tenderness measurements. Textural features within the LD muscles predicted shear force at 2 days (R^2 = .26), lipid (R^2 = .25), moisture (R^2 = .23) and collagen solubility (R^2 = .12). Regression equations for the other muscles had low predictability (R^2 = .04 to .39). Textural features used in prediction equations ($f12$, $f13$) tended to be highly correlated to each other, therefore accounting for similar variation in elastograms. These results indicated that ultrasonic elastography has potential to predict beef tenderness, but further research into extraction techniques are needed.

RESULTS

- Elastograms (Figures 1 and 2)
  - Images from the ES; LD appeared more homogeneous than images from other treatment muscles
  - Images from the ES; LD appeared less complex and variable than images from other treatment-muscles

- Characteristics of tenderness and elastography data
  - Means and standard errors for tenderness measures and selected elastography data of ES, LD muscles (Table 1)

- Correlations
  - Several parameters were highly correlated to themselves at all distances
  - Several parameters were highly correlated to each other
    - $f12$ and $f13$ (Table 2)

- Correlations between selected textural parameters and tenderness measures were generally non-significant (Table 3)

- Linear Regression
  - When muscles were grouped together, predictability was generally low (R^2 = .04 to .16)
  - No trend in parameters used to predict each variable across muscles
  - When muscles were analyzed separately, predictability improved, especially for the ES, LD (Table 4)
  - Predictability for other muscles was generally low (R^2 = .04 to .39)

Table 1. Means and standard errors for tenderness measures and selected elastography data of ES, Ld muscles (n = 28).

Variable*	Mean	Standard Error	Minimum	Maximum
Shear force, 2d kg	3.93	.26	1.45	7.5
Shear force, 14d, kg	3.4	.19	1.91	6.47
Shear force, 28d, kg	3.32	.15	1.91	5.42
Shear force, 42d, kg	3.01	.16	1.87	5.00
Calpastatin activity, per g	1.92	.11	1.17	3.36
Sarcomere length, mm	1.75	.02	1.61	2.00
Total collagen, mg/g	2.05	.05	1.48	2.52
Soluble collagen, %	17.92	.37	13.19	21.34
Moisture, %	72.92	.34	66.67	75.49
Lipid, %	4.39	.3	2.35	10.17
d1/f12	-.25	.004	-.30	-.22
d2/f12	-.15	.004	-.19	-.11
d5/f12	-.06	.003	-.10	-.04
d10/f12	-.05	.001	-.07	-.03
d1/f13	.76	.004	.73	.80
d2/f13	.62	.01	.56	.69
d5/f13	.43	.01	.35	.52
d10/f13	.38	.01	.3	.47
d1/f14	.01	.0003	.01	.01
d2/f14	.01	.0004	.01	.01
d5/f14	.01	.0004	.01	.01
d10/f14	.01	.0004	.004	.01

*Variables: Textural parameters where d followed by a number represents the distance from the center of the texture kernel from which the parameter was measured and *f* followed by a number indicates the parameter from 1 to 14.

Table 2. Simple correlation coefficients for *f*12 and *f*13 across all distances.

	d1/f13	d2/f13	d5/f13	d10/f13
d1/f12	-.76	-.79	-.75	-.48
d2/f12	-.87	-.91	-.88	-.66
d5/f12	-.90	-.93	-.96	-.81
d10/f12	-.89	-.92	-.97	-.94

Textural parameters where d followed by a number represents the distance from the center of the texture kernel from which the parameter was measured and *f* followed by a number indicates the parameter from 1 to 14.
Values ≥ ± .37 are significant at $P < .05$.

Table 3. Simple correlation coefficients for selected textural parameters and tenderness measurements for ES, Ld muscles from beef carcasses of three different breed types (n = 28).

	Textural Parameters					
Dependent Variable	d1/f12	d1/f13	d1/f14	d2/f14	d5/f14	d10/f14
Shear force, 2 day, kg	-.30	.28	..07	-.07	-.35	-.01
Shear force, 14 day, kg	-.44	.35	.06	.01	-.23	.02
Shear force, 28 day, kg	-.43	.41	.22	-.19	-.29	.02
Shear force, 42 day, kg	.12	-.11	-.06	.21	.00	.10
Calpastatin activity, per g	.02	.14	-.17	.12	.02	-.15
Sarcomere length, μm	-.11	.06	-.08	.01	.14	-.02
Total collagen, mg/g	.1	-.13	-.02	-.06	-.08	-.16
Soluble collagen, %	.24	-.09	-.39	.21	.01	-.13
Moisture, %	-.22	.37	-.05	.13	-.13	.13
Lipid, %	.04	-.21	.11	-.16	.10	.05

[a]Textural parameters where d followed by a number represents the distance from the center of the texture kernel from which the textural parameter was measured and *f* followed by a number indicates the textural parameter from 1 to 14.
Values ≥ ± .37 are significant at P < .05.

Table 4. Linear regression equations for estimating chemical and mechanical factors for ES, Ld muscles from beef carcasses of three different breed types (n = 29).

Dependent Variable[a]	Independent Variable[b]	R^2	SEE[c]
Shear force, day 2, kg	d2/f12, d5/f14, d1/f2, d10/f2, d5/f2	.47	1.09
Shear force, day 14, kg	d1/f12, d2/f12, d2/f13	.40	.81
Shear force, day 28, kg	d2/f12, d5/f14	.26	.71
Soluble collagen, %	d5/f2	.12	1.86
Moisture, %	d1/f13	.23	1.68
Lipid, %	d10/f8	.25	1.56

[a]Dependent variables: Any dependent variable not included in table is not significant (P > .15). Variables in each model are significant (P < .15).
[b]Independent variables: Textural parameters where d followed by a number represents the distance from the center of the texture kernel from which the parameter was measured and *f* followed by a number indicates the parameter from 1 to 14
[c]SEE: Standard error of the estimation.

CONCLUSIONS

- Correlations indicated that textural parameters were accounting for similar variations in tenderness.
- Tenderness components appear to have low to moderate relationships with information obtained from ultrasonic elastography.

- Information obtained from elastography accounted for 47% of the variation in shear force for ES, Ld muscles at 2 days postmortem, and therefore has efficacy as a potential automated grading technology.