BIOCHEMICAL AND PHYSICAL ESTIMATES OF GROWTH AND DEVELOPMENT IN LARGE SCALE AND SMALL SCALE BOVINE

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1965

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1971

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
December, 1973

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ACKNOWLEDGEMENTS

The author expresses his sincere appreciation to Dr. John J. Guenther, Professor of Animal Science, for his guidance and counsel during the course of this study and the preparation of this thesis.

Grateful acknowledgement is also extended to Dr. L. E. Walters, Professor of Animal Science, Dr. R. D. Morrison, Professor of Mathematics and Statistics, Dr. Donald G. Wagner, Associate Professor of Animal Science, Dr. Billy G. Hudson, Assistant Professor of Biochemistry, and Dr. Wilbur S. Newcomer, Professor of Physiological Sciences for their cooperation and assistance in the preparation of this thesis.

Special appreciation is extended to Dr. Thomas R. Thedford, Associate Professor of Veterinary Medicine and Surgery, Dr. Thomas C. Randolph, Jr., Assistant Professor of Veterinary Medicine and Surgery, and Dr. Lawrence E. Evans, Associate Professor of Veterinary Medicine and Surgery, for their tireless efforts in obtaining the live animal biopsy samples and radiograms.

Further appreciation is extended to Mr. Roy Escoubas, graduate student in Food Science, Mrs. Kris Novotny and Mrs. Sharon Strain, laboratory technicians, for their invaluable assistance in the data collection and sample analysis.

The writer also wishes to express thanks for the understanding and continuous encouragement from Carolyn, Darryl, and Darcia, during this program of graduate study.

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CHAPTER I

INTRODUCTION

For many years, a primary goal of animal scientists has been to selectively breed and produce meat animals with the ability to grow rapidly, efficiently convert food stuffs to gain and to deposit a large percentage of "quality" lean tissue.

In assessing the efficiency of quality meat production in cattle, many "gross" indices such as birth weight, weaning weight, rib eye area and carcass cutability have been utilized by a number of researchers. Since these particular indices are not available until weaning age, or later, obviously a considerable amount of time and money has been invested by the producer in growing the animal to that stage of development. Therefore, if indices of future growth rate and performance were available to the breeder shortly after birth, the utilization of these indices would result in considerable monetary savings to the producer since those animals with poor potential would be discarded from the breeding program at an earlier age, as well as identifying those animals with superior breeding potential more rapidly.

The purpose of this study was to attempt to identify possible pre-weaning indices of superior growth and performance from the investigation of differences in the chemical composition, biochemical

metabolic activity, and physical skeletal structure of a small scale bovine breed and a large scale "exotic" bovine breed from shortly after birth to market age.

CHAPTER II

LITERATURE REVIEW

The review to follow includes a general discussion of the composition, morphology, and biochemistry of red and white muscles and fibers, a definition of growth and development, and a general review of the gross indices that may be utilized to follow patterns of growth in the live animal.

Red and White Muscle

General

The biochemical composition of red and white muscle has been identified by several workers. However, there are discrepancies in the literature probably as a result of the extent of "redness" or "whiteness" of the muscle. It is generally accepted that most muscles are a mixture of red and white muscle fibers; therefore, the "redness" or "whiteness" may depend on the ratio of red to white fibers or to pigment concentration.

Biochemistry and Metabolism

It is difficult to identify the metabolic characteristics of an individual fiber because of its size and functional relationship to adjoining fibers. However, the literature indicates considerable

research has been done with muscle preparations, by which the terms "red" and "white" muscle have become widely used.

The terms "red" and "white" when applied to muscle denote a combination of morphologic and physiologic differences observed by many investigators in numerous vertebrae species. Needham (1926) summarized the early pioneering investigations on the biochemical as well as the structural and functional differences in the two types of muscle. The classic theory accepted by most all researchers is that "white" muscle is capable of rapid but brief contractions, primarily utilizing glycolysis for energy production; whereas "red" muscle, which can contract for prolonged periods, relies chiefly on oxidative mechanisms (Szent-Gyorgyi, 1953). Recent studies have indicated that red and white muscle fibers respond differently to denervation and to various disease processes (Fahimi and Ray, 1966). The slow muscle in the dystrophic mouse was less affected than the fast muscle (Brust, 1966) and the pale, soft, exudative condition in pig muscle has been correlated with a high percentage of intermediate type fibers in the affected muscles (Cooper, Cassens, and Briskey, 1969).

It is well known that red and white muscles are not homogeneous with respect to fiber type but are composed of varying ratios of red, white, and intermediate fibers. There are reports of some homogeneous white muscles (Arangio and Hagstrom, 1969) and also homogeneous red muscles (Bocek and Beatty, 1966). Most mammalian muscles, however, contain at least three types of fibers (Moody and Cassens, 1968).

Differentiation of Fiber Types in Skeletal Muscle

It has been generally accepted there are two basic skeletal muscle

fiber types, both of which are found in most all mammalian muscles. These two fiber types are known by several different names, as well as a third, intermediate fiber type being recognized by some workers.

Dubowitz and Pearse (1960) recognized two fiber types based on the reciprocal activity of phosphorylase and various dehydrogenases in individual muscle fibers. These are the Type I fibers rich in dehydrogenases and poor in phosphorylase and Type II fibers which are rich in phosphorylase and poor in the dehydrogenases. These workers noted the intermediate type of fibers which had no specific enzymatic reaction.

Stein and Padykula (1962) recognized three fiber types (A, B, and C) in the rat gastrocnemius based on the succinate dehydrogenase reaction. They correlated the A fiber with the classical "white" fiber (Type II) while the B and C represented two forms of "red" fiber (Type I). Romanul (1964) recognized eight fiber types utilizing numerous enzyme systems including cytochrome oxidase, the diaphorases, various dehydrogenases, phosphorylase, and esterase on cross sections of rat calf muscle. Some muscles (gastrocnemius and plantarius) contained all eight, while others (soleus) had only three. He then separated these eight fiber "types" into three groups. One group had a high capacity to utilize glycogen, a low lipid metabolism, low oxidative metabolism, and a low myoglobin content. These groups could well correlate to the Type II or "white" fiber recognized by other workers. Another group of fibers had a low capacity for glycogen breakdown, a very high lipid metabolism, high oxidative metabolism, and high myoglobin content. These groups could well represent the Type I or "red" fiber recognized by others. The third group recognized by Romanul

(1964) had a moderate ability to utilize glycogen, moderate lipid metabolism, and a high myoglobin content. This group is similar to the "intermediate" type of fiber previously recognized. A similar type of study was conducted by Stein and Padykula (1962) with the same characteristic groups being recognized.

Most skeletal muscles are composed of all three types of fibers with very few muscles containing only one specific type. There are also differences within the same muscles among different species. Nystrom (1968) reported all three fiber types in the gastrocnemius of the cat, a "fast-white" muscle. Nystrom also reported that the "slow-red" type of muscles were primarily a Type C fiber as described by Stein and Padykula (1962).

The techniques which have led to the definition of the types of skeletal muscle fibers have also made possible the study of their development and differentiation. In some animals it has been reported that skeletal muscle is fully differentiated into its fiber types at birth. Examples of full differentiation at parturition would be in the guinea pig and man. In other animals such as the mouse, rat, and rabbit, complete differentiation only occurs postnatally (Dubowitz, 1963). It has been generally accepted by most workers that the undifferentiated fiber type most closely approximates the Type I (or C) red fiber.

While there is considerable evidence of variation in distribution of fiber types in animals of different species, there is also considerable variation from one muscle to the other in the same animal. Dubowitz (1965) and Nystrom (1968) have shown histochemically that some muscles may differentiate earlier than others and there may

also be earlier differentiation with some enzymes than with others. Individual muscles may show characteristic patterns of change. Cosmos (1966), using phosphorylase and SDH activities, has shown that in the chick both the pectoralis and the gastrocnemius initially contain only one fiber type, which conforms to the Type I fiber. The pectoralis changes postnatally into Type II fibers while the gastrocnemius differentiates into three types. Nystrom (1966) observed in the gastrocnemius of the newborn cat that the fibers were initially all of one type and subsequently differentiated into two and then three types. The soleus of the cat consisted of one type initially but remained uniform in fiber type, except for a transitory period of differentiation into two types between 2 and 7 weeks.

Composition of Red and White Muscle

There are several differences that have been identified as being associated with the two types of muscle. One obvious difference is the pigment concentration of the two types of muscle. Lawrie (1950) found that horse longissimus muscle contained 0.465% myoglobin (wet weight) as compared to 0.705% in horse psoas. It is also well known that the myoglobin content of muscle increases as an animal matures. Lawrie (1952) postulated that the more myoglobin there is in skeletal muscle the greater appears to be its capacity for respiratory metabolism and the less its ability to carry out glycolytic processes. This conclusion appears to be in conflict with other researchers who have shown that as an animal matures there is less oxidative metabolism in the muscle tissue and increased glycolytic metabolism. Lawrie does not discuss the differences in the oxygen affinity of the different

types of hemoglobin present in the young and old animals which may have an influence on the amount of myoglobin required in muscle for adequate oxidative processes or the vascular system.

There are also reported differences in the soluble protein content of red and white muscle. Barany et al. (1965) found that rabbit extensor digitorum longus (white muscle) contained 52 mg of soluble sarcoplasmic protein per gm fresh muscle as compared to only 23 mg/gm fresh muscle of soluble sarcoplasmic protein in the soleus (red muscle). There was virtually no difference between the two muscles in myosin and actin (myofibrillar) content. The red muscle was also shown to contain more noncollagenous (stroma) protein than the white muscle by these same workers.

The two principle energy sources in the two types of muscles are also varying in concentration. Glycogen is higher in the white muscles (Ogato, 1960) than in the red muscles. Conversely, Beecher (1966) found that trapezius (red) muscle contained more than twice as much lipid as does longissimus (white) muscle.

The differences in the mineral composition of different bovine muscles was studied by Swift and Berman (1959). They reported that they found bovine longissimus (white) muscle contained 415 mg potassium/100 gm wet tissue as compared to 381 mg potassium/100 gm wet tissue in trapezius (red) muscle. Similar values were found in other muscles with the predominantly white muscles being higher in potassium than the red muscles.

Similar results were reported by Sreter and Woo (1963). These workers, using rat muscles, found that the extensor digitorium longus (white) muscle contained 114.0 mEq/kg fat-free wet weight of

potassium as compared to 97.7 mEq in the soleus (red) muscle. These researchers also examined both red and white fibers of the gastrocnemius muscle. The white fibers were found to contain 116.24 mEq of potassium per kilogram fat-free wet weight as compared to 107.69 mEq for the red fibers. Their work also showed that the sum of the potassium and sodium concentrations were quite constant in all muscles analyzed and that in mixed muscles as the ratio of red-to-white fiber content increased, the sodium concentration increased while the potassium concentration decreased.

Morphology

The simplest morphological characteristic that can be used to identify red and white fibers is size. Goldspink (1970) states that the total number of fibers a particular muscle receives is genetically determined, whereas the size of the fibers is determined by the physiological conditions to which the muscle is subjected. Also, once differentiation is complete all the fibers in the muscle are about the same size (20 μ in diameter). Some fibers stay at this size (Goldspink and Rowe, 1968) while others may undergo further development during growth. Therefore, the smaller fibers are predominant in early life while the larger fibers are more prominent near maturity.

It has also been reported that these large phase fibers may revert back to a small phase fiber (Goldspink, 1965). Goldspink found the effect of partial starvation on the mouse bicep brachii was to cause "large phase" muscle fibers (42 μ) to revert back to a "small phase" fiber (23 μ). This was a rapid change that could be accomplished in 1-2 days. When adequate nutrition was supplied, the "large

phase" fibers increased in diameter to their original size. Goldspink thereby disagreed with others (Dubowitz and Pearse, 1960) who stated that these were two discrete types of fibers. The latter researchers reported that histologically the large fibers reacted weakly for the oxidative enzymes and strongly for phosphorylase, while the small fibers reacted strongly for oxidative enzymes and weakly for phosphorylase. These small fibers were found to correspond to red muscle fibers in animals and the larger fibers to white muscle fibers.

Citric Acid Cycle

There is considerable evidence in the literature that the citric acid cycle (CAC) activity is higher in red muscle than white muscle. Bocek, Basinger, and Beatty (1966) reported a glucose uptake of 1.90 mg/gm per hr wet weight in red muscle and an uptake of 1.65 mg/gm per hr wet weight in white muscle. Of the total uptake, 22.5% of the radioactive glucose was incorporated into glycogen in red muscle and only 9.2% in white muscle. Also, 9.7% was found in CO_2 produced by red muscle and only 6.4% was found in CO_2 produced by white muscle. While 52.1% of the labeled glucose was found in lactate and pyruvate in white muscle, only 37.7% was found in red muscle. This reflects the increased oxidation of pyruvate and lactate into CO_2 in the more active CAC found in red muscle. Furthermore, these same authors found that red muscle produced 59 μ moles of ATP/gm per hour and white muscle, 54 μ moles of ATP/gm per hour, further evidence of the greater oxidative capability of red muscles.

Several workers have demonstrated higher respiratory rates in red muscle homogenates and mitochondria, muscle slices, and muscle fiber

groups (Ogata, 1960; Cassens, Bocek, and Beatty, 1969). Ogata (1960) demonstrated a greater stimulation of respiration for red than for white muscle with pyruvate and succinate as substrates.

Several authors have shown a greater activity of succinate dehydrogenase (SDH) in red muscle than white muscle. Beatty, Basinger, Dully, and Bocek (1966) reported 28.7 μg formazan/15 min per mg nitrogen produced in soleus muscle (red) of the rhesus monkey versus only 5.8 μg formazan/15 min per mg nitrogen in brachioradialis (white) muscle. They also reported an activity of 58.8 units in the red part of rat semimembranosus with only 21.6 units in the white portion. Beecher, et al. (1969) reported 2.6 units/gm of muscle of SDH activity in serratus ventralia (red) muscle of the pig, whereas the predominantly white longissimus dorsi had 1.2 units of SDH activity.

Other authors have studied the changes in SDH activity with growth and development of various species. Greenfield and Boell (1968), measured SDH activity in embryonic and newly hatched chicks by the phenazine methosulphate (PMS) method. They found a specific activity for muscle mitochondria of 0.13 μ moles per min per mg mitochondrial protein in 11 day old embryos versus 0.46 μ moles in newly hatched chicks.

Blackshaw (1963) measured the enzymatic activity of mouse testis by a tetrazolium salt, 2-(p-iodophenyl)-3-(p-nitrophenyl)-5-phenyl tetrazolium chloride (INT). He reported a Km for SDH of mouse testis of 4.14×10^{-4}.

Pennington (1961) used INT to measure the SDH activity of liver mitochondria in dystrophic mice muscles. Pennington found that INT was superior to neotetrazolium. Also, the formazan production was

proportional to the amount of mitochondria present and increases, linearly, with time. There was negligible INT reduction by the mitochondria when succinate was omitted from the medium. In addition, Pennington studied the effect of phenazine methosulphate (PMS), which can act as a direct acceptor of electrons in the oxidation of succinate by SDH of heart muscle (Singer, 1959). Therefore, it would seem possible that PMS might increase formazan production by acting as an intermediate electron carrier. However, it was found that INT was also reduced non-enzymatically in the presence of PMS, even with malonate. It was therefore suggested PMS not be used as an intermediate electron carrier with INT.

Glycolysis and Glycogen Metabolism

The rate of glycogenolysis plus glycolysis as measured by the production of chemical lactate and pyruvate was at least twofold higher in white than in red muscle (Bocek, Basinger, and Beatty, 1966). Lactate dehydrogenase (LDH) activity was found to be higher in white muscle than red muscle (Blanchaer, Van Wijhe, and Mozersky, 1963). Also, the distribution of the LDH isozymes were found to be different in the different fiber types. In single red muscle fibers isozymes I, II, and III were found to be moderate to strong in activity; however, these fibers also contained isozymes IV and V. Isozyme V was strongly represented in white muscle fibers while the other isozymes were less active (Van Wijhe, Blanchaer and Stubbs, 1964).

Growth and Development

General

Growth has been defined in the literature in many different ways. Schloss (1911) defined growth as a correlated increase in the body mass of the body in definite intervals of time in a way characteristic of the species. Brody (1945) defined growth as the production of new biochemical units brought about by cell division (hyperplasis), cell enlargement (hypertrophy) or incorporation of materials from the environment. McKeenan (1941) simply defined growth as an increase in weight until a mature size is reached. Therefore, there are several different ideas as to an exact definition of growth. Russell (1969) pointed out the fact that growth is not composed of point-to-point changes but is a continual balance of gain and loss of total animal mass. As long as the gain exceeds the loss of animal mass, growth will occur. Growth normally is linear during the early phase of an animal's lifetime because as the equilibrium between the increase and loss of mass was relatively constant during the linear phase, a shift in the equilibrium occurs during the curvilinear phase. This relationship between gain and loss may be applied to the animal as a whole as well as the major tissues: muscle, bone, and fat.

Development is another term with widespread disagreement as to its relative definition. Some want to define growth to include development while others insist the two should be separated. Needham (1931) referred to development as the directive coordination of diverse processes into an adult or into an "organized heterogeneity". Gall (1969) states that while growth may be an increase in size or mass,

development leads to the establishment of a certain definite shape or form. In early developmental stages, morphogenetic changes take place essentially by segregation and differentiation of tissues. In later stages of development, they are mainly caused by the relative but different growth rates exhibited by various components of the body.

Bone Growth and Development

In studying bone growth and development one must immediately be impressed by the complicated structural and functional system with many biochemical and physiological relationships. Whereas bone is a dense, hard, mineralized, cellular tissue, it is not a passive or inert tissue but a very active tissue undergoing constant activity.

Bone growth may be defined as the period when addition of ions predominates over withdrawal of ions, resulting in a net increase in size and possibly in number of bone crystals (Zobrisky, 1969). Since bone is a rigid, calcified structure, this eliminates the possibility of interstitial (intercellular) growth. The increase in size of bone is therefore by appositional growth which is the deposition of new tissue (minerals and matrix) on the surfaces of pre-existing bone. Therefore, an increase in bone length can occur only at the cartilaginous epiphyseal plates. This growth can occur only as long as the epiphyseal plates are open and growth therefore terminates at "maturity" or closure of these plates. It is important to note that growth rate and thickness of the epiphyseal plate tend to parallel each other. Henceforth, the epiphyseal cartilage growth is a process of interstitial, not appositional, growth such as observed in the

true bone material. This phenomena is utilized as a quantitative measure of the presence of growth hormone (McLean and Urist, 1968).

CHAPTER III

MATERIALS AND METHODS

General

The experimental units for this study were eight (8) grade Angus steer calves and eight (8) crossbred Charolais (7/8 Charolais x 1/8 Angus) steer calves. The Angus calves were purchased from a commercial herd located in Woodward County, Oklahoma, and were selected to represent a small scale type of bovine. The Charolais calves were purchased from a purebred breeder in Tulsa County, Oklahoma, and were selected to represent a large scale type of bovine.

The main criteria used for selection of the calves were that all calves be of the same sex (male), and of as uniform age as possible. Also, all calves utilized were from the first calf-crop of their dams and all calves within each breed had a common sire. In addition, all dams were appraised visually and attempts were made to select calves from dams of size and structure common to the particular growth regimes being investigated.

After selection, the calves and their respective dams were transported to Stillwater and delivered to a previously designated University range. Both groups were maintained on the same pasture under similar environmental conditions. The animals were delivered about March 15, 1972, and kept on the designated pasture until the middle of July when all were transferred to the Lake Carl Blackwell South

Range due to the availability of a water supply for the herd.

All calves were maintained with their respective dams until weaning at the end of the fourth evaluation period (approximately 210 days of age). Creep feed was available ad libitum on the Lake Carl Blackwell range and the calves were treated (i.e. dehorned, castrated, shots) as necessary at the first evaluation period.

Upon weaning, the calves were removed from their dam and transferred to a finishing dry-lot at the OSU Beef Evaluation Center for the post-weaning phase of the study. Also, at this time the dams were returned to their respective owners.

During the dry-lot phase of this study, all calves were fed in the same pen (or pens) on a standard finishing ration. The protein content of each ration being based initially on the requirements of the small scale calves, and then was adjusted appropriately as the animals increased in body weight.

Procedure

Evaluation Periods

The animals were evaluated at specific times in their market lifetime irrespective of growth rate or body weight. Hence, this particular project was designed to compare the two groups at the same chronological age.

This particular study was divided into two separate phases, the maternal (pre-weaning) phase and the feedlot (post-weaning) phase. Each phase was composed of four periods. Each period was 56 days long. All calves were weaned at the conclusion of the fourth period

in the maternal phase, and slaughtered at the end of the fourth period in the feedlot phase.

Data Obtained by Period

Data were obtained at each period from each animal to include: 1) linear body measurements, 2) live weight, 3) rate of gain, 4) radiographs of left metacarpal, 5) whole body ^{40}K count and 6) muscle tissue "live animal" biopsy samples. Each of these responses will be discussed individually.

Whole Body Variables

Body Measurements

In order to evaluate the differences in the body growth patterns of the two maturity groups, eight specific linear skeletal measurements were obtained from each animal at each evaluation date. These measurements were selected to evaluate the growth of the animal relative to length, width, and depth of body. The various measurements were identified as follows: 1) body depth, 2) thickness of forequarter, 3) thickness of hindquarter, 4) width of rump, 5) length of rump, 6) depth of forequarter, 7) length of topline, and 8) length of side.

Body depth was obtained with a set of wooden calipers by placing the fixed arm of the calipers against the sternum just posterior to the front limb (parallel to area of 5th and 6th ribs) and then allowing the movable arm of the calipers to slide down until it fit snugly against the dorsal surface of the animal. Thickness of the forequarter was determined by fitting the jaws of the calipers to the lateral

surface of each shoulder parallel with the spine of the scapula and allowing the frame of the calipers to rest on the dorsal surface of the animal. The thickness of the hindquarter was obtained similarly by aligning the jaws of the calipers vertically with the hind limbs. The distance between the jaws of the calipers was then measured with a steel measuring tape.

Metal calipers were utilized to measure the length and width of the rump and the depth of the forequarter. Width of rump was determined by physically palpating the lateral extremity of each tuber coxae and then fitting the point of the jaws of the calipers to these positions. The length of rump was determined by palpating the anterior tubercle of the tuber coxae and the most posterior tubercle of the tuber ischii. The calipers were then fitted over these two points. The depth of forequarter was measured by placing the point of one jaw of the calipers on the dorsal surface of the scapula in line with the spine of the scapula and extending the calipers until the other jaw rested on the posterior point of the olecranon. Again, a steel tape was used to measure the distance between the points of the jaws of the metal calipers.

The length of topline was determined by measuring the distance between the most anterior and dorsal point of the scapula to the extreme posterior surface of the tuber ischii. Length of side was obtained in the same manner using the anterior lateral tuberosity of the humerus and the anterior point of the tuber coxae as reference points.

The animal was positioned squarely on all four limbs while all eight measurements were obtained then moved and repositioned

for the second series of measurements. This gave duplicate measurements from the right side of the animal.

Whole-Body ^{40}K Count

Whole-body ^{40}K count was determined on each animal at each evaluation date. The calves were delivered to the Oklahoma State University Live Animal Evaluation Center approximately 24 hours prior to counting, washed with soap and water and allowed to dry overnight. They received no feed or water. Animals were weighed immediately prior to being placed into the counter; therefore, the live weight of each animal at each date was based on a full 24-hour shrink.

Two types of counting configurations were utilized. The small calf counter was used for Periods 1-5 and the large calf counter was used for Periods 6-8. Wood slats were utilized when needed to raise the smaller animals to a uniform distance from the counter logs. This increased the precision of the counting effort since it standardized the distance animals of different scale were from the counting logs.

The counting procedure utilized consisted of a beginning KCl standard (619.03 gm KCl) count immediately before and a closing standard count after each group was counted. Each KCl standard count and the individual steer count consisted of five two-minute counts. Each standard and animal count were both preceded and followed by separate background counts of the same duration.

Since this study encompassed a period of approximately 14 months with varying climatic and environmental conditions and since two types of counters were utilized, it was necessary to adjust each day's net count by the counter efficiency for that day. The formula

for counter efficiency was: $\frac{\text{Average Net KCl count}}{66,300} \times 100 = \text{counter efficiency (\%)}$. The adjusted net counts for each animal was determined by: $\frac{\text{Net Count}}{\text{Counter Efficiency (\%)}} = \text{adjusted net count.}$

Radiograph

One of the major tissues composing the growing animal is bone. It is generally accepted that of the three major tissues comprising the beef animal (i.e. bone, muscle, fat) that bone is the first to fully mature. Therefore, it would seem reasonable to study the development of this tissue in relation to the other two.

One method of analyzing bone development is by radiographs. In this experiment, the left metacarpal of each animal at each period was radiographed for later evaluation.

The animals were radiographed within 2-3 days of each date that the ^{40}K count was taken, thereby enabling evaluation of bone development at the same weight and age as when the other whole body measurements and tissue samples were obtained.

On the days the radiographs were to be made, the animals were delivered to the OSU Veterinary Medicine Radiology Laboratory, radiographed and returned immediately to the pasture or feedlot as appropriate.

To obtain the radiograph, the animals were haltered and led to the X-ray room. A portable field X-ray machine (Picker) was utilized, consequently it was necessary to only position the animal at the specified distance in front of the machine. All radiograms were taken anterior to posterior (A-P).

The measurements acquired on each radiogram are illustrated in

Figure 1. Total length of the bone was determined by measuring the distance between the dorsal surface of the proximal condyle and the ventral surface of the distal condyle. The proximal width of the bone was measured as the horizontal distance between the lateral edges of the metacarpal approximately 1 cm ventral to the dorsal surface of the proximal condyle. The distal bone width was determined approximately 1.5 cm dorsal to the distal epiphyseal line.

The total median diameter was the distance between the lateral and radial surfaces of the bone located midway between the extreme proximal end and the distal epiphyseal line. The marrow diameter was obtained at the same point as the median diameter except it consisted of the dark, porous area only. Results were expressed in millimeters.

Total bone area was estimated by tracing the outline of the bone along the proximal surface, both lateral and medial edges and through the epiphyseal line with a compensating polar planimeter. Results were expressed in square inches.

Biochemical and Histological Determinations

Biopsy Procedure

The procedures for obtaining the "live animal" biopsies utilized in this study have previously been described by Guenther (1972).

Animals were biopsied immediately following ^{40}K counting at each period; therefore, the handling of animals prior to surgery was as described for the ^{40}K procedure.

In order to obtain "live animal" biopsies, it was necessary to place the animals under a general anesthetic. This technique of

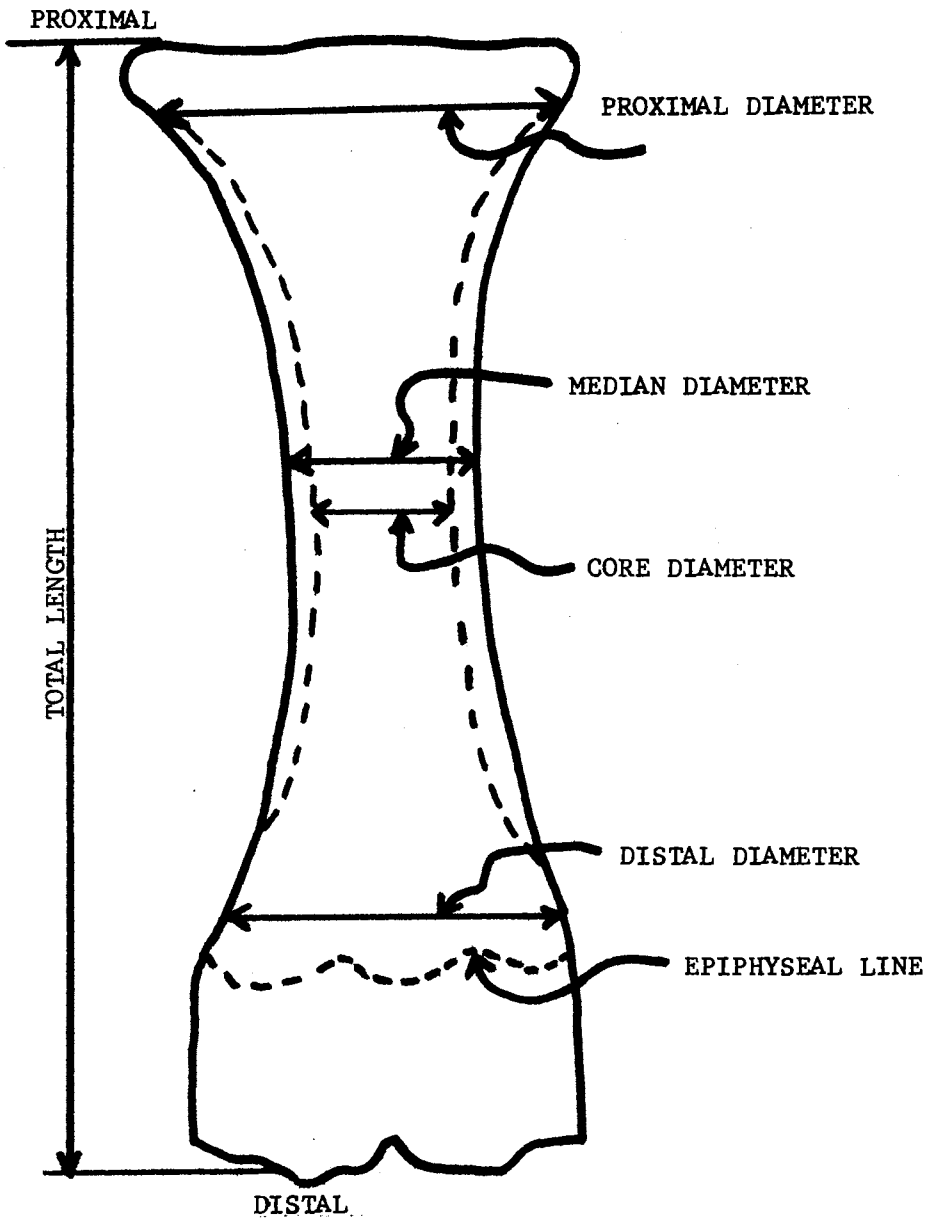

Figure 1. Illustration of Radiogram Measurements from Left Metacarpal

immobilization was selected to reduce the amount of stress imposed on the animal and to prevent an abnormal in vivo condition of the muscle tissue. The use of a general anesthetic would thereby eliminate the effect of a local type anesthetic on the muscle tissue being obtained that might interfere with the biochemical and histological determinations to be made on the tissue.

Immediately after completion of the ^{40}K counting the animal was haltered and a blood sample (100 ml) was obtained via jugular puncture. The same puncture was then utilized for intraveneous injection of SURITAL (Parke-Davis Pharmecutical), a sodium thiamylal preparation, at the rate of 4 mg per pound of body weight. The anesthetic completely immobilized the animal within 15-30 seconds and the animals were laid on their side for surgery. The biopsy area was clipped, washed with soap and water, alcohol, and iodine. Then, an incision was made above the designated biopsy site beginning just off the midline and running laterally for three to four inches. The cutaneous tissue was clamped and pulled back to expose the fascia covered muscle tissue. Samples were removed with a 1/4 HP electric drill equipped with a one inch diameter stainless steel coring device. Samples weighing 15-20 grams each were obtained via this technique, blotted free of excess blood, wrapped in aluminum foil, and immersed in liquid nitrogen.

After core removal, the surgical site was treated with FURACIN (Eaton Veterinary Laboratories), a nitrofurazone compound, and the site was sutured with two to three stiches.

The frozen samples were removed from the liquid nitrogen and stored on ice until arriving at the Meat Laboratory. Samples were then transferred to small plastic bags (Whirl-Pak), labelled, and

stored at -20°C until biochemical and histological analysis could be accomplished.

Biopsy Sites

Previous discussions have described the overall statistical design of this study as being an 8 x 8 Latin Square with eight animals, eight periods, and eight sampling sites (positions). Therefore, to insure that each sampling site could be distinguished from animal to animal each period, it was necessary to designate these sites in a manner that could be repeated.

The biopsy sites selected are illustrated in Fig. 2. The left side of the animal was designated as side 1 and the right side as side 2. Position 1 was immediately above the 11th rib and Position 2 was above the 13th rib. Positions 3 and 4 were extracted from the area of the 2nd and 4th lumbar vertebrae respectively.

Enzyme Analysis

It is pointed out in Chapter II that the metabolic activity of muscle tissue may be estimated by various biochemical techniques. An estimate of the state of metabolic activity of the muscle tissue samples was accomplished by determining the total oxidative and total glycolytic activity of the individual samples. This was accomplished by measuring spectrophotometrically the reduction of a tetrazolium salt by succinate dehydrogenase (oxidative) and lactate dehydrogenase (glycolytic). Procedures utilized were adapted from Beecher (1966), and Blackshaw (1963). The tetrazolium salt utilized was 2-(p-iodophenyl)-3-p-nitrophenyl-5-phenyl-tetrazolium chloride (INT) obtained from Sigma

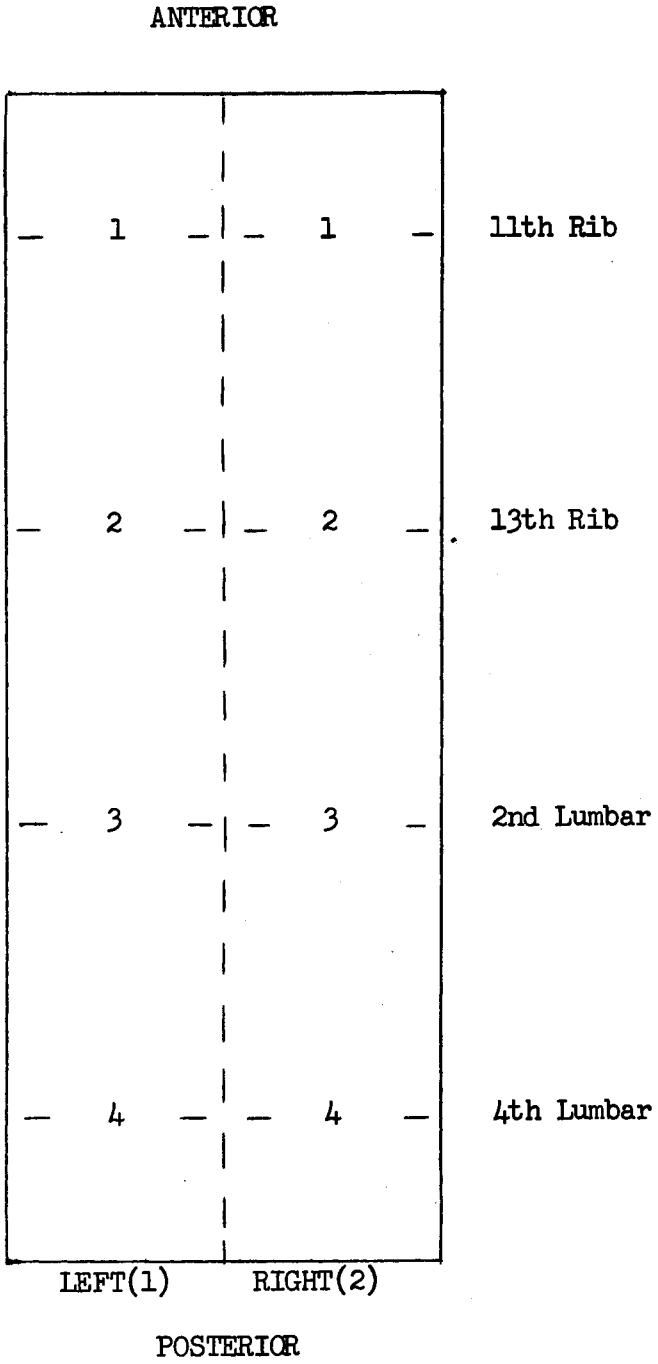

Figure 2. Illustration of Biopsy Sites in Longissimus Dorsi Muscle

Chemical Co.

Succinate dehydrogenase (SDH) activity and lactate dehydrogenase (LDH) activity were determined from the dilute salt soluble fraction of the muscle tissue homogenate. The frozen tissue sample was removed from the freezer and duplicate samples of approximately one gram each were chipped from the sample core. The samples were rapidly weighed and then immersed in 25 ml of cold ($4^{o}C$) 0.2M $Na_2HPO_4 \cdot 7H_2O$ (pH 7.5) buffer prior to thawing. The samples were then finely minced with scissors in a petri dish and transferred to Potter-Elvehjem all-glass tissue homogenizer fitted with a teflon pestle that was serrated on the bottom. The dilute salt soluble fraction was extracted by several complete passes (6-8) of the pestle which was connected to a small electric laboratory motor. The homogenized sample was then poured into a 50 ml plastic centrifuge tube, capped, and centrifuged at 3,000 rpm in a Sorvall RC-2B refrigerated centrifuge at $0^{o}C$ for 15 minutes. The dilute salt insoluble fraction was thereby sedimented to the bottom of the tube and the supernatant could be decanted and extract volume was recorded (20-23 ml).

The supernatant from this extraction procedure should now contain the dilute salt soluble enzymes common to the Embden-Meyerhoff pathway, as well as the intact mitochondria (Beecher, 1966; Chappel and Perry, 1954; Holloszy, 1967). Care must be taken to insure that the mitochondria are not ruptured to such an extent that the enzymatic activity is destroyed or inhibited. Preliminary studies in this laboratory indicated that the above extraction procedure would produce a fraction containing viable mitochondria. The most critical factor affecting the extraction procedure was that the teflon pestle in the

Potter-Elvehjem tissue grinder must be loose fitting, but not to such an extent that the tissue could pass without being thoroughly homogenized. This was accomplished by grinding the pestle to where there was a tolerance of about one mm between the pestle and homogenizing flask.

For the sample analysis, tubes were labelled and reagents were added as follows (duplicate samples):

Tube No.	Reagent	Volume
1-4 & 8-11	1.5×10^{-4} M PO_4 buffer	1.3 ml
	1.0 M Na Succinate	0.1 ml
	1.5×10^{-3} M INT	0.1 ml

These were the tubes that were utilized for the determination of SDH activity. Succinate blanks were prepared as follows:

Tube No.	Reagent	Volume
5-7 & 12-14	1.5×10^{-4} M PO_4 buffer	1.3 ml
	1.0 M Na Succinate	0.1 ml
	Distilled H_2O	0.1 ml

The above system was prepared and allowed to stand at room temperature until the reaction was initiated, with the INT solution being added just prior to the sample because the oxidized form of the INT utilized is light sensitive and can be spontaneously reduced by light.

The reaction was initiated by the addition of 1.0 ml of the sample extract to each tube (both substrate and blank systems). After the sample extract was added, the tubes were placed in a 37°C water bath and allowed to incubate for 15 minutes. The reaction was terminated by the addition of 0.5 ml of 20% TCA and shaking. The reduced INT formazan was extracted by the addition of 3.0 ml of Ethyl Acetate

(CH_3 $COOC_2$ H_5) followed by vigorous (1 minute) shaking of the capped tube. The ethyl acetate and water layers were separated by centrifuging the sample tubes at 8,000 rpm for 15 minutes at 15°C in the previously described centrifuge.

The optical density (O.D.) of each tube was measured by removing an aliquot from the ethyl acetate layer (red layer) and transferring such to a 1.0 ml micro-cuvette. Density was measured at 490 nm against an ethyl acetate blank on a Gilford Spectrophotometer (Model 240).

Net activity was calculated by the difference in the average of the quadruplicate substrate containing tubes and the triplicate blank tubes. This difference reflects the total reduction of INT per 15 minutes expressed in units of optical density.

Lactate dehydrogenase activity was determined exactly as for SDH except that Na Lactate was substituted for the Na Succinate in the appropriate tubes.

The net activity of both SDH and LDH were expressed in terms of O.D. units per 15 minutes. In order to account for the differences in sample weight and extract volume among samples, the term gm/vol was utilized. Gram/volume (gm/vol) was determined by: $\text{gm/vol} = \frac{\text{Sample Weight}}{\text{Extract Volume}}$. The net activities of SDH and LDH were calculated by: Net SDH = $\frac{\text{SDH}}{\text{gm/vol}}$; Net LDH = $\frac{\text{LDH}}{\text{gm/vol}}$. These units of measure were then utilized in the analysis of the data.

One method of analysis was to combine the net SDH activity and the net LDH activity to give the total metabolic activity (TMA). Then the relationship bewteen SDH and LDH was expressed by: % oxidative activity = $\frac{(\text{Net SDH}) \times 100}{\text{TMA}}$; % glycolytic activity = $\frac{(\text{Net LDH}) \times 100}{\text{TMA}}$.

Because several earlier researchers have attributed the reduction of oxidative metabolic activity in muscle tissue (per unit weight) to a dilution effect due to increased protein concentration with chronological age, the activities were also calculated so as to investigate this possibility. To do this, the net activity of both SDH and LDH were expressed per unit (mg) of extractable protein in the tissue extract. The protein concentration of the extract was determined by the biuret method (Layne, 1957).

Chemical Potassium

The chemical muscle tissue potassium concentration was determined via atomic absorption spectroscopy following acid digestion of the sample.

Samples were removed from the freezer and duplicate (approx. one gram) samples were chipped from the frozen core. After weighing, the tissue was placed into a 50 ml beaker and the acid digestion solution was added. The digestion solution consisted of 25 ml of 3 parts Perchloric acid (70%) to one part of Nitric acid. The digestion solution was mixed just prior to addition of the sample.

The samples were allowed to digest under a perchlorate stainless steel hood until only a small amount of moisture was left in the bottom of the beaker. For digestion the sample beakers were set on an electrical hot plate on a low heat setting. Digestion took from 24 to 48 hours for most samples.

After digestion was complete, the samples were removed from the hot plate and allowed to cool. The beaker was then thoroughly rinsed with deionized glass distilled water and the contents filtered through

a long stem funnel into a 500 ml volumetric flask. After thorough rinsing of the beaker, the volume in the flask was brought up to 500 ml with the distilled water.

Ten ml aliquots was taken from each flask and labelled. These vials were then taken to the OSU Soils Testing Laboratory for analysis on a Perkin-Elmer 403 Atomic Absorption Spectrophotometer. Blank samples of digested acid and distilled water were also read to correct for exogenous potassium.

Readings were received from the soils lab in ppm which were converted to gm ($X10^{-2}$) potassium by the formula: ppm x 5 = gm($X10^{-2}$) potassium. The concentration of potassium was then expressed on a wet tissue basis by dividing by the sample wet weight.

Experimental Design

This study was designed as an 8 x 8 Latin Square with the eight locations being used as the rows, and the eight periods as the columns. The rows and columns were randomized and then the eight animals were randomly assigned into the square as the treatments. Therefore all muscle biopsy data were analyzed in this manner. A typical analysis of variance would be as follows within each breed:

Source	d.f.
Total	117[a]
Rows (Periods)	7
Columns (Positions)	7
Treatments (Animals)	7
Error	37[b]

Source	d.f.
Residual	59[c]

[a]Total of 10 d.f. lost for animals that died (3 periods for one; 2 periods for other)

[b]Total of five d.f. lost for missing values

[c]Total of five d.f. lost for missing values

Statistical Analysis

The statistical procedure utilized for the data analysis was the least squares procedure for the method of fitting constants (Snedecor and Cochran, 1967). The statistical model for each breed and phase of the animal's lifetime was $Y_{ijkr} = u + T_i + A_{ij} + M_k + P_{kr} + B_{ij}X_i + \mathcal{E}_{ijkr}$ where:

Y_{ijkr} = observed response.

μ = population mean.

T_i = effect due to ith breed where i = 1, 2.

A_{ij} = effect due to the jth animal in the ith breed.

M_k = effect due to the kth phase where K = 1, 2.

P_{kr} = effect due to the rth period in the kth phase.

$B_{ij}X_i$ = slope of linear regression (B) on period number (X), where period = 1, 2, 3, 4.

$\mathcal{E}_{ijkr}$ = random error associated with Y_{ijkr}.

The slope of the linear regression of the response in the period for each phase was then utilized as an indication of the rate of change of the response variables over time. Comparisons were made for each breed between the maternal and feedlot phases and also between the two breeds within each phase. The mean value for each period by breed and

phase was calculated from the values produced by the method of fitting constants.

The sum of squares for periods was partitioned further into its linear, quadratic, and cubic effects. Tests of parallelism for these lines were made. These tests were then used to interpret the differences in the responses among the four phase-groups.

CHAPTER IV

BIOCHEMICAL ESTIMATES OF CHANGES IN METABOLIC ACTIVITY OF LARGE AND SMALL SCALE BOVINE LONGISSIMUS MUSCLE DURING GROWTH AND DEVELOPMENT

Summary

The difference in the oxidative enzymatic metabolic activity (succinate dehydrogenase) and glycolytic enzymatic metabolic activity (lactate dehydrogenase) between a large scale bovine breed (Charolais) and a small scale bovine breed (Angus) was studied on live animal biopsy samples obtained periodically from shortly after birth to market age. Activity was estimated by the reduction of INT by SDH and LDH from the dilute salt soluble extract from the longissimus muscle tissue homogenate. Results indicated that there was a significant reduction ($P < .01$) in oxidative activity with increased chronological age in both breeds. The greatest change noted in oxidative activity, on a wet tissue weight basis, was in the post-weaning phase of the animals' lifetime with the decrease in oxidative activity of the Angus breed being significantly greater ($P < .01$) than for the Charolais breed. When oxidative activity was expressed per mg of dilute salt extractable protein, the decrease noted in the Charolais group was significantly greater ($P < .01$) than that of the Angus during

the pre-weaning phase, with no significant decrease during the post-weaning phase. There was a significant ($P < .01$) decrease in glycolytic activity for both breeds from the pre-weaning to the post-weaning phase when expressed per mg of extractable protein. However, the glycolytic activity of both breeds was relatively constant following the first half of the pre-weaning phase of this study. The concentration of dilute salt extractable protein increased significantly ($P < .01$) with age in both breeds with the greatest changes being found in the pre-weaning phase.

Introduction

Several studies on muscle tissue growth and development (Goldspink and Rowe, 1968; Goldspink, 1970) have advocated that the oxidative enzymatic activity (i.e. succinate dehydrogenase) in mature, adult muscle tissue is less than that in immature, young muscle tissue. This decrease in oxidative activity is accompanied by an increase in the activity of the enzymes common to the glycolytic pathway (i.e. lactate dehydrogenase). The oxidative enzymes have been reported to be located in mitochondria (Greenfield and Boell, 1968) while the glycolytic enzymes are distributed within the sarcoplasm of the muscle fiber (Cahn et al., 1962). Muscle fibers have also been separated into different types according to their enzymatic activity (Dubowitz and Pearse, 1960). The Type I or "red" muscle fiber has been shown to be high in activity for the enzymes common to the oxidative metabolic capability of the tissue, while the glycolytic enzymes are more active in the Type II or "white" fiber. Based on the relative concentration and activity of the oxidative and glycolytic enzymes in the different

fiber types, three general theories can be advanced relative to the decrease in oxidative enzymatic activity of muscle tissue with increasing chronological age.

One theory advocates that post-natal differentiation of fiber type is incomplete (Dubowitz, 1963). If this is so, then the reduction in oxidative activity would be attributed to the transformation of certain "red" fibers to "white" fibers. Ashmore and Doerr (1971a, b) reported that certain "α red" fibers could transform to "α white" fibers in chicks, lambs, calves, and piglets.

Another theory is that the reduction in oxidative activity is due not to post-natal transformation but to a "dilution" of the mitochondria associated with "red" fibers (Gauthier, 1970). This theory advocates that the number of mitochondria remains constant but as protein concentration in the muscle fiber increases along with hypertrophy of the fiber, the mitochondria present are diluted to such an extent that the oxidative metabolism of the tissue is reduced. The increase in sarcoplasm in the enlarged fiber leads to physiological and morphological changes more suitable to glycolytic metabolism (Henneman and Olson, 1965; Nystrom, 1968).

A third theory suggests that the mitochondria undergo age-dependent degenerative changes that are correlated with a decrease in biochemical function. Sacktor and Shrimada (1972) reported that in the mitochondria from flight muscle of aging blowflies there was a reorganization of the inner membrane in myelin-like whorls which replaces the normal cristal conformation. While cytochrome oxidase activity was present in the normal cristal, this activity was not found in the reorganized portion.

The purpose of this study was to compare the changes in the oxidative and glycolytic metabolic activity of muscle tissue from two bovine breeds of different body size, scale, and growth rate from shortly after birth to market age.

Materials and Methods

The experimental units for this study were eight (8) small scale (Angus) steer calves and eight (8) large scale (Charolais) steer calves. The small scale calves were selected to represent a small scale type of bovine and may or may not be typical of that particular breed.

Both groups of calves were maintained with their respective dams during the pre-weaning phase of this study under similar range conditions. Both groups were weaned at approximately 205 days of age and placed in a dry-lot for the post-weaning phase of the study.

Since this experiment was designed to study the changes in oxidative and glycolytic metabolic activity of the two groups from birth to weaning, the muscle tissue samples were removed by live animal biopsy techniques as described by Guenther (1972). Samples were frozen in liquid nitrogen immediately after removal from the anesthetized animal and stored at $-20^{\circ}C$ until biochemical analysis could be completed.

To insure that the different factors (i.e. age, location, animals) influencing enzymatic activity could be accounted for, the experiment was designed in an 8 x 8 Latin Square utilizing eight animals in each breed, eight sampling periods, and eight biopsy positions. The eight sampling periods are described in Table I and the eight biopsy positions were as described in Figure 2 (Chapter III).

TABLE I

PERIODS OF LIVE ANIMAL BIOPSY
AND EVALUATION

PHASE	PERIOD	AVERAGE AGE
MATERNAL	1	30 Days
(Pre-Weaning)	2	86 Days
	3	142 Days
	4	198[a] Days
FEEDLOT	1[c]	254 Days
(Post-Weaning)	2	310 Days
	3	366 Days
	4	422[b] Days

[a]Animals were weaned at the completion of Period 4 in the Maternal Phase.

[b]Animals were slaughtered at the completion of Period 4 in the Feedlot Phase.

[c]Animals were in Feedlot for 56 day period between Maternal Period 4 and Feedlot Period 1.

The estimation of oxidative enzymatic activity and glycolytic enzymatic activity was accomplished according to modified techniques of Beecher (1966) and Blackshaw (1963). Activity was estimated by the enzymatic reduction of 2-(p-iodophenyl)-3-p-nitrophenyl-5-phenyl-tetrazolium chloride (INT) by succinate dehydrogenase (oxidative) and lactate dehydrogenase (glycolytic). The INT formazan produced was extracted into ethyl acetate and density measured at 490 nm on a Gilford 240 spectrophotometer. Activity was expressed as net reduction in optical density units. Results were expressed as percent oxidative activity ($\frac{\text{Net SDH x 100}}{\text{Net SDH + Net LDH}}$), oxidative activity per mg extractable protein, and quantity of extractable proteins.

Results and Discussion

Position Effect

This experiment was designed as an 8 x 8 Latin Square to eliminate, or control, the influence of side and sampling location on the results of the biochemical and histological analyses. Table III shows that this design was successful because there were no significant side or position components of variance for any of the variables studied. Therefore, the sampling sites were statistically homogeneous.

Percent Oxidative Activity

The least squares mean values for percent oxidative metabolic activity are presented in Table II and are illustrated graphically in Figure 3. It is apparent from the data presented that there was little difference between the percent oxidative activity for the two breeds

TABLE II

LEAST SQUARES MEANS FOR BIOCHEMICAL DATA BY PHASE AND PERIOD

VARIABLE		MATERNAL PHASE 1	2	3	4	AVG.	AVG.	FEEDLOT PHASE 1	2	3	4	AVG.	AVG.	
PERCENT OXIDATIVE ACTIVITY	Angus	62.31	60.53	60.71	63.02	61.65[a]	61.63	60.09	54.78	55.36	51.58	55.46	57.08	58.55[b]
	Charolais	63.33	60.81	60.01	62.25	61.60[a]		60.34	57.95	58.93	57.52	58.69		60.15[b]
OXIDATIVE ACTIVITY Per mg extractable protein)	Angus	2.91	1.98	1.40	2.00	2.08	2.30	1.33	0.95	1.32	0.94	1.14[a]	1.26	1.61
	Charolais	4.18	2.92	1.56	1.39	2.52		1.31	1.11	1.61	1.47	1.38[a]		1.93
GLYCOLYTIC ACTIVITY Per mg extractable protein)	Angus	1.81	1.24	0.91	1.27	1.31	1.32	0.95	0.78	1.11	0.71	0.89[a]	0.96	1.10[b]
	Charolais	1.99	1.96	1.04	0.80	1.32		0.80	0.80	1.12	1.38	1.03[a]		1.18[b]
EXTRACTABLE PROTEIN	Angus	94.0	127.4	114.1	109.6	111.3[a]	108.3	107.7	128.6	123.9	171.1	132.9[b]	134.6	122.1[c]
	Charolais	96.2	91.7	122.8	110.5	105.3[a]		151.6	124.8	141.9	127.3	136.2[b]		134.6[c]

[a,b,c]Those means within each variable with common superscript are not significantly ($P < .05$) different.

TABLE III

SEQUENTIAL MEAN SQUARES FROM THE ANALYSES OF VARIANCE OF BIOCHEMICAL DATA BY BREED

SOURCE	d.f.	OXIDATIVE ACTIVITY (PERCENT)[a]	OXIDATIVE ACTIVITY (PROTEIN)[b]	GLYCOLYTIC ACTIVITY (PROTEIN)[b]	EXTRACTABLE PROTEIN[c]
Breed	1	14.99	0.00041*	0.00007	4.8635
Ani (Breed)	14	10.95	0.00011	0.00005	4.3859
M vs. F in Charolais[d]	1	18.37	0.00414**	0.00121**	224.7529**
Linear (Periods)	1	12.56	0.00306**	0.00072**	1.1124
Parallelism	1	3.73	0.00458**	0.00177**	85.6318**
Quadratic	1	12.26	0.00026	0.00001	1.0663
Parallelism	1	0.57	0.00021	0.00002	29.6971
Cubic	1	1.73	0.00001	0.00001	90.8090**
Parallelism	1	3.40	0.00029*	0.00015*	11.6185
M vs. F. in Angus	1	90.25**	0.00221**	0.00030**	210.1345**
Linear (Periods)	1	13.44	0.00061**	0.00015*	56.9129**
Parallelism	1	38.72*	0.00028*	0.00023**	14.7483
Quadratic	1	3.84	0.00053**	0.00014*	0.8188
Parallelism	1	0.60	0.00041**	0.00015*	149.2150**
Cubic	1	2.61	0.00001	0.00001	40.2724*
Parallelism	1	5.18	0.00021	0.00009	0.1205
Side	1	4.84	0.00006	0.00001	5.1619
Position	3	3.11	0.00016	0.00008	12.3470
Side x Position	3	1.78	0.00013	0.00008	14.2368
Breed x Side	1	0.45	0.00004	0.00012	0.0824
Breed x Position	3	2.18	0.00003	0.00001	15.4578
Breed x Side x Position	3	4.94	0.00004	0.00001	8.6152
Error	79	6.30	0.00007	0.00003	6.8633
Residual (Duplicates)	123	4.26	0.00002	0.00001	2.7720

[a] Expressed as percent of total metabolic activity $\frac{(\text{Net SDH} \times 100)}{(\text{Net SDH} + \text{Net LDH})}$ = % oxidative.

[b] Expressed per unit of extractable protein.

[c] Expressed as dilute salt soluble fraction.

[d] M vs. F represents difference in Maternal (M) and Feedlot (F) phases.

* Significant $P < .05$.

** Significant $P < .01$.

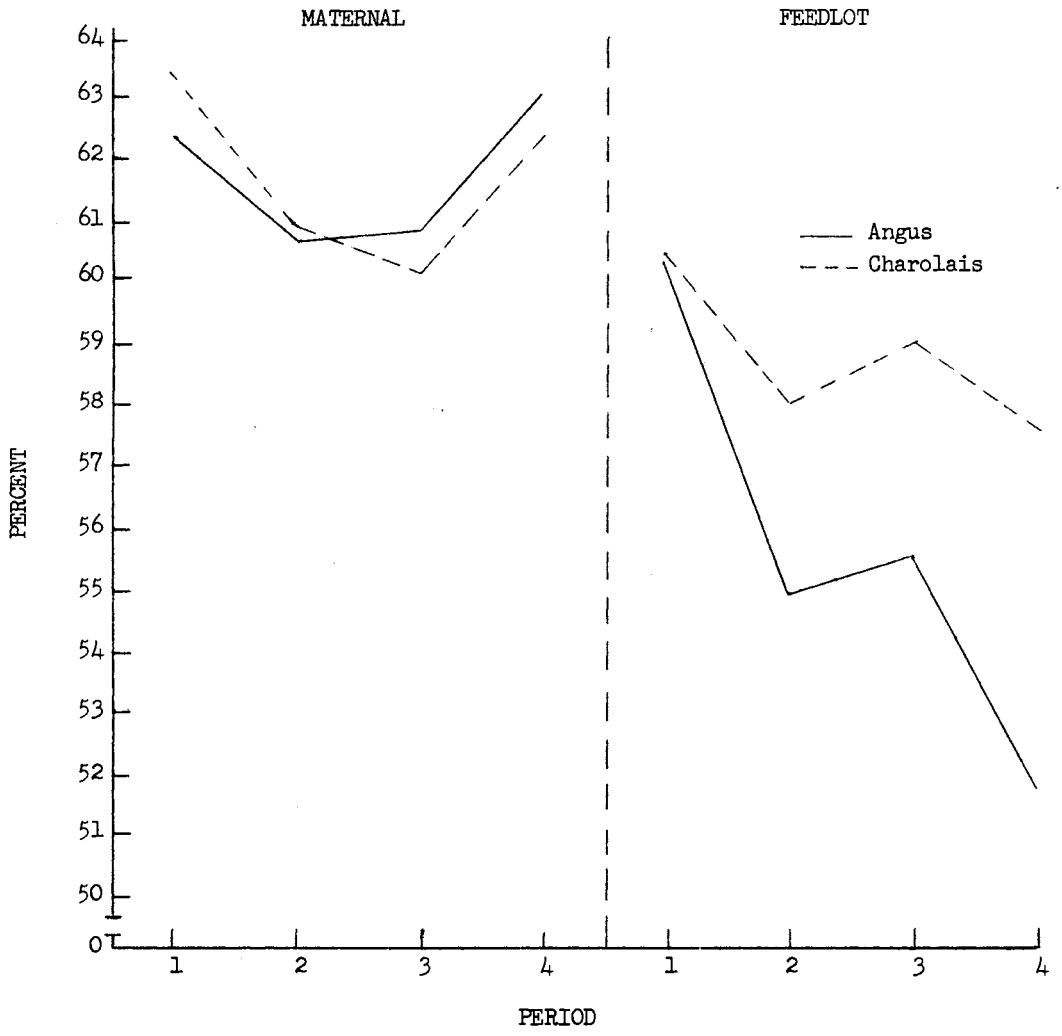

Figure 3. Percent Oxidative Activity in Muscle Tissue by Phase and Period

during the maternal phase of their lifetime. However, significant differences were apparent during the feedlot phase of this study.

At maternal period 1, the average percent oxidative activity (POA) for the small scale Angus cattle was 62.31%, while the large scale Charolais were slightly higher at 63.33%. A reduction in activity was noted for both breeds at maternal period 2, where there was only a 0.28% difference in the average POA for the two breeds. At maternal period 3 the Angus increased slightly in POA followed by a more rapid increase at maternal period 4. The Charolais group showed a slight decrease in POA from maternal period 2 to maternal period 3; however this was followed by a sharp increase in POA at maternal period 4 that was almost identical to the increase noted for the Angus group. The difference in POA between the two breeds at maternal period 3 was 0.70% compared to 0.77% at maternal period 4, the Angus breed being higher in POA at both periods.

At the end of maternal period 4, the calves were weaned and transferred to a drylot for the feedlot phase of the study. The animals were then allowed an eight week adjustment period prior to the next evaluation period.

From the data plotted in Figure 3 it is apparent that vast differences were now apparent in the POA between the two breeds. At feedlot period 1 the average value for the Charolais was 60.34% compared to 60.09% for the Angus a difference of 0.25%. Both breeds diminished in POA at feedlot period 2, increased slightly at feedlot period 3 and then decreased sharply at feedlot period 4. The average POA value for the Charolais at feedlot period 4 was 57.52% versus 51.58% for the Angus, a difference of 5.94%.

During the maternal phase there was no significant change in POA between the two breeds, while there was a total reduction in POA for the Charolais of 2.82% as compared to 8.51% for the Angus during the feedlot phase of this study.

The by breed analysis in Table III indicates that there was no significant difference in the overall POA mean value for the two breeds over the duration of this study. The Charolais POA results showed no significant difference between the average maternal value and the average feedlot value. The lack of a significant linear parallelism component of variance indicates that there was no difference in the rate of decrease in POA during the maternal or feedlot phases for the Charolais group.

The Angus POA results show a significant difference ($P < .01$) in the average maternal (61.65%) and feedlot (55.46%) phase values. There was no significant ($P > .05$) linear component of variance which means that the slope of the average of the maternal and feedlot lines was not significantly different from zero. The significant ($P < .05$) linear parallelism component of variance shows that there was a significant difference in the rate of change of POA in the two phases of the Angus' lifetime. All other components of variance were non-significant ($P > .05$).

The by phase analysis of variance (Table IV) shows that there was a significant difference ($P < .01$) in the overall average maternal POA versus the average feedlot POA, with the two breeds averaging 4.55% greater POA in the maternal phase than in the feedlot phase.

In comparing the two breeds during the maternal phase, there were no significant components of variance for differences between the two

TABLE IV

SEQUENTIAL MEAN SQUARES FROM THE ANALYSES OF VARIANCE OF BIOCHEMICAL DATA BY PHASE

Source	d.f.	OXIDATIVE ACTIVITY (PERCENT)[a]	OXIDATIVE ACTIVITY (PROTEIN)[b]	GLYCOLYTIC ACTIVITY (PROTEIN)[b]	EXTRACTABLE PROTEIN[c]
M vs. F[d]	1	91.02**	0.00598**	0.00132**	422.6191**
Ani (Breed)	14	10.86	0.00012	0.00005	4.7738
Breed in Maternal	1	0.13	0.00062**	0.00024**	5.2047
Linear (Periods)	1	0.06	0.00678**	0.00232**	52.8471**
Parallelism	1	3.44	0.00165**	0.00043**	9.2346
Quadratic	1	12.40	0.00137**	0.00025**	57.1057**
Parallelism	1	0.54	0.00004	0.00007	9.8592
Cubic	1	0.24	0.00018	0.00011	8.8031
Parallelism	1	0.01	0.00001	0.00003	99.4204**
Breed in Feedlot	1	33.76**	0.00001	0.00001	6.5018
Linear (Periods)	1	58.09**	0.00001	0.00010	1.0941
Parallelism	1	6.86	0.00008	0.00003	95.2300**
Quadratic	1	3.76	0.00001	0.00001	97.5998**
Parallelism	1	0.57	0.00001	0.00001	16.2325
Cubic	1	12.36	0.00032**	0.00012*	0.3106
Parallelism	1	0.32	0.00001	0.00001	34.2863*
Error	79	6.30	0.00007	0.00003	6.8633
Residual	123	4.26	0.00002	0.00001	2.7720

[a] Expressed as percent of total metabolic activity $\left(\frac{\text{Net SDH} \times 100}{\text{Net SDH} \quad \text{Net LDH}}\right)$ = % oxidative.

[b] Expressed per unit of extractable protein.

[c] Expressed as dilute Salt soluble fraction.

[d] M vs. F represents difference in Maternal (M) and Feedlot (F) phases.

* Significant P < .05.

** Significant P < .01.

breeds.

In the feedlot phase the average Charolais value (58.69%) was significantly greater ($P < .01$) than the average Angus value (55.46%). There was a significant ($P < .01$) linear component of variance but all other components were non-significant ($P > .05$). Therefore, while the Angus exhibited a greater reduction in activity during the feedlot phase, the rate of change was not statistically different from that of the Charolais.

The apparent lack of change in POA during the maternal phase of this study would indicate that the oxidative metabolic activity remained fairly constant, when expressed on a percentage basis. However, during the feedlot phase, both breeds showed a reduction in oxidative activity. This reduction might best be explained by the possibility of intramuscular fat infiltration or "marbling" during the feedlot phase. Cramer, Hecker, and Cornforth (1973) reported that Angus begin to marble about 9 months of age while other breeds of growth patterns similar to Charolais do not begin to marble heavily until about 12-15 months of age.

The present results show that the greatest reduction in percent oxidative activity in the Angus group occurred between feedlot period 1 and feedlot period 2 at which time the animals averaged 9 and 11 months of age, respectively. Since the reduction in POA in the Charolais cattle was not as great at this time, it would appear that possibly there was less marbling in the Charolais group, especially at slaughter (15 months of age). This is substantiated by the final marbling score for the breeds where the small scale Angus cattle averaged typical modest while the large scale Charolais averaged typical

small. Also, specific gravity determinations showed that the Charolais group averaged 27.5% fat while the Angus group averaged 32.65% fat on a carcass basis.

The data in Table II and Figure 4 illustrate the change in oxidative metabolic activity when the results were expressed as activity per milligram of extractable protein. It is apparent from the plotted data that there was an initial breed difference (maternal period 1) in the oxidative enzymatic activity per mg protein (OXPRO). The actual difference of OXPRO between the two breeds decreased at maternal period 2 and thereafter virtually no difference was noted between the two breeds from maternal period 3 to the end of the experiment.

At maternal period 1, the large scale Charolais demonstrated an activity of 4.18 units versus 2.91 units for the small scale Angus group. By maternal period 2, the Angus had decreased in activity to 1.98 units, a fall of 31.96%, while the Charolais activity had subsided to a value of 2.92 units, a decrease of 30.14%. At maternal period 3, the small scale Angus cattle had decreased to an activity of 1.40 units which was 48.11% of the initial (maternal period 1) value while the large scale Charolais had decreased to 1.56 units, which was 37.32% of its maternal period 1 value. At maternal period 4 the Angus showed a slight increase in activity to a level quite comparable to the maternal period 2 value while the Charolais continued to decrease, though the decrease in activity between maternal period 3 and maternal period 4 was not nearly as great as that between maternal period 1 and maternal period 3.

Little difference was noted between the mean values for the two breeds during the final three feedlot evaluation periods.

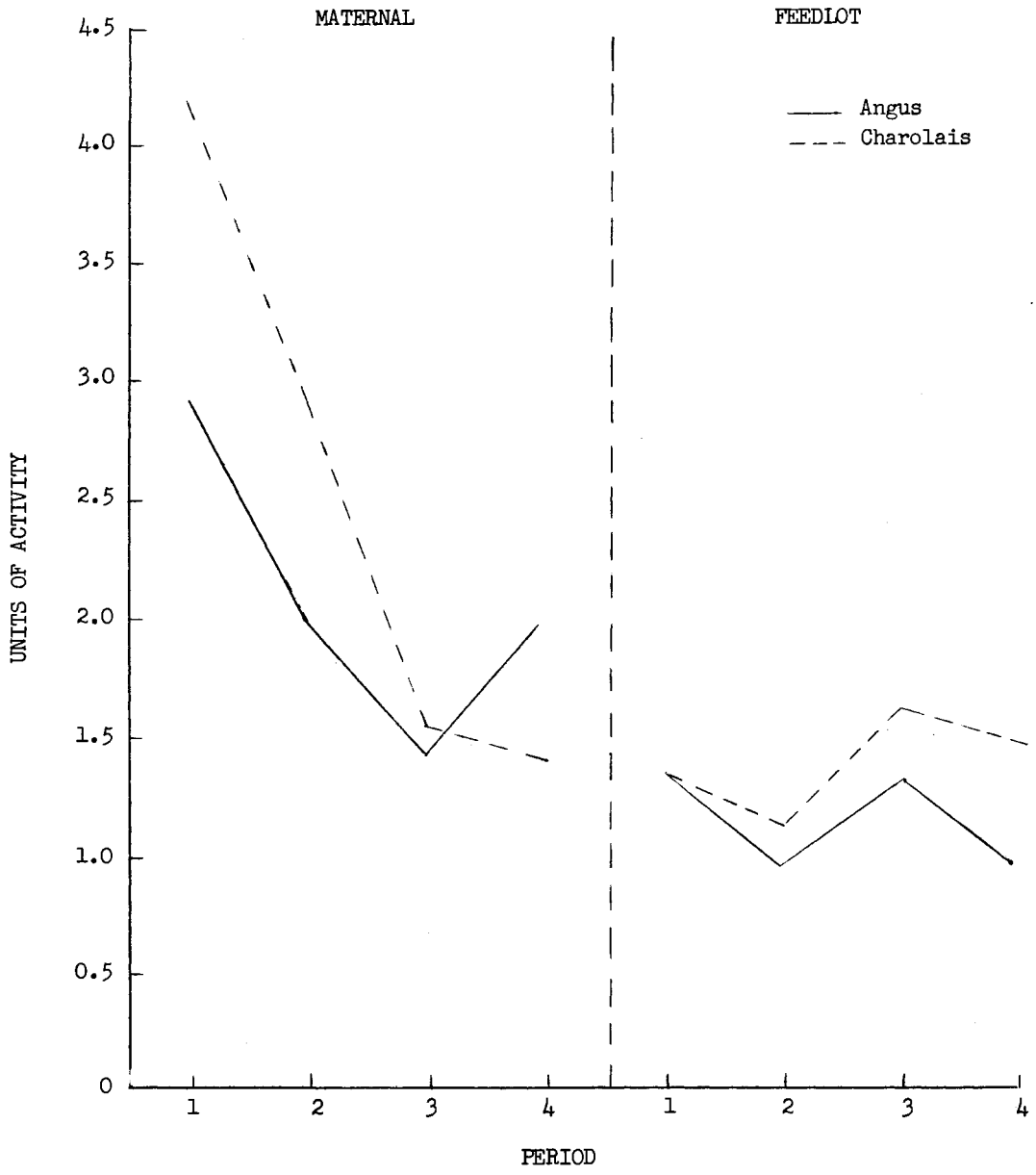

Figure 4. Oxidative Activity Per Unit Extractable Protein in Muscle Tissue by Phase and Period

The noticeable changes in OXPRO during the maternal phase followed by a relatively stable rate of activity during the feedlot phase is supported by the analyses of variance for OXPRO presented in Tables III and IV. The by breed analysis (Table III) shows that there was a significant ($P < .05$) difference in OXPRO between the Charolais and Angus breeds, over both phases, with the Charolais being slightly higher in each. The Charolais breed analysis shows that there was a significant ($P < .01$) decrease in the mean OXPRO for the large scale cattle between the two phases, and that while the slope of the average line was significantly greater ($P < .01$) than zero, there was a definite lack of parallelism of the maternal phase line with that of the feedlot phase. This lack of parallelism suggests that the rate of change in the maternal phase was significantly different from the rate of change in the feedlot phase. This is evidenced by the 2.79 units decrease in activity during the first four evaluation periods as compared to the slight increase of 0.16 units during the last four periods.

The by phase analysis (Table IV) shows that the mean maternal value for OXPRO over both breeds was significantly greater ($P < .01$) than that of the feedlot phase. Also, while the Charolais mean value for OXPRO was significantly higher ($P < .01$) than the Angus mean value over the four maternal periods, there was no significant difference between the two breeds during the feedlot phase. The greater change for the Charolais during the maternal phase (2.79 units) as compared to the Angus change (0.91 units) is substantiated by the significant ($P < .01$) difference in the linear parallelism of the maternal phase response lines for the two breeds. This indicates that the large

scale Charolais were decreasing OXPRO activity at a significantly greater ($P < .01$) rate than the small scale Angus calves during the first 6-7 months of their lifetime.

Figure 5 illustrates the changes in glycolytic (LDH) metabolic activity per mg extractable protein (GLYPRO), by phase and period, between the two breeds. These values are also presented in tabular form in Table II. From the graph, a general trend of decreasing activity can be noted for both breeds during the maternal phase. During the feedlot phase, both breeds were exhibiting relatively the same amount of activity except at feedlot period 4 where there was a slight increase in activity for the Charolais and a decrease for the Angus, when compared to the other feedlot values.

The by breed analysis of variance presented in Table III shows that the mean Charolais activity (1.18 units) is not significantly greater ($P > .05$) than the overall Angus value (1.10 units). However, within each breed, the maternal mean value for each was significantly higher ($P < .01$) than the feedlot mean value (Table II). The significant ($P < .01$) lack of linear parallelism of the two phase lines in both breeds was apparent from the difference in the rate of change in activity between the two breeds. While the Charolais group decreased in activity by 0.69 units between maternal period 1 to maternal period 4, there was an increase of 0.58 units in the feedlot phase. This was due to a marked increase in GLYPRO in the Charolais group over the last two evaluation periods. The Angus group decreased slightly during the feedlot phase by 0.24 units as compared to a decrease of 0.54 units during the overall maternal phase. However, it should be noted that the maternal period 4 value was 0.36 units higher than the maternal

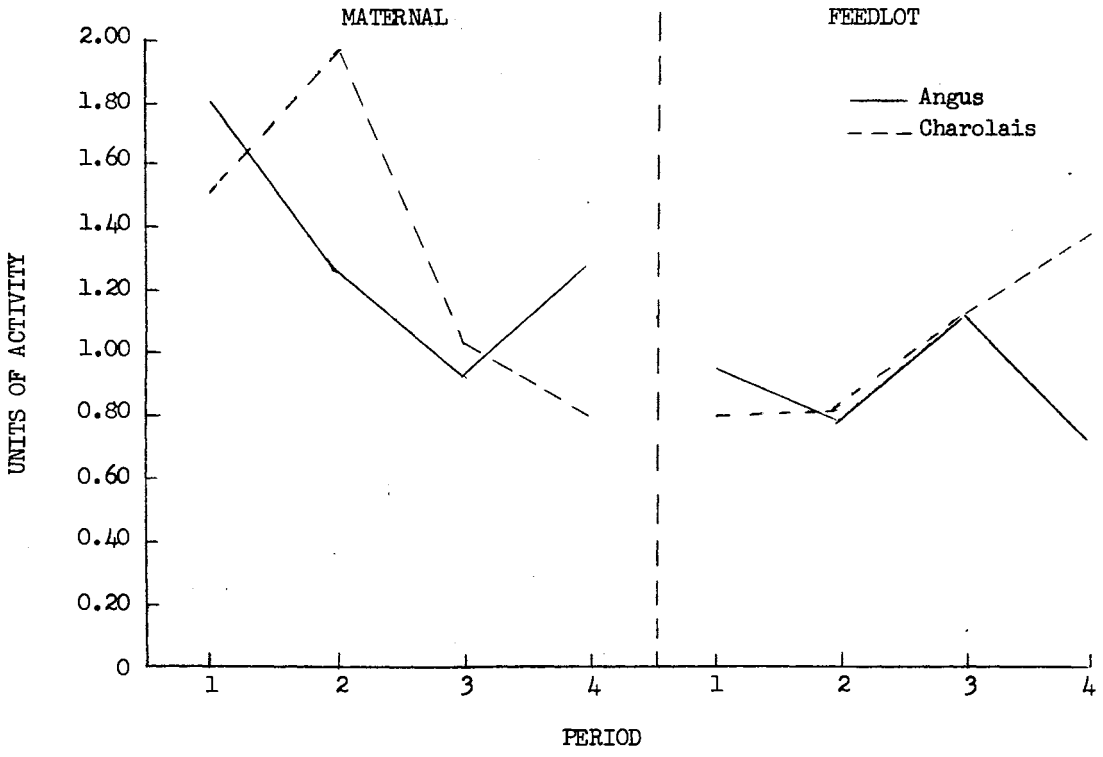

Figure 5. Total Glycolytic Activity Per Unit Extractable Protein by Phase and Period

period 3 value for some unexplainable reason. Therefore, the rate of change for both breeds was different in the two phases.

The by phase analysis presented in Table IV shows that the overall maternal average (1.32 units) was significantly higher ($P < .01$) than the overall feedlot average (0.96 units). In addition, the Charolais maternal average was significantly higher ($P < .01$) than the Charolais feedlot average. As noted earlier, there was a greater decrease in activity in the Charolais group than the Angus group from maternal period 1 to maternal period 4, which is substantiated by the significant ($P < .01$) difference in the parallelism of the maternal lines for each breed. The feedlot phase analysis showed no significant components of variance indicating that there was no significant differences in the GLYPRO activity of the two groups, nor a difference in the rate of change in activity during the feedlot phase.

Figure 6 presents the change in concentration of dilute salt extractable protein by phase and period. There was a general but rather erratic increase in dilute salt extractable protein with increasing chronological age. Table II shows that there was an increase in extractable protein from 108.3 mg per gm of wet tissue at maternal period 1 to 120.8 mg/gm at feedlot period 4, an increase of 11.54%. This phase difference was significant at the 1% level. Also, within each breed the feedlot mean value was significantly greater ($P < .01$) than the maternal phase value.

The analyses of variance presented in Tables III and IV support the trends that are apparent from Figure 6. The by breed analysis (Table III) shows that there was a significant ($P < .01$) difference in

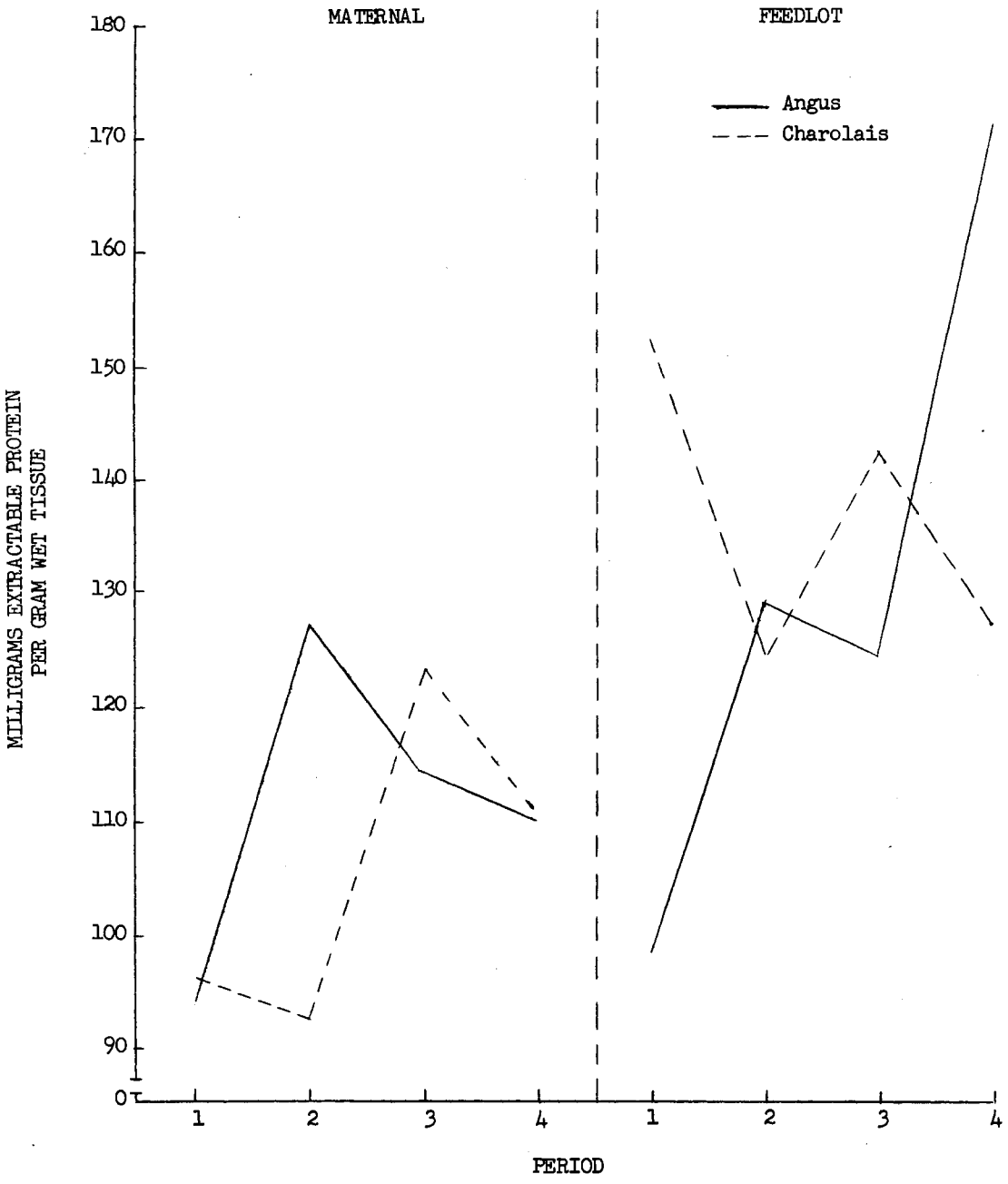

Figure 6. Dilute Salt Extractable Protein by Phase and Period

the maternal and feedlot mean values for both breeds. Also, within the Charolais breed there was a significant difference in the slope of the maternal and feedlot phase line as evidenced by the increase of 14.3 mg/gm dilute salt extractable protein from maternal period 1 to maternal period 4, as compared to a 24.3 mg/gm decrease from feedlot period 1 to feedlot period 4. The slopes of the lines within the Angus breed were not significantly ($P > .05$) different.

The by phase analysis (Table IV) indicated that while there was a significant increase ($P < .01$) in extractable protein from the maternal to the feedlot phase, there was no difference between the breeds within each phase. However, there was a significant ($P < .01$) difference in the parallelism of the two breeds in the feedlot phase as evidenced by the decrease of 24.3 mg/gm in the Charolais as compared to a 63.4 mg/gm increase in the Angus.

In summary, there was a decrease in the ratio of oxidative enzymatic activity to glycolytic enzymatic activity as evidenced by the decrease of percent oxidative activity. This change in activity agrees with the generally accepted theory that oxidative enzymatic activity decreases and that glycolytic enzymatic activity increases in muscle tissue with age (Cosmos and Butler, 1966). These changes have also been reported to be associated with the predominance of red muscle fibers in the very young tissue as opposed to the predominance of white muscle fibers in mature muscle (Wissen and Larrson, 1964).

The increase in sarcoplasmic proteins with age has also been reported. Sink and Judge (1971) reported that porcine muscle had 31.5 mg sarcoplasmic protein per gram of longissimus dorsi muscle at 75

days of age which increased to 41.2 mg/gm at 225 days. This increase of 30.8% noted in Hampshire swine compares quite favorably to the 32.3% increase in dilute salt extractable protein noted between maternal period 1 and feedlot period 4 in the Charolais group, and the 29.3% increase from the average maternal value to the average feedlot value in the Charolais.

CHAPTER V

INFLUENCE OF BODY SIZE AND MUSCLE TISSUE POTASSIUM CONCENTRATION ON WHOLE BODY ^{40}K COUNT IN LARGE AND SMALL SCALE BOVINE FROM BIRTH TO MARKET AGE

Summary

Changes in concentration of muscle tissue potassium and the influence of body size and scale on whole body ^{40}K count were reported on eight large scale bovine (Charolais) and eight small scale bovine (Angus) from shortly after birth to market age. There was a significant ($P < .01$) increase in net ^{40}K count, in both breeds, from the maternal to the feedlot phase. Charolais steers increased in net count at a more rapid rate than Angus steers, especially during the feedlot phase. Concentration of detectable potassium per unit of live weight decreased with increasing body size, but there was no breed difference after 150 kg live weight. Chemical tissue potassium concentration increased in both breeds through weaning with the greatest increase noted in the large scale animals.

Introduction

In recent years considerable research effort has been directed toward the feasability of utilizing the whole-body ^{40}K counter as a

means of identifying breeding animals of superior muscling (Frahm, Walters, and McLellan, 1971; Lohman, 1968). Johnson (1971) studied the influence of the ration on ^{40}K counting of market steers. Selk, (1973), evaluated the ^{40}K counter as a predictor of lean in young, light weight, growing beef calves, as in finished beef cattle. These studies involved animals of similar genetic background, body size, and weight at the time of evaluation. Little effort has been expended in attempting to identify the influence of bovine body size, scale and rate of maturity on whole-body ^{40}K counting.

This study was designed to study the changes in muscle tissue potassium, the influence of body size, and scale on the efficiency of whole-body ^{40}K counting utilizing bovine of a large scale breed (Charolais) and a small scale breed (Angus) from shortly after birth to market age.

Materials and Methods

The animals utilized in this study were eight (8) grade Angus steer calves and eight (8) crossbred Charolais (7/8 Charolais x 1/8 Angus) steer calves. The Angus calves were selected to represent a small scale type of bovine. The two groups of animals were selected to represent differences in body scale and size; therefore the animals utilized may or may not be representative of their respective breed.

As the animals were evaluated at eight specific periods during their market lifetime (Table I), considerable size differences existed between the two groups of test calves throughout the course of the study. The ^{40}K counting procedure utilized has been previously described by Frahm, Walters, and McLellan (1971) and in Chapter III.

However, because of the size differential, it was necessary to utilize two different counting configurations. A small calf counter configuration was utilized for maternal period 1 through feedlot period 1. The large steer counter configuration was utilized from feedlot period 2 to feedlot period 4. Both configurations were availabe at the OSU Live Animal Evaluation Center, and all animals were counted following a 24-hour shrink.

Since the data obtained involved a total of 16 separate counting dates, the net count obtained was adjusted for the counter efficiency for that day as follows:

$$\text{Counter Efficiency}(\%) = \frac{\text{Net count of KCl Standard (per minute)}}{66{,}300}$$

where the value of 66,300 is obtained as the total emissions per minute of the potassium standard source (619.03 gm KCl). Adjusted net count was then obtained as:

$$\frac{\text{Net Count per minute of sample}}{\text{Counter Efficiency (\%)}}$$

The data were also expressed as grams detectable potassium per kilogram live weight by the formula:

$$\text{Detectable K (grams)} = \frac{\text{Net Count per minute}}{\text{Eff x CPM x Live Wt.}}$$

where,

Net Count (per minute) = Gross Count (per minute) minus background count (per minute)

Eff = Counter Efficiency (%)

$$\text{CPM} = \frac{\text{Net Standard KCl Count}}{325}$$

Live Weight = Body weight in Kilograms

In addition to the ^{40}K whole body evaluation, live animal biopsy muscle samples were obtained at each test period for muscle tissue K

analysis. These samples were obtained as illustrated in Figure 2. Samples were wrapped in aluminum foil, frozen in liquid nitrogen and stored at -20°C until analysis was accomplished.

The concentration of muscle tissue potassium was determined via atomic absorption spectroscopy following complete digestion of duplicate one gram samples in 25 ml of digestion acid solution (3 parts of 70% Perchloric Acid + 1 part Nitric Acid). Results were expressed per gram of wet tissue weight.

Statistical analysis was accomplished by the least squares method of fitting constants with unequal subclass numbers (Snedecor and Cochran, 1967).

Results and Discussion

The whole-body ^{40}K results are presented in Table V and Figures 7 and 8.

Table V shows the least squares means by phase and period of net count for the two breeds for the duration of this study. Figure 8 is a plot of the least squares means presented in Table V. These results suggest that there was an increase in net count within each breed with increasing age and body size. Also, there appeared to be a greater increase in net count within the Charolais group than the Angus group as the animals matured. It may be noted that the average net count for both groups in the feedlot phase was 6242 counts per minute (cpm) versus 3631 cpm in the maternal phase, an increase of 71.9%. The Angus increased from 2839 cpm to 5476 cpm, an increase of 92.9% from the maternal to the feedlot phases. The Charolais increased from 4423 cpm to 7008 cpm, an increase of 58.4%. These data suggest that

TABLE V

LEAST SQUARES MEANS FOR WHOLE-BODY ^{40}K VARIABLES
AND CHEMICAL TISSUE POTASSIUM
BY PHASE AND PERIOD

VARIABLE		MATERNAL PHASE						FEEDLOT PHASE						
		1	2	3	4	AVG.	PHASE AVG.	1	2	3	4	AVG.	PHASE AVG.	BREED AVG.
NET COUNT (per minute)	Angus	20 52	27 14	35 84	30 04	28 39	36 31	50 63	55 79	55 60	57 03	54 76	62 42	41 58
	Charolais	20 34	46 74	45 02	64 82	44 23		56 12	72 38	70 02	81 80	70 08		57 16
DETECTABLE[a] POTASSIUM	Angus	12.58	10.14	9.02	9.55	10.32	11.67	7.61	7.00	5.59	5.35	6.39	6.22	8.61[c]
	Charolais	13.40	14.59	9.81	8.89	11.67		7.37	6.20	5.70	4.91	6.05		8.86[c]
CHEMICAL TISSUE[b] POTASSIUM	Angus	3.28	3.30	3.48	3.55	3.40[c,e]	3.26[d]	3.54	3.38	2.51	3.21	3.16[e,g]	3.24[d]	3.28[h]
	Charolais	2.79	2.83	3.06	3.79	3.12[c,f]		3.53	3.57	2.94	3.28	3.33[f,g]		3.23[h]

[a] Expressed as grams potassium (X10) per kilogram live weight.

[b] Expressed as milligrams potassium per gram wet tissue weight.

[c,d,e] [f,g,h] Those means with common supercript within each variable are not significantly ($P < .05$) different.

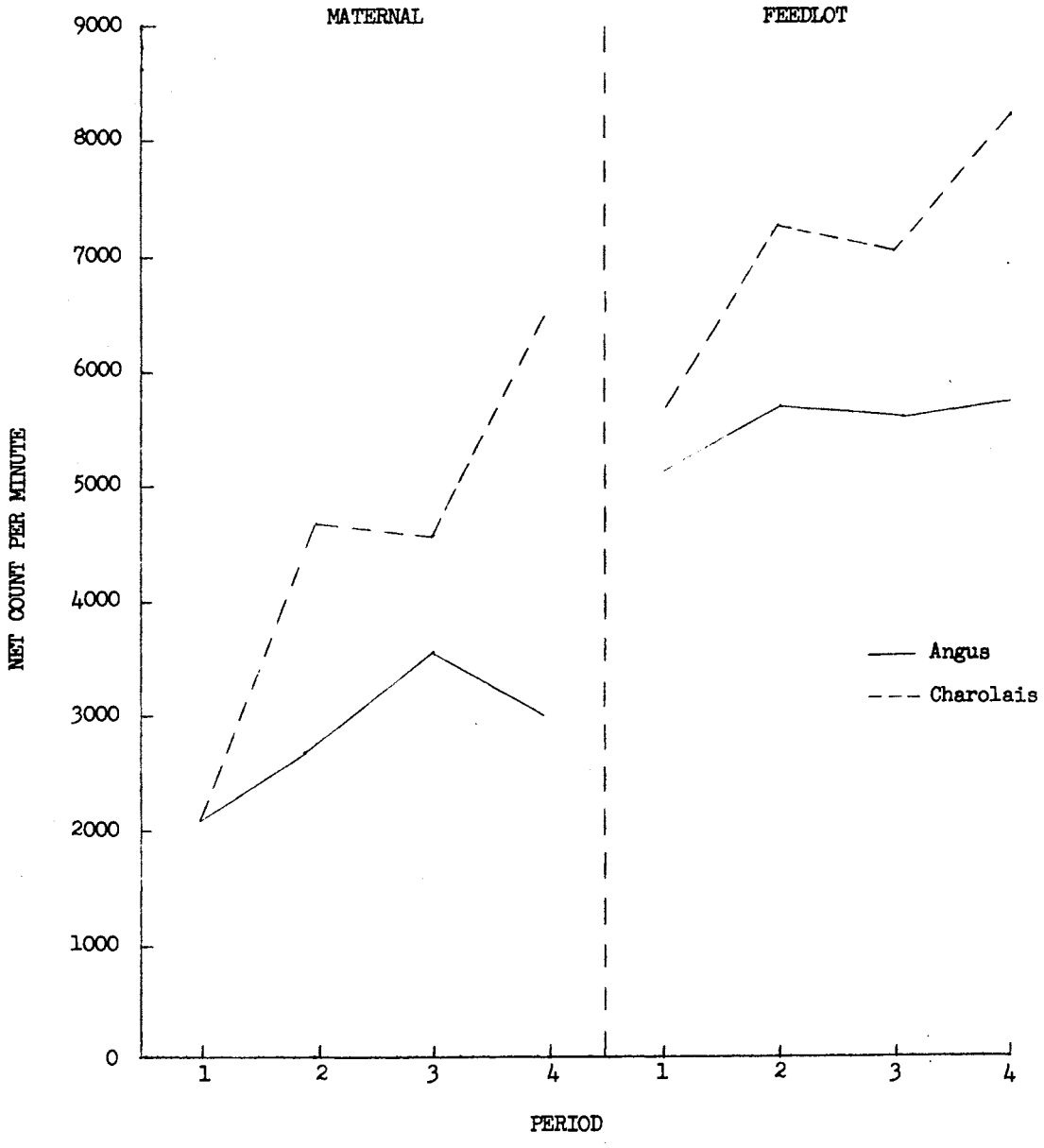

Figure 7. Whole-body ^{40}K Net Count by Phase and Period

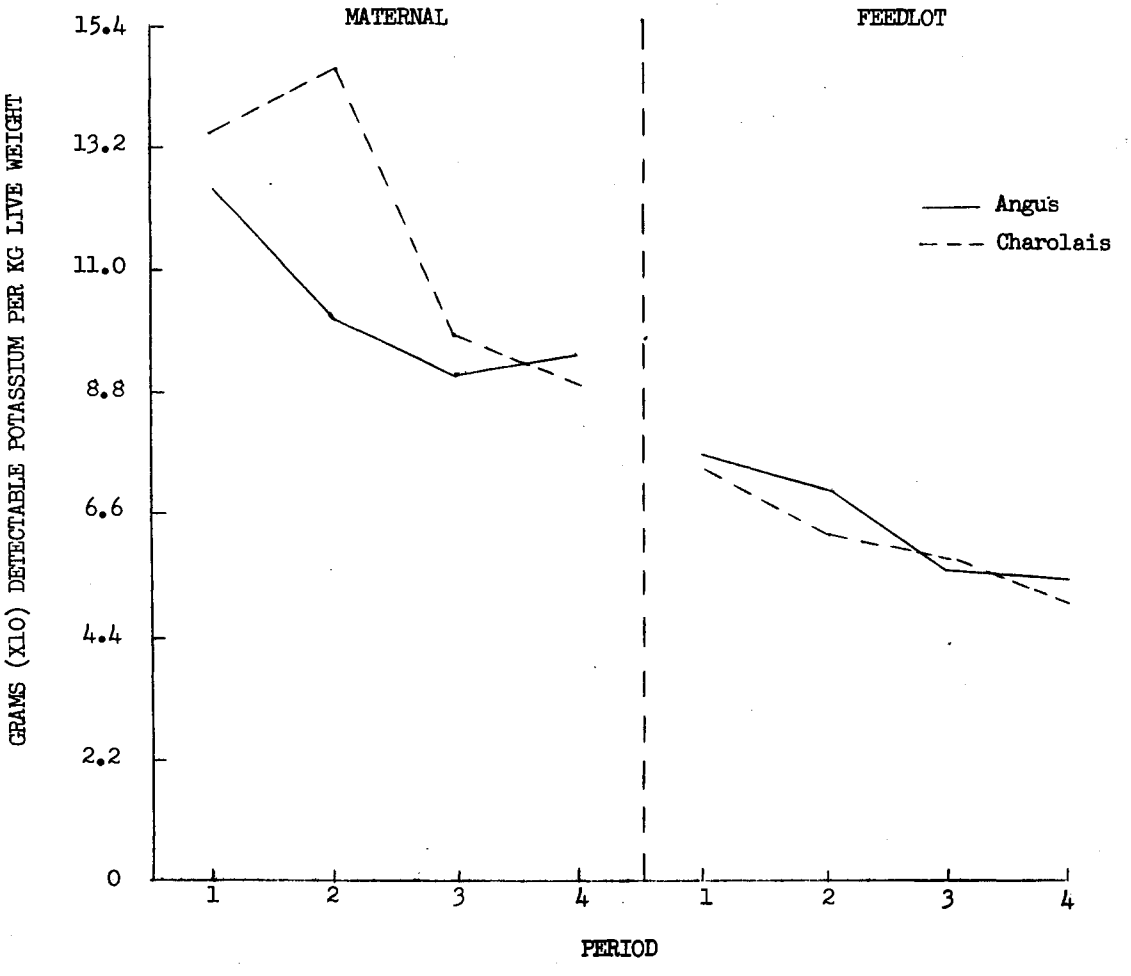

Figure 8. Detectable Potassium (X10) per Kilogram Body Weight by Phase and Period

the increase in average net count from the maternal to the feedlot phase was greater for the Angus when the data was expressed as a percentage of the maternal average net count.

However, within the maternal phase, there was virtually no difference between the two breeds at maternal period 1 where the Angus had a net count of 2052 cpm while the Charolais had a net count of 2034 cpm. At maternal period 4, the Angus count was 3004 cpm, an increase of 46.4% over the maternal period 1 value while the Charolais count was 6482 cpm, an increase of 218.7% over the same length of time. Therefore during the maternal phase, the large scale cattle were depositing lean tissue at a much faster rate than the small scale cattle.

Also, during the feedlot phase, the small scale cattle increased from 5063 cpm to 5703 cpm, an increase of only 12.6%. The large scale cattle increased from 5612 cpm to 8180 cpm during the same time interval, an increase of 45.8%. Again, the large scale cattle appeared to be depositing lean tissue at a much faster rate than the small scale cattle during the feedlot phase.

These above results are supported by the analyses of variance presented in Tables VI and VII. The by phase analysis presented in Table VI shows that the overall feedlot mean net count was significantly greater ($P < .01$) than the maternal average net count. In addition, within each phase, the large scale Charolais cattle counted significantly higher ($P < .01$) than the small scale Angus cattle. The greater rate of increase mentioned earlier for the Charolais over the Angus in each phase is substantiated by the significant ($P < .01$) difference in the slopes of the two lines within each phase.

The within breed analysis presented in Table VII shows that the

TABLE VI

SUMMARY OF SIGNIFICANCE LEVELS OF ANALYSES OF VARIANCE BY BREED FOR POTASSIUM VARIABLES

SOURCE	NET COUNTS	CONCENTRATION[a]	CHEMICAL POTASSIUM[b]
Breed	**	ns	ns
Ani (Breed)	**	*	ns
M vs. F in Charolais[c]	**	**	ns
Linear (Periods)	**	**	ns
Parallelism	**	**	**
Quadratic	**	*	*
Parallelism	ns	**	ns
Cubic	**	**	*
Parallelism	**	**	ns
M vs. F in Angus	**	**	ns
Linear (Periods)	**	**	ns
Parallelism	*	ns	**
Quadratic	**	**	ns
Parallelism	*	**	ns
Cubic	ns	ns	ns
Parallelism	**	ns	*

[a]Grams detectable potassium per kilogram live weight.

[b]Milligrams potassium per gram wet tissue weight.

[c]M vs. F represents difference in Maternal (M) and Feedlot (F) phase.

[ns]Nonsignificant ($P > .05$)

[*]Significant ($P < .05$)

[**]Significant ($P < .01$)

TABLE VII

SUMMARY OF SIGNIFICANCE LEVELS OF ANALYSES OF VARIANCE BY PHASE FOR POTASSIUM VARIABLES

SOURCE	NET COUNTS	CONCENTRATION[a]	CHEMICAL POTASSIUM[b]
M vs. F[c]	**	**	ns
Ani (Breed)	**	ns	ns
Breed in Maternal	**	**	ns
Linear (Periods)	**	**	**
Parallelism	**	**	*
Quadratic	**	ns	ns
Parallelism	ns	**	ns
Cubic	**	**	ns
Parallelism	**	**	ns
Breed in Feedlot	**	*	ns
Linear (Periods)	**	**	**
Parallelism	**	ns	ns
Quadratic	**	ns	*
Parallelism	ns	ns	ns
Cubic	**	ns	**
Parallelism	*	ns	ns

[a]Grams detectable potassium per kilogram live weight.

[b]Milligrams potassium per gram wet tissue weight.

[c]M vs. F represents difference in Maternal (M) and Feedlot (F) phase.

[ns]Nonsignificant ($P > .05$)

[*]Significant ($P < .05$)

[**]Significant ($P < .01$)

Charolais average net count (5716 cpm) was significantly higher ($P < .01$) than the Angus net count (4158 cpm). This would indicate a greater quantity of fat free lean in the large scale cattle than the small scale cattle. Within each breed the feedlot mean value was significantly greater ($P < .01$) than the maternal mean value. The significant ($P < .01$) lack of parallelism in both breeds was evidence of a difference in the rate of increase in net count between the two phases of the animals' lifetime. This was shown by the increase in net counts of 46.4% during the maternal phase versus an increase of 12.6% during the feedlot phase for the Angus. The Charolais exhibited an increase in net count of 218.7% during the maternal phase as compared to 45.8% during the feedlot phase. Therefore, the Charolais group was increasing in net count at a faster rate during both phases than the Angus, and both breeds increased in net count at a faster rate during the maternal phase than during the feedlot phase.

Table V also presents the least squares mean value for concentration of detectable potassium per kg of live body weight. This expression is the net count per unit of live weight and could possibly be used to estimate self-absorption due to varying body size and scale of the test animals.

During the maternal phase of this study, both breeds decreased in quantity of detectable potassium per kg of body weight (Figure 9). The small scale Angus decreased from 12.58 gms to 9.55 gm, a decrease of 24.1%. The large scale Charolais decreased from 13.40 gms to 8.89 gm, a reduction of 33.7%. The drop in detectable K between maternal period 1 and maternal period 4 for the Charolais was 4.51 gms compared to 3.03 gms for the Angus. Therefore, the Charolais'

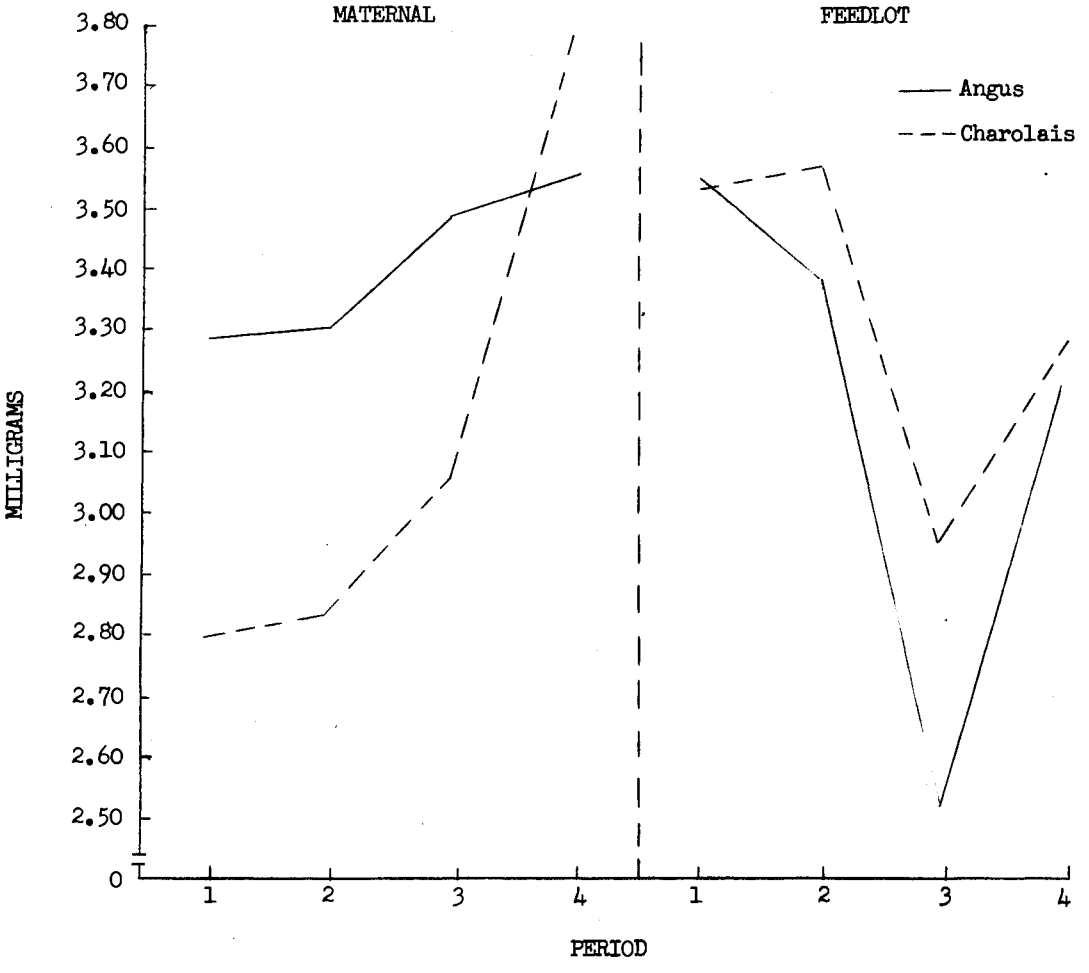

Figure 9. Milligrams Muscle Tissue Potassium by Phase and Period

decrease in detectable potassium was 32.9% greater than the Angus. During this same period the Angus increased in live weight by 115.7 kg compared to 158.8 kg for the Charolais. Therefore the increase in body weight was 37.3% greater for the Charolais than the Angus. This shows a direct, but inverse, relationship between the increase in body weight and decrease in detectable potassium per kg of live weight as was evidenced by the 37.3% difference in the rate of body weight increase, as opposed to the 39.9% difference in rate of detectable potassium decrease.

During the feedlot phase, both breeds continued to decrease in concentration slightly with the Angus falling from 7.61 gm/kg to 5.35 gm/kg (29.7%) versus a decrease from 7.37 gm/kg to 4.91 gm/kg (33.4%) for the Charolais. Hence, there was no appreciable difference between the two breeds during the feedlot phase.

The results are confirmed by the analyses of variance in Tables VI and VII. The by phase analysis in Table VI shows that the overall maternal concentration of 11.00 gm/kg was significantly greater ($P < .01$) than the feedlot average of 6.22 gm/kg. In the maternal phase, the Charolais concentration of detectable potassium of 11.67 gm/kg live weight was significantly greater ($P < .01$) than the 10.32 gm/kg evident for the Angus group. Also, the difference in the rate of decrease of concentration of detectable potassium, presented earlier, is supported by the lack of parallelism of the linear lines.

In the feedlot phase, the Angus exhibited a slightly higher ($P < .05$) concentration of detectable potassium than the Charolais while there was no significant difference ($P > .05$) in the slope of the two response lines within the feedlot phase. Thus, the

statistical analysis supports the conclusion that both breeds decreased in detectable potassium at a faster rate in the maternal phase than in the feedlot phase, which may be attributed to increase in body mass. Also, the Charolais decreased in detectable potassium at a faster rate than the Angus during the maternal phase with no difference between the two groups being noted during the feedlot phase.

The least squares means for the concentration of muscle tissue chemical potassium, as determined via atomic absorption spectroscopy, are also presented in Table V. From these means one may note that there was very little change in concentration of chemical tissue potassium with age in the two breeds. The data plotted in Figure 9 show that there was an increase from 3.28 mg/gm wet tissue to 3.55 mg/gm in the small scale Angus group during the maternal phase. This increase of 8.2% is less than the 1.00 mg/gm or 35.8% increase noted for the large scale Charolais group.

In the feedlot phase, a decline may be noted in the potassium concentration of the muscle tissue in both breeds. The feedlot period 1 value of 3.54 mg/gm in the Angus is identical to the 3.53 mg/gm noted for the Charolais. Both groups show an unexplainable, sharp decrease in concentration at feedlot period 3 but then revert to values quite comparable to the values obtained in feedlot periods 1 and 2.

The by phase analysis of variance (Table VI) shows no significant effects except a significant ($P < .05$) lack of parallelism between the two breed response lines in the maternal phase. This was evidenced by the 35.8% increase in tissue potassium concentration noted for the Charolais as compared to 8.2% in the Angus.

The by breed analysis in Table VII shows no significant effects

except for a highly significant ($P < .01$) difference in the parallelism of the maternal and feedlot response lines (Fig. 9) within each breed. This is evidenced by the increase in the maternal phase followed by a decrease in the feedlot phase in tissue potassium.

The results presented in Tables V to VII and Figures 7 to 9 suggest that while there were definite differences in the overall net ^{40}K count of breeds of differing size and scale, these differences were not apparent when the counts were equated to unit of live weight. Also, any difference in concentration of chemical tissue potassium in the longissimus dorsi muscle occurs during the early lifetime of the animal.

From the chemical tissue data (Figure 9) one may realize that after the maternal lifetime of the animal there was very little difference between breeds of differing size and scale in either phase. However, as the data in Figure 4 indicates, the small scale animals underwent less change from birth to weaning than the large scale animals. Since the concentration of potassium has been related to fiber type (Sreter and Woo, 1963), with the white fibers being higher in potassium than the red fibers, these results would indicate that the small scale Angus calves appear to be more chemically mature at birth than the large scale animals since they more closely approximate their adult level of potassium in the longissimus dorsi muscle. The large scale Charolais animals would appear to be less "chemically mature" because they undergo a greater quantitative change in concentration of tissue potassium during maturation.

The decrease in concentration of potassium per unit of wet tissue during the post-weaning phase of both breeds could be attributed to

the infiltration of intramuscular fat with age. Other workers (Sreter and Woo, 1963; Swift and Berman, 1959) showed an increase in tissue potassium to a certain point in the animal's lifetime. However, their results were reported on a moisture-free, fat-free basis.

Since net count (Figure 7) continued to increase during the feedlot phase and there were no corresponding increase in tissue potassium (Figure 9), the increase in net count must be due to an increase in the quantity of lean tissue. The relatively steady increase in net count in the Charolais would mean that the group was still increasing in lean tissue at slaughter. However, there is no increase in net count in the Angus group between feedlot period 2 and feedlot period 4 even though there was an increase in the average live weight of 110 kg. This lack of increased net count could be due to the deposition of adipose tissue during this period or to a quenching effect resulting from increased body mass (Martin, Harrington, and Kessler, 1968).

The decrease in quantity of detectable potassium per unit of live weight agrees with the work of Martin, Harrington, and Kessler (1968) who reported that as the weight of standard KCl sources was increased, less efficient detection of the quantity of radioactive potassium present was experienced. Thus, as the animal increases in size and scale, there is a corresponding decrease in the efficiency of detecting whole-body potassium. These results show a difference between the two breeds when the animals were small (pre-weaning phase), but after they attain 150 kg body weight, there is no difference in the efficiency of detection of the potassium present in animals of differing size and scale.

CHAPTER VI

COMPARISON OF GROWTH PATTERNS OF LARGE SCALE AND SMALL SCALE BOVINE BY LINEAR SKELETAL MEASUREMENTS AND METACARPAL RADIOGRAMS

Summary

Changes in skeletal development, as assesed by eight linear skeletal measurements and radiographs of the left metacarpal, were studied on eight large scale bovine (Charolais) and eight small scale bovine (Angus) from shortly after birth to market age (14 months). Results indicated that the large scale cattle were faster growing, especially during the pre-weaning (maternal) phase of their lifetime with little difference between the two breeds in the post-weaning (feedlot) phase. The large scale cattle were significantly larger ($P < .01$) for all skeletal measurements with the greatest changes in body size between the two breeds occurring in the maternal phase. Radiograph measurements of the left metacarpal indicated that the large scale cattle increased in bone dimension at a significantly faster ($P < .01$) rate than the small scale group. Also, the rate of increase in bone dimension in the Angus was significantly less ($P < .01$) during the feedlot phase than in the maternal phase while there was no significant difference ($P > .05$) between the maternal and feedlot phase for the Charolais.

Introduction

Considerable research effort has been directed towards utilizing body measurements as predictors of carcass composition (Green, Stevens, and Gauch, 1969). These types of measurements have also been used to study the growth rates from birth to maturity in Hereford and Angus cattle (Brown, Brown, and Butts, 1972). Gregory (1969) reported that selection for growth rate should improve efficiency of gain because of the high heritability of gain and its favorable association with feed conversion.

The per cent and amount of bone in meat animal carcasses have been indicated as relatively accurate criteria for prediction of animal growth and carcass meatiness (McMeenan, 1941; Harrington and King, 1963). Orme et al (1959) reported significant relationships of metacarpal and metatarsal weights or lengths with meatiness characters. Coble et al, (1971a) studied the effect of sire, sex and laterality effects on bovine metacarpal and metatarsal characters.

The purpose of this study was to investigate the differences in the growth patterns of a small scale type of bovine and a large scale type of bovine by linear skeletal measurements, bone development, and increase in body weight.

Materials and Methods

The experimental units for this study were eight (8) grade Angus steer calves and eight (8) crossbred Charolais (7/8 Charolais x 1/8 Angus) steer calves. The small scale calves were selected to represent a small scale type of bovine and may or may not be typical of that

particular breed.

This study was designed to investigate the growth patterns of a large scale bovine versus a small scale bovine from shortly after birth to market age. Therefore, these animals were evaluated at specific times in their market lifetime irrespective of growth rate or body weight. Hence, this particular project was designed to include definite periods of evaluation in order to compare the two groups at the same chronological age (Table I).

The study was divided into two separate phases, the maternal (pre-weaning) phase and the feedlot (post-weaning) phase. Each of these phases was then composed of four specific periods of evaluation with an interval of 56 days between each period. All calves were weaned at the conclusion of the fourth period in the maternal phase and slaughtered at the end of the fourth period in the feedlot phase.

In order to evaluate the differences in the body growth patterns of the two maturity groups, eight specific linear skeletal measurements were obtained from each animal at each evaluation period. These measurements were selected to evaluate the growth of the animal relative to length, width, and depth of body. The various measurements were identified as follows: 1) body depth, 2) thickness of forequarter, 3) thickness of hindquarter, 4) width of rump, 5) length of rump, 6) depth of forequarter, 7) length of topline, and 8) length of side.

The body depth of each animal was obtained with a set of wooden calipers by placing the fixed arm of the calipers against the sternum just posterior to the front limb (parallel to area of 5th and 6th ribs) and then allowing the movable arm of the calipers to slide down

until it fit snugly against the dorsal surface of the animal. The thickness of the forequarter of each animal was determined by fitting the jaws to the lateral surface of each shoulder parallel with the spine of the scapula and allowing the frame of the calipers to rest on the dorsal surface of the animal. The thickness of the hindquarter was obtained similarly by aligning the jaws of the calipers vertically with the hind limbs. The distance between the jaws of the calipers was then measured with a steel measuring tape and recorded to the nearest 0.1 inch.

Metal calipers were utilized to measure the length and width of the rump and the depth of the forequarter. Width of rump was determined by physically palpating the lateral extremity of each tuber coxae and then fitting the point of the jaws of the calipers to these positions. The length of rump was determined by palpating the anterior tubercle of the tuber coxae and the most posterior tubercle of the tuber ischii. The calipers were then fitted over these two points. The depth of forequarter was measured by placing the point of one jaw of the calipers on the dorsal surface of the scapula in line with the spine of the scapula and extending the calipers until the other jaw rests on the posterior point of the olecranon. Again, a steel tape was used to measure the distance between the points of the jaws of the metal calipers.

The length of topline was determined by measuring the distance between the most anterior and dorsal point of the scapula to the extreme posterior surface of the tuber ischii. Length of side was obtained in the same manner using the anterior lateral tuberosity of the humerus and the anterior point of the tuber coxae as reference

points.

All measurements were obtained in duplicate from the right side of the animal. The animal was positioned squarely on all four limbs while all eight measurements were obtained then moved and repositioned for the second series of measurements.

Radiograph

One of the major tissues composing the growing animal is bone. It is generally accepted that of the three major tissues comprising the beef animal (i.e. bone, muscle, fat) that bone is the first to fully develop. Therefore, it would seem reasonable to study the development of this tissue in relation to the other two.

One method of analyzing bone development is by radiographs. In this experiment, the left metacarpal of each animal at each period was radiographed for later evaluation.

On the days the radiographs were to be made, the animals were delivered to the OSU Veterinary Medicine Radiology Laboratory, radiographed and returned immediately to the pasture or feedlot as appropriate.

To obtain the radiograph, the animals were haltered and led to the X-ray room. A portable field X-ray machine (Picker) was utilized; consequently, it was necessary to only position the animal in front of the machine at the specified distance. All radiograms were taken anterior to posterior (A-P).

The measurements acquired on each radiogram are illustrated in Figure 1. Total length of the bone was determined by measuring the distance between the dorsal surface of the proximal condyle and the

ventral surface of the distal condyle. The proximal width of the bone was measured as the horizontal distance between the lateral edges of the metacarpal approximately 1 cm below the dorsal surface of the proximal condyle. The distal bone width was determined approximately 1.5 cm dorsal to the distal epiphyseal line.

The total median diameter was the distance between the lateral surfaces of the bone located midway between the extreme proximal end and the distal epiphyseal line. The marrow diameter was obtained at the same point as the median diameter except it consisted of the dark, porous area only. Results were expressed in millimeters.

Total bone area was estimated by tracing the outline of the bone along the proximal surface, both lateral edges and through the epiphyseal line with a compensating polar planimeter. Results were expressed in square inches.

The data were analyzed by the least squares method of fitting constants with unequal subclass numbers (Harvey, 1960).

Results and Discussion

Linear Skeletal Measurements

In order to study the physiological maturity patterns of the large scale breed (Charolais) and the small scale breed (Angus), eight linear skeletal measurements were obtained at each evaluation period. These measurements were selected to estimate the rate of growth relative to depth, width, and length of body. The least squares means for each measurement are presented in Table VIII. Also, the period mean values for maternal periods 1 and 4 and feedlot period 3 were

TABLE VIII

LEAST SQUARES MEANS FOR BODY MEASUREMENTS

Phase	Period	Depth of FQTR[a]		Body Depth[a]		Thickness of FQTR[a]		Thickness of HQTR[a]		Thickness of Rump[a]		Thickness of Top[a]		Length of Rump[a]		Length of Side[a]		Live Weight[b]		Daily Gain[c]		AVERAGE Depth[d] (%)		AVERAGE Thickness[e] (%)		AVERAGE Length[f] (%)	
		A[g]	C[g]	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
Maternal	1	10.5 (54.1)[h]	11.5 (54.0)	12.0 (50.9)	12.3 (48.4)	9.8 (49.0)	8.8 (45.1)	10.7 (54.4)	10.6 (50.5)	7.1 (43.3)	7.1 (39.7)	23.6 (53.9)	25.0 (51.1)	9.1 (55.2)	9.6 (50.5)	18.4 (54.0)	19.8 (52.0)	54.0 (14.5)	52.6 (11.6)	—	—	(52.5)	(51.2)	(48.9)	(45.1)	(54.4)	(51.2)
	2	12.4	13.3	14.9	15.0	11.3	10.5	12.7	12.7	8.9	9.0	29.9	30.8	10.8	11.6	22.0	23.6	91.2	93.9	0.66	0.74						
	3	14.0	15.5	16.8	17.7	12.6	12.3	14.2	15.4	10.6	10.9	34.1	36.5	11.8	13.4	25.8	27.3	136.1	153.3	0.80	1.06						
	4	15.4 (79.4)	17.0 (79.8)	18.1 (76.7)	19.7 (77.6)	13.4 (67.0)	13.7 (70.3)	15.3 (77.7)	17.1 (81.4)	11.8 (72.0)	12.6 (70.4)	37.5 (85.6)	40.5 (82.8)	13.2 (80.0)	14.9 (78.4)	28.2 (82.7)	31.1 (81.6)	169.6 (45.4)	211.4 (46.7)	0.60	1.04	(78.1)	(78.7)	(72.2)	(74.0)	(82.8)	(80.9)
Feedlot	1	16.7	18.6	19.9	21.4	15.4	16.4	16.9	18.5	13.3	14.2	39.1	44.3	14.3	16.2	29.6	33.2	227.3	285.3	1.03	1.32						
	2	17.4	19.5	21.1	23.1	17.2	17.8	17.8	19.7	14.5	16.3	40.4	46.7	15.1	17.6	30.9	34.9	264.4	346.1	0.78	1.08						
	3	18.6 (95.9)	20.8 (97.7)	22.6 (95.8)	24.4 (96.1)	18.4 (92.0)	18.9 (96.9)	18.5 (93.9)	20.2 (96.2)	15.4 (93.9)	17.3 (96.6)	41.1 (93.8)	48.0 (98.2)	16.2 (98.2)	18.4 (96.8)	32.2 (94.4)	36.9 (96.9)	325.7 (87.3)	404.6 (89.5)	1.09	1.04	(95.9)	(96.9)	(93.3)	(96.6)	(95.5)	(97.3)
	4	19.4	21.3	23.6	25.4	20.0	19.5	19.7	21.0	16.4	17.9	43.8	48.9	16.5	19.0	34.1	38.1	373.3	452.2	0.81	0.97						

[a] Expressed in inches.

[b] Expressed in kilograms.

[c] Expressed in kilograms/day.

[d] Average of depth of forequarter + body depth

[e] Average of thickness of forequarter + thickness of hindquarter + thickness of rump.

[f] Average of length of top + length of rump + length of side.

[g] A = Angus; C = Charolais.

[h] Value in parentheses ( ) are expressed as percentage of Feedlot period 4 value.

also expressed as a percentage of the final (feedlot period 4) value for each measurement. These three periods represent the initial measurement, weaning measurement, and 56 days prior to slaughter respectively.

From the data presented in Table VIII, it appears that the large scale Charolais calves were initially larger than the small scale calves except in thickness of forequarter, thickness of hindquarter and thickness of rump. These are the three measurements that comprise the thickness or width comparison between the two breeds. As indicated by the skeletal measurements listed in Table VIII, the large scale cattle continued to exceed the small scale group in body size throughout the duration of this study.

Figure 10 illustrates the variation in growth patterns obtained between the two breeds as indicated by total body weight. It is apparent from these data that initially there was no difference in the average live weight of the two groups. However, at maternal period 4, the Charolais mean live weight exceeded that of the Angus by 41.8 kg or 24.6%. Therefore, there appears to be a significant difference in the growth rate of the two breeds during the maternal phase with the large scale cattle growing more rapidly than the small scale cattle. This was opposed to the relatively constant growth rate between the two breeds during the feedlot phase as evidenced by the 58.0 kg difference in weight at feedlot period 1 and 78.9 kg difference at feedlot period 4. This is a 25.5% and 21.1% difference respectively at each period, with the Charolais being larger.

The eight linear skeletal measurements followed the same general trend as body weights as evidenced by the data in Table VIII and

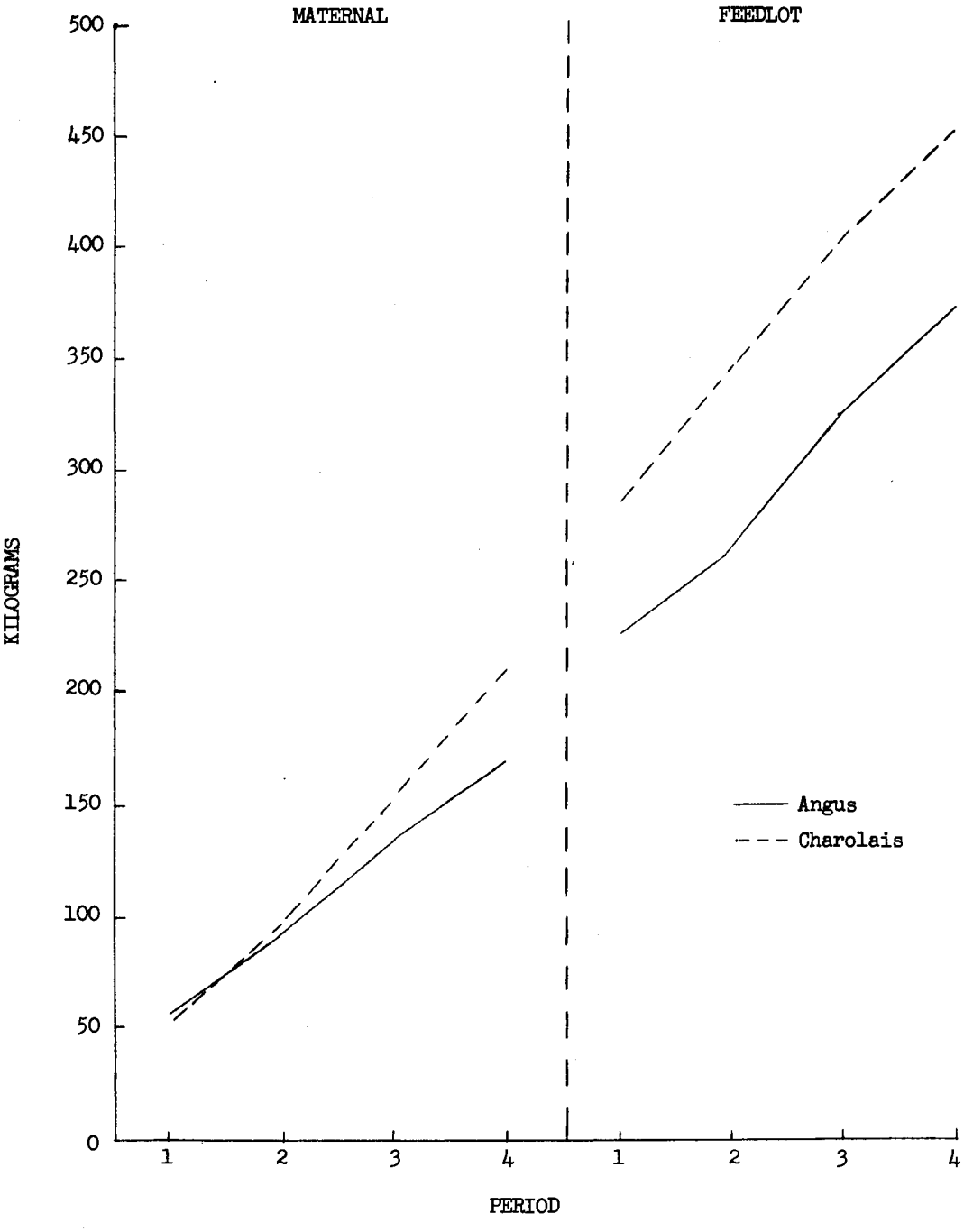

Figure 10. Live Weight by Phase and Period

Figures 15 to 22 in the Appendix.

These patterns are substantiated statistically by the by phase analysis of variance for each variable presented in Table IX. From these analyses, it was apparent that there was a significant increase in body size for all linear measurements from the maternal to the feedlot phase. The Charolais were significantly larger ($P < .01$) than the Angus except for thickness of hindquarter and thickness of rump. Most importantly, there was a significant difference ($P < .01$) in the linear parallelisms of the two breed response lines in the maternal phase indicating that the Charolais were increasing in body scale at a significantly faster rate than the small scale Angus cattle. There were no other significant components of variance which is indicative of the linearity of the maternal growth pattern in both breeds.

In the maternal phase, the Charolais measurements were significantly greater ($P < .01$) than the Angus group. However, there was no significant difference ($P > .05$) in the linear parallelism of the breed response lines except for depth of forequarter. Therefore, while the Charolais were larger than the Angus, there was no statistically significant difference in their feedlot pattern of growth.

The by breed analysis presented in Table X shows that the large scale cattle were larger than the small scale cattle for all variables studied. Also, there was a significant increase ($P < .01$) in all measurements from the maternal to the feedlot phase. Also, there was a significant difference in the parallelism of the Charolais maternal and feedlot response lines. Therefore, as illustrated by the graphic plots of the data in Figures 15 to 22 of the Appendix, the large scale Charolais were increasing in skeletal structure at a

TABLE IX

SUMMARY OF SIGNIFICANCE LEVELS OF ANALYSES OF VARIANCE BY PHASE FOR LINEAR SKELETAL MEASUREMENTS

	Body Depth	Depth of Forequarter	Thickness of Forequarter	Thickness of Hindquarter	Thickness of Rump	Length of Topline	Length of Rump	Length of Side
M vs. F[a]	**	**	**	**	**	**	**	**
Ani (Breed)	**	**	**	ns	ns	ns	**	**
Maternal	**	*	**	ns	ns	**	**	**
Linear	**	**	**	**	**	**	**	**
Parallelism	**	**	**	ns	ns	*	**	*
Quadratic	**	ns	**	ns	ns	ns	*	ns
Parallelism	ns	ns	ns	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	ns	ns	ns	ns
Parallelism	ns	ns	ns	ns	ns	ns	ns	ns
Feedlot	**	**	**	**	**	**	**	**
Linear	**	**	**	**	**	**	**	**
Parallelism	ns	**	ns	ns	ns	ns	ns	ns
Quadratic	*	ns	ns	ns	ns	ns	ns	ns
Parallelism	ns	ns	ns	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	ns	ns	*	ns
Parallelism	ns	ns	ns	ns	ns	ns	ns	ns

[a]M vs. F represents difference in Maternal (M) and Feedlot (F) phases

ns Non-significant ($P > .05$)

* Significant ($P < .05$)

** Significant ($P < .01$)

TABLE X

SUMMARY OF SIGNIFICANCE LEVELS OF ANALYSES OF VARIANCE BY BREED FOR LINEAR SKELETAL MEASUREMENTS

	Body Depth	Depth of Forequarter	Thickness of Forequarter	Thickness of Hindquarter	Thickness of Rump	Length of Topline	Length of Rump	Length of Side
Breed	**	*	**	**	**	**	**	**
Ani (Breed)	**	**	**	ns	ns	ns	**	**
M vs. F in Charolais	**	**	**	**	**	**	**	**
Linear	**	**	**	**	**	**	**	**
Parallelism	**	**	**	*	**	**	**	**
Quadratic	**	ns	ns	ns	ns	ns	ns	ns
Parallelism	ns	ns	ns	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	ns	ns	*	ns
Parallelism	ns	ns	*	ns	ns	ns	ns	ns
M vs. F in Angus	**	**	**	**	**	**	**	**
Linear	**	**	**	**	**	**	**	**
Parallelism	**	ns	**	ns	**	ns	**	**
Quadratic	**	ns	ns	ns	ns	ns	ns	ns
Parallelism	*	ns	*	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	ns	ns	ns	ns
Parallelism	ns	ns	ns	ns	ns	ns	ns	ns

ns Non-Significant ($P > .05$)

* Significant ($P < .05$)

** Significant ($P < .01$)

significantly faster rate in the maternal phase than in the feedlot phase.

The Angus breed analyses presented in Table X show a pattern similar to the Charolais except that there was no significant difference in the rate of growth from the maternal to the feedlot phase for depth of forequarter, thickness of hindquarter, and length of topline. There were no other significant effects.

Another method of comparing growth rate between the two breeds would be to express each period linear measurement as a percentage of its final (feedlot period 4) value. Figures 11, 12, and 13 represent the average of the length, depth, and width measurements respectively. From these data, it was apparent that initially (maternal period 1) the small scale cattle exhibited a greater percentage of their final body size than the large scale cattle (Table VIII). From these data, the Angus would appear to be more physiologically mature, assuming their final (feedlot period 4) size as the physiologically mature state. However, by weaning age (maternal period 4), the large scale cattle measurements (expressed as a percent of final size) exceeded those of the Angus except for length. At feedlot period 3 (56 days prior to slaughter) the Charolais exceeded the Angus in percentage of final body size for all measurements. Therefore, based on the size of these animals at slaughter age (14 months), it would appear that the large scale cattle were more physiologically mature in body size than the small scale cattle. This conclusion was drawn from the fact that the small scale cattle had a proportionally greater increase in body size from feedlot period 3 to feedlot period 4 (slaughter) than the large scale cattle.

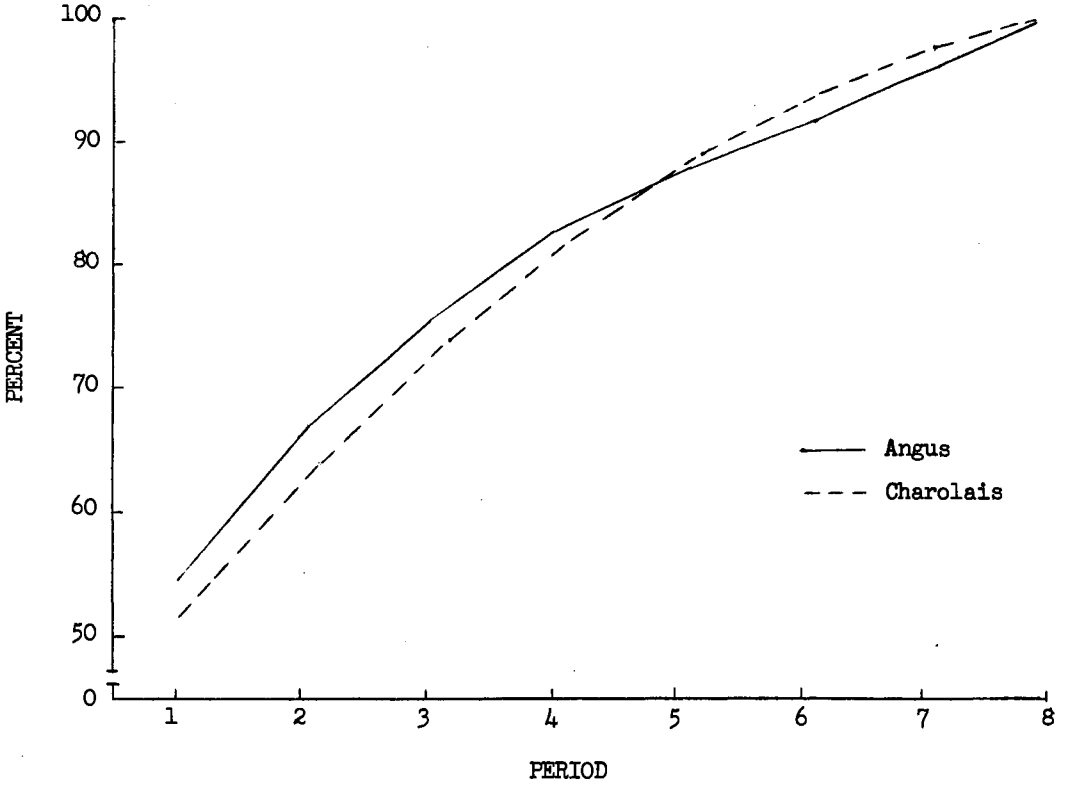

Figure 11. Average of Length Measurements as Percent of Final Measurement by Period

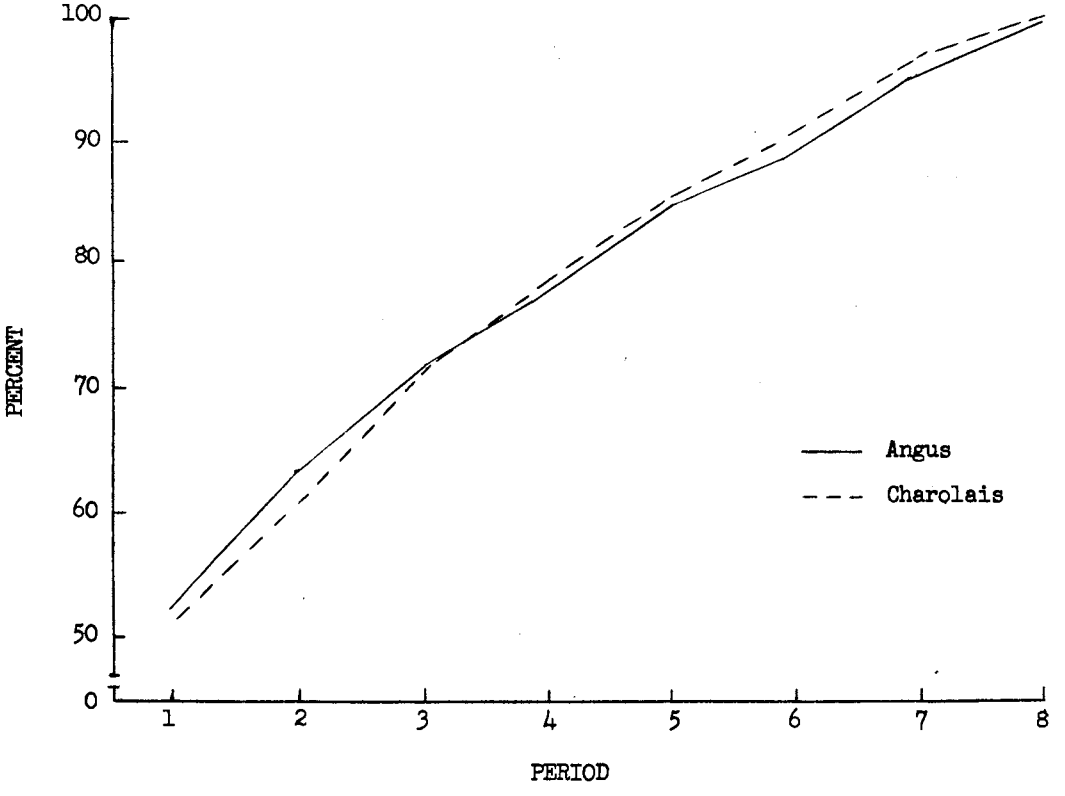

Figure 12. Average of Depth Measurements as Percent of Final Measurement by Period

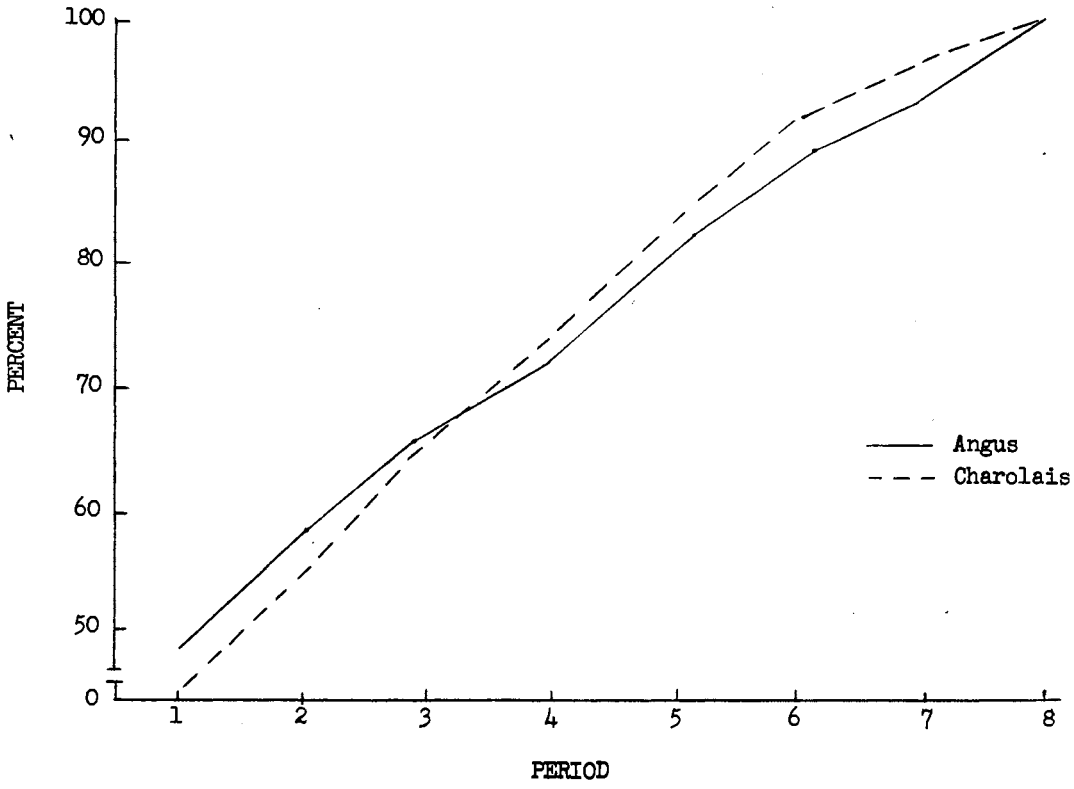

Figure 13. Average of Width Measurements as Percent of Final Measurement by Period

Radiograph Analysis

The least squares means for the various radiograph measurements obtained are presented in Table XI. From these data it is apparent that the large scale Charolais cattle were larger for all metacarpal measurements at each evaluation period than the small scale Angus. However, the relative growth patterns for the two breeds are quite consistent as evidenced by the percent increase of each measurement from maternal period 1 to feedlot period 4. The only exception was for total bone area which increased by 88.5% in the Angus compared to 105.3% in the Charolais. This would tend to support the general conclusion that the large scale type of cattle are normally heavier boned and have a higher percentage of bone in the carcass. Specific gravity estimates of carcass composition in these animals showed that the Angus carcasses had 12.08% bone as compared to 13.77% for the Charolais.

The general growth and developmental patterns between the two breeds may be typified by one particular radiogram variable, bone length (Figure 14). From the data presented in Table XI it was apparent that at maternal period 1, the mean total length of the Angus left metacarpal was 142.4 millimeters (mm). This was compared to 170.1 mm for the Charolais which was 27.7 mm or 19.5% greater than the Angus. At maternal period 4 (weaning), the Charolais exceeded the Angus by 30.2 mm or 17.6%. At slaughter (feedlot period 4), the Charolais exceeded the Angus by 39.9 mm or 21.6%.

Upon examination of the growth patterns within each breed, certain differences in time of increased growth rate become apparent between

TABLE XI

LEAST SQUARES MEANS FOR RADIOGRAPH MEASUREMENTS

BREED	PHASE	PERIOD	Total Length[a]	Proximal Diameter[a]	Distal Diameter[a]	Median Diameter[a]	Core Diameter[a]	Total Area[b]
ANGUS	MATERNAL	1	142.4	47.4	38.8	25.0	16.5	6.1
		2	162.3	52.1	46.9	27.3	17.9	7.6
		3	167.6	56.5	53.5	30.0	18.1	8.8
		4	171.8	57.0	57.8	32.2	19.4	9.1
	FEEDLOT	1	179.7	59.9	57.8	34.0	20.4	9.8
		2	183.6	60.2	58.1	35.5	20.8	10.3
		3	190.5	64.6	61.0	38.9	21.2	11.8
		4	185.0	66.6	62.1	39.2	21.5	11.5
CHAROLAIS	MATERNAL	1	170.1	56.88	44.3	25.4	17.0	7.6
		2	180.3	60.60	48.6	26.4	17.3	8.5
		3	190.6	61.60	54.4	27.9	17.1	9.4
		4	202.0	65.85	63.0	31.7	18.4	11.2
	FEEDLOT	1	208.7	70.23	65.9	34.4	20.0	12.4
		2	216.1	71.25	67.8	36.2	20.5	13.1
		3	219.41	72.45	69.3	37.7	20.4	13.9
		4	224.9	74.98	71.9	41.2	22.0	15.6

[a]Expressed in millimeters

[b]Expressed in square inches

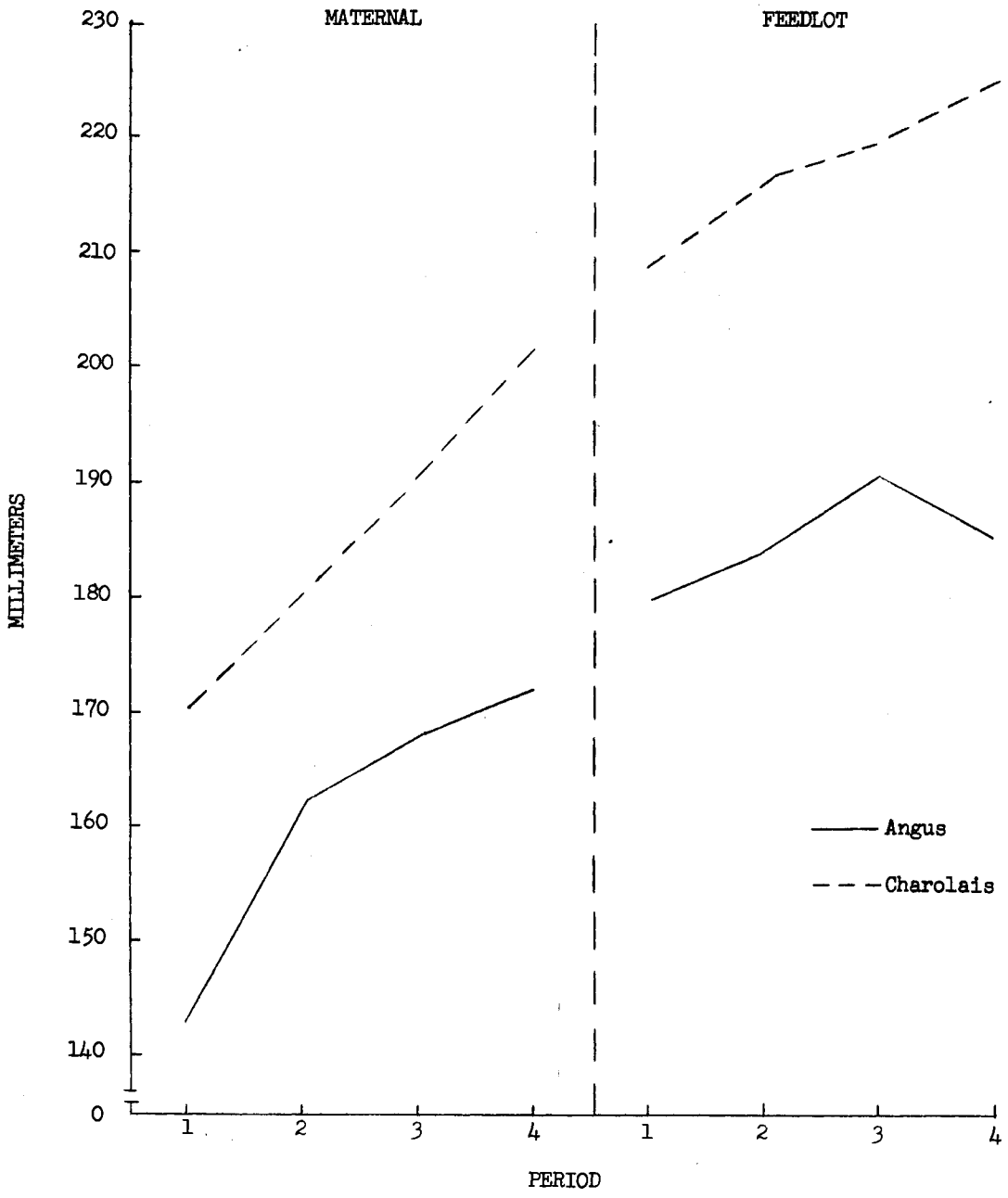

Figure 14. Metacarpal Length by Phase and Period

the two breeds. The small scale Angus increased by 29.4 mm from maternal period 1 to maternal period 4, a 20.6% increase during the maternal phase. During the feedlot phase, the Angus increased in total length by only 8.1 mm (using average of feedlot period 3 and feedlot period 4 for reasons explained in Chapter III as the final size) or a 4.5% increase over the feedlot period 1 value. By comparison, the Charolais increased in total length by 31.9 mm (18.8%) during the maternal phase and 13.5 mm (6.4%) during the feedlot phase. Therefore, the Angus appeared to have a greater relative (percent) increase during the maternal phase as opposed to a greater relative (percent) increase during the feedlot phase for the large scale Charolais cattle. Similar developmental trends were noted upon examination of the graphs for the other radiograph measurements presented in the Appendix, Figures 23 to 27.

These findings are substantiated by the analyses of variance presented in Tables XII and XIII. Table XII presents the by phase analysis for the six radiogram measurements. It is apparent from these data that there was a significant increase ($P < .01$) for each measurement from the maternal phase to the feedlot phase. In the maternal phase, the Charolais mean value was significantly greater ($P < .01$) than the Angus mean value for all measurements. However, there was no significant difference ($P > .05$) in the parallelism of the two breed response lines for any variable except core diameter.

In the feedlot phase, the Charolais group was significantly greater ($P < .01$) than the Angus for all variables except core diameter. Again, there was no significant difference in the parallelism of the two breed response lines except for total bone length

TABLE XII

SUMMARY OF SIGNIFICANCE LEVELS OF ANALYSES OF VARIANCE BY PHASE FOR RADIOGRAPH MEASUREMENTS

	Total Length	Proximal Diameter	Distal Diameter	Median Diameter	Core Diameter	Total Area
M vs. F[a]	**	**	**	**	**	**
Ani (Breed)	**	**	**	**	**	**
Breed in Maternal	**	**	**	**	**	**
Linear	**	**	**	**	**	**
Parallelism	ns	ns	ns	ns	**	ns
Quadratic	**	*	ns	*	ns	ns
Parallelism	**	*	**	**	ns	**
Cubic	ns	ns	ns	ns	ns	ns
Parallelism	ns	*	ns	ns	ns	ns
Feedlot	**	**	**	**	ns	**
Linear	**	**	**	**	**	**
Parallelism	**	ns	ns	ns	ns	**
Quadratic	**	ns	ns	ns	ns	ns
Parallelism	*	ns	ns	**	ns	**
Cubic	ns	ns	ns	ns	ns	ns
Parallelism	**	ns	ns	**	ns	**

[a]M vs. F represents difference in Maternal (M) and Feedlot (F) phases

ns Non-Significant ($P > .05$)

* Significant ($P < .05$)

** Significant ($P < .01$)

TABLE XIII

SUMMARY OF SIGNIFICANCE LEVELS OF ANALYSES OF VARIANCE BY BREED FOR RADIOGRAPH MEASUREMENTS

	Total Length	Proximal Diameter	Distal Diameter	Median Diameter	Core Diameter	Total Area
Breed	**	**	**	*	ns	**
Ani (Breed)	**	**	**	**	**	**
M vs. F in Charolais[a]	**	**	**	**	**	**
Linear	**	**	**	**	**	**
Parallelism	**	**	**	ns	ns	*
Quadratic	ns	ns	*	**	*	**
Parallelism	ns	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	*	ns
Parallelism	ns	ns	ns	ns	ns	ns
M vs. F in Angus	**	**	**	**	**	**
Linear	**	**	**	**	**	**
Parallelism	**	ns	**	*	**	**
Quadratic	**	ns	ns	ns	ns	**
Parallelism	ns	**	*	ns	ns	ns
Cubic	ns	*	ns	*	ns	**
Parallelism	**	ns	ns	ns	ns	*

[a] M vs. F represents difference in Maternal (M) and Feedlot (F) phases

ns Non-Significant ($P > .05$)

* Significant ($P < .05$)

** Significant ($P < .01$)

and total bone area which were both significantly different ($P < .01$). Moreover, while the by phase analysis showed that the Charolais were larger than the Angus for all measurements, there were no apparent differences in the rate of increase between the two breeds for any variable. This was a result of the significant initial (maternal period 1) difference between the two breeds for almost all measurements. The difference between breeds was then rather constant throughout the remainder of the animal's market lifetime.

The by breed analyses of the radiograph measurements are presented in Table XIII. From this analysis, one may note that the large scale Charolais group was significantly larger ($P < .01$) than the small scale Angus for all variables except core diameter. Within the Charolais group, there was a significant increase ($P < .01$) from the maternal to the feedlot phase for all variables. Also, the lack of linear parallelism for all variables except median and core diameter shows that the Charolais increased in size at a significantly faster rate during the maternal phase than in the feedlot phase.

Within the Angus breed, there was also a significant increase ($P < .01$) for all variables from the maternal to the feedlot phase. The growth pattern for the Angus followed the same trends as for the Charolais as indicated by the lack of parallelism between the Angus maternal and Angus feedlot response lines for all variables except proximal diameter.

The results of this study show that the larger scale Charolais calves were larger in skeletal structure from both linear skeletal measurements and actual bone dimensions as enduced by radiograms of

the left metacarpal. The Charolais also had a faster growth rate than the small scale Angus. These results are in agreement with Coble et al (1971b) who reported that animals with greater bone dimensions grew more rapidly, deposited more muscle per day of age and were leaner.

CHAPTER VII

SUMMARY

In reviewing the results of this study, it was apparent that there were numerous biochemical and physical differences between the two bovine breeds studied. However, due to the large variation present within some of the biochemical assays, and the limited number of animals utilized, it is difficult to actually identify a single biochemical index of performance.

The most promising index appeared to be muscle tissue oxidative metabolic activity. These results indicated that there was a significant difference between the two breeds in oxidative metabolic activity per unit of wet tissue during the early lifetime or pre-weaning phase of this study. It would be of interest to determine if such a difference might exist between animals of differing rates of growth within the same breed. From the results of this study, it was apparent that those animals exhibiting less "chemical maturity" at an early age were the animals that eventually had a faster growth rate and larger body size. In contrast, those animals that were more "chemically mature" at an early age developed into the slower growing, smaller scale animal that appeared to mature earlier in their lifetime but with a smaller body size. This theory is based on earlier discussion that immature muscle tissue is higher in oxidative metabolic activity than mature muscle tissue.

The above observation of change in oxidative activity and its relationship to growth rate, final body size and chemical maturity is substantiated by the muscle tissue chemical potassium results. Earlier research has shown that muscle tissue potassium concentration increased with maturity. A similar trend was noted in this study, with the larger scale animals (Charolais) being lower, initially, in tissue potassium than the smaller scale animals (Angus). Both breeds progressively increased in tissue potassium to a similar level at weaning age then declined during the feedlot phase. Therefore, the Charolais group was initially less "chemically mature" for muscle tissue potassium concentration than the Angus group.

Other factors, such as whole body ^{40}K count, might also be integrated into a multifactor index of performance. The present results indicated that there was a significant ($P < .01$) increase in whole body net ^{40}K count from the maternal to the feedlot phase in both breeds. Hence, both breeds appeared to be increasing in total lean tissue from early lifetime to late lifetime. While the small scale cattle increased in net count at a more rapid rate during the maternal phase of the study than the large scale cattle, the reverse was true during the feedlot phase. Overall, the Angus cattle reached their maximum net ^{40}K count at about 11 months of age (feedlot period 2) while the Charolais were continuing to increase in net count even at the termination of this study, indicating a continuous deposition of lean tissue. Therefore, it is apparent that the large scale cattle are the type of animal that can be carried to a heavier market weight, and continue to deposit lean tissue rather than large quantities of fat, which was suggested by the Angus whole body ^{40}K count data

during the feedlot phase.

The results of the linear skeletal measurement data agree with the whole body ^{40}K count estimates of increase in lean, since the small scale cattle attained a greater proportion of their final body size during the maternal phase of their lifetime than did the large scale cattle. However the large scale cattle grew more rapidly in body size and scale, especially during the maternal phase, than the small scale cattle. Radiograph measurements of the left metacarpal indicated that the large scale cattle increased in bone dimension at a significantly ($P < .01$) faster rate than the small scale group. Also, the rate of increase in bone dimension in the Angus was significantly ($P < .01$) less during the feedlot phase than in the maternal phase, while there was no significant ($P > .05$) difference in the rate of increase between the maternal and feedlot phase for the Charolais. This indicated that the small scale cattle had reached a state of physiological maturity, relative to bone development, not evident in the large scale cattle.

Future research might be aimed at determining the differences in these criteria in animals within the same breed. This work should use a large group of animals within one particular breed with extremes in growth rate and body size. These animals should be biopsied and evaluated at an early age (30-45 days), fed to a final market age or weight and then again biopsied and evaluated. By comparing overall growth rate, final body size, and carcass merit to the initial data, the merits of these biochemical and physical tools of selection would be evident, as to economical value.

In conclusion, if these biochemical and physical tools of selection can be proven statistically useful by future research this

would be a major contribution to the beef industry because it would: (1) allow the culling of less desirable animals from the breeding herd without investing time and expense of raising these animals to weaning age or later, (2) give a rapid objective measurement of potential rather than utilizing subjective visual means of evaluation, and (3) enable the early identification of superior breeding animals.

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APPENDIX

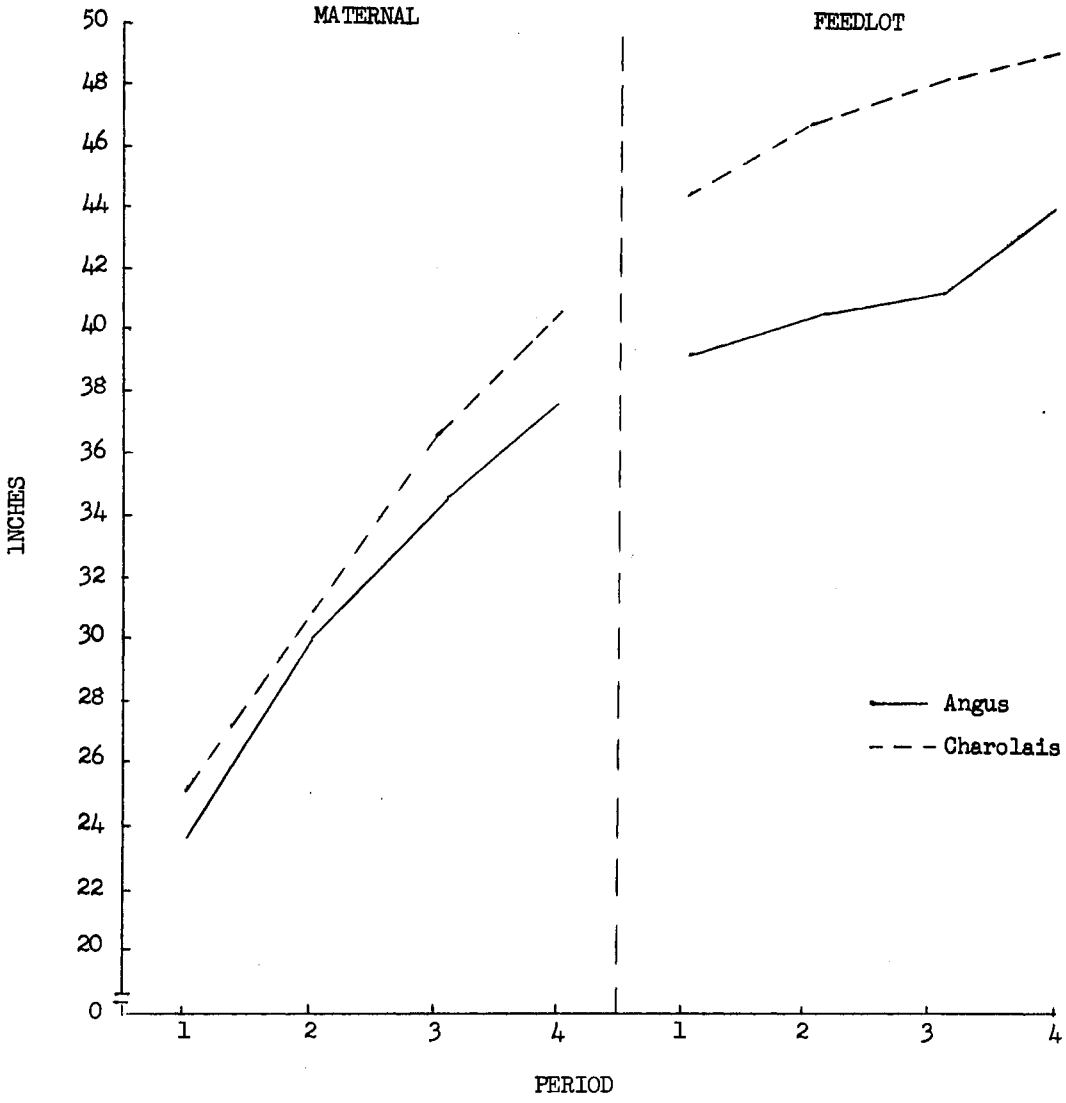

Figure 15. Length of Topline by Phase and Period

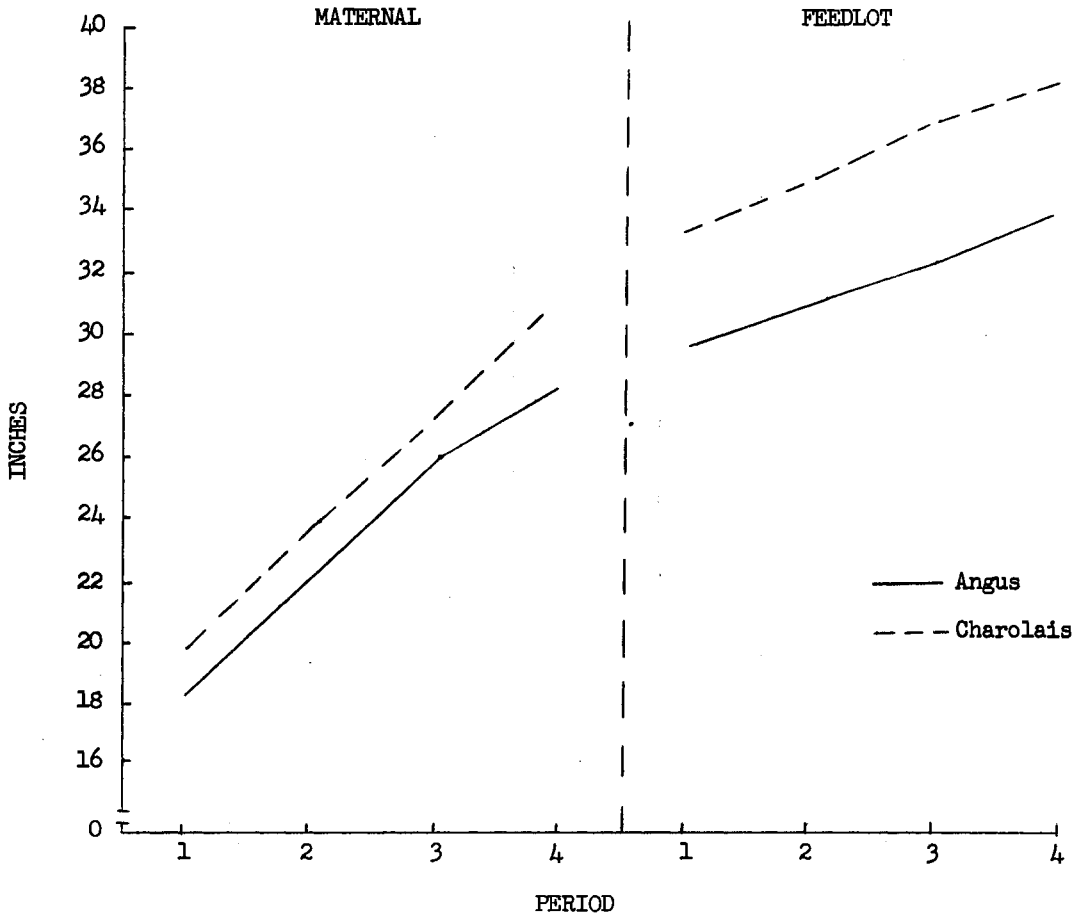

Figure 16. Length of Side by Phase and Period

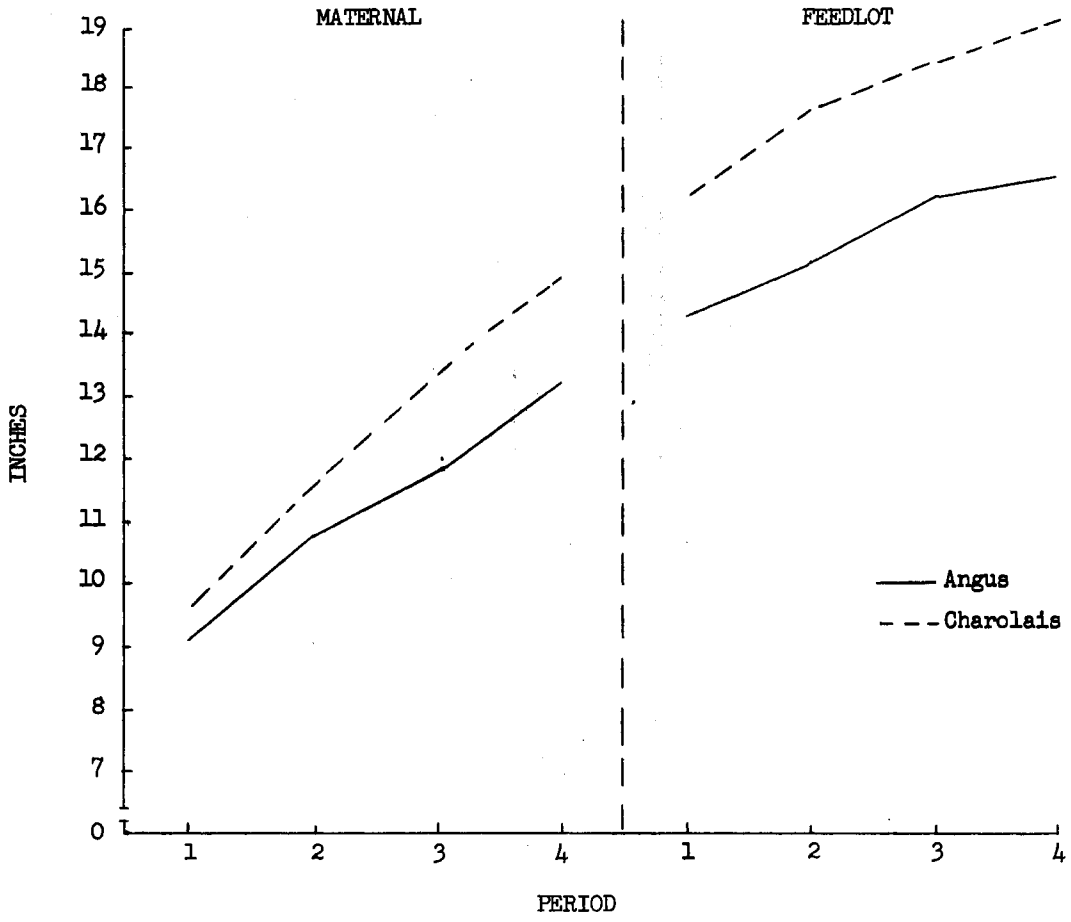

Figure 17. Length of Rump by Phase and Period

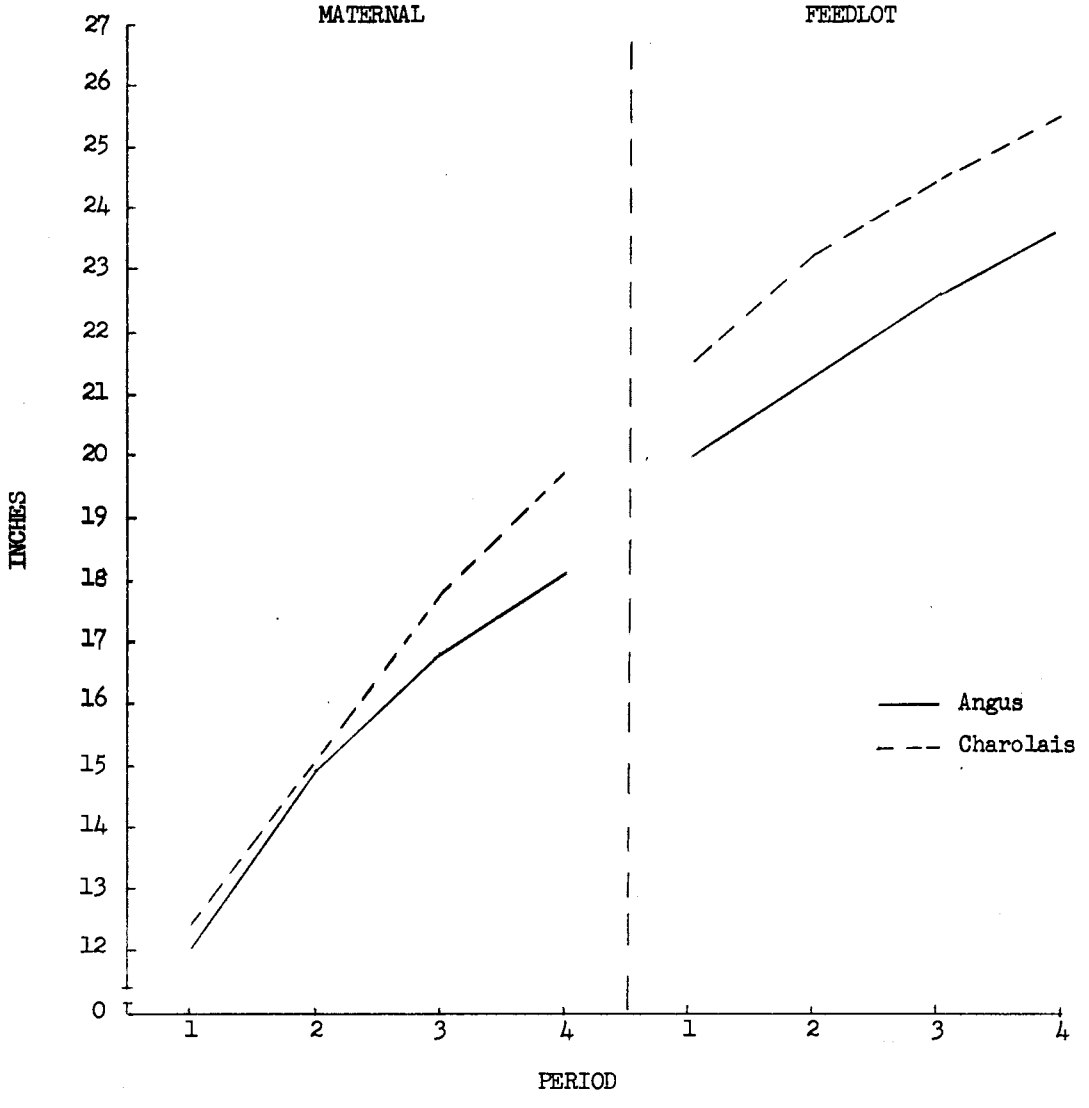

Figure 18. Depth of Body by Phase and Period

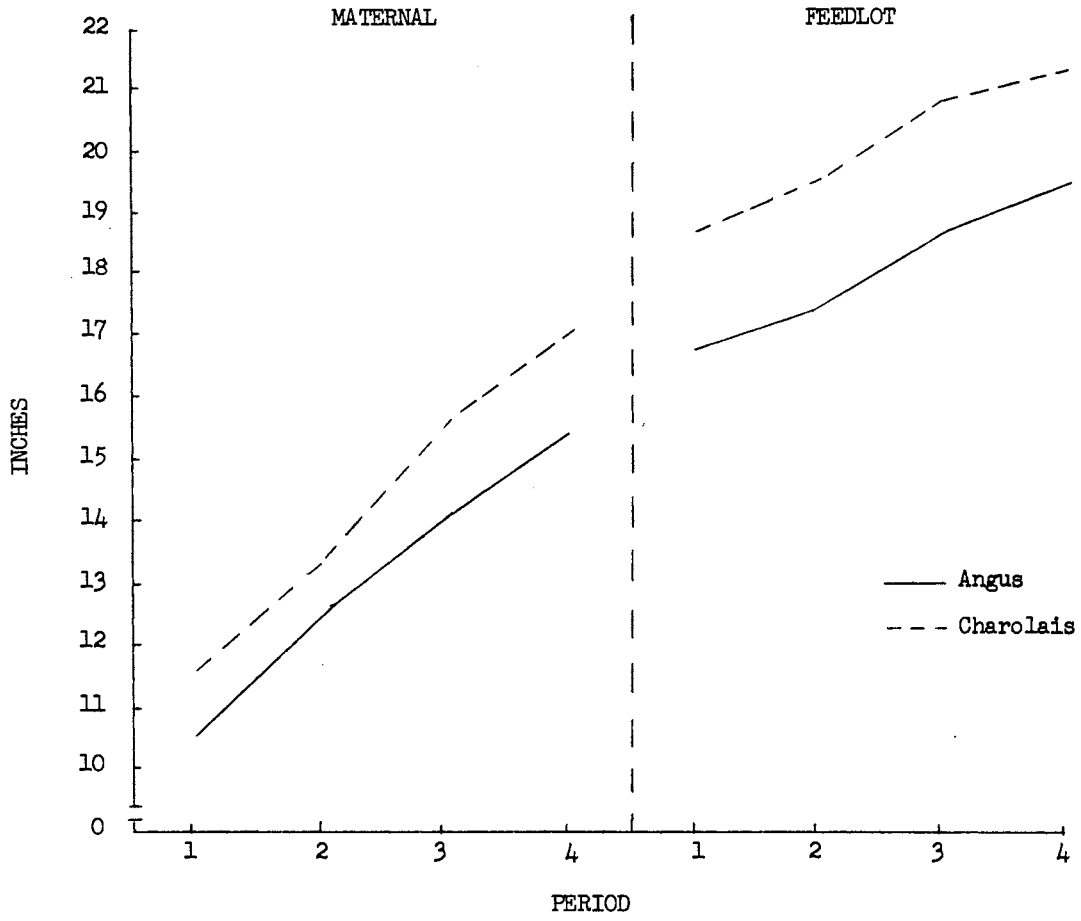

Figure 19. Depth of Forequarter by Phase and Period

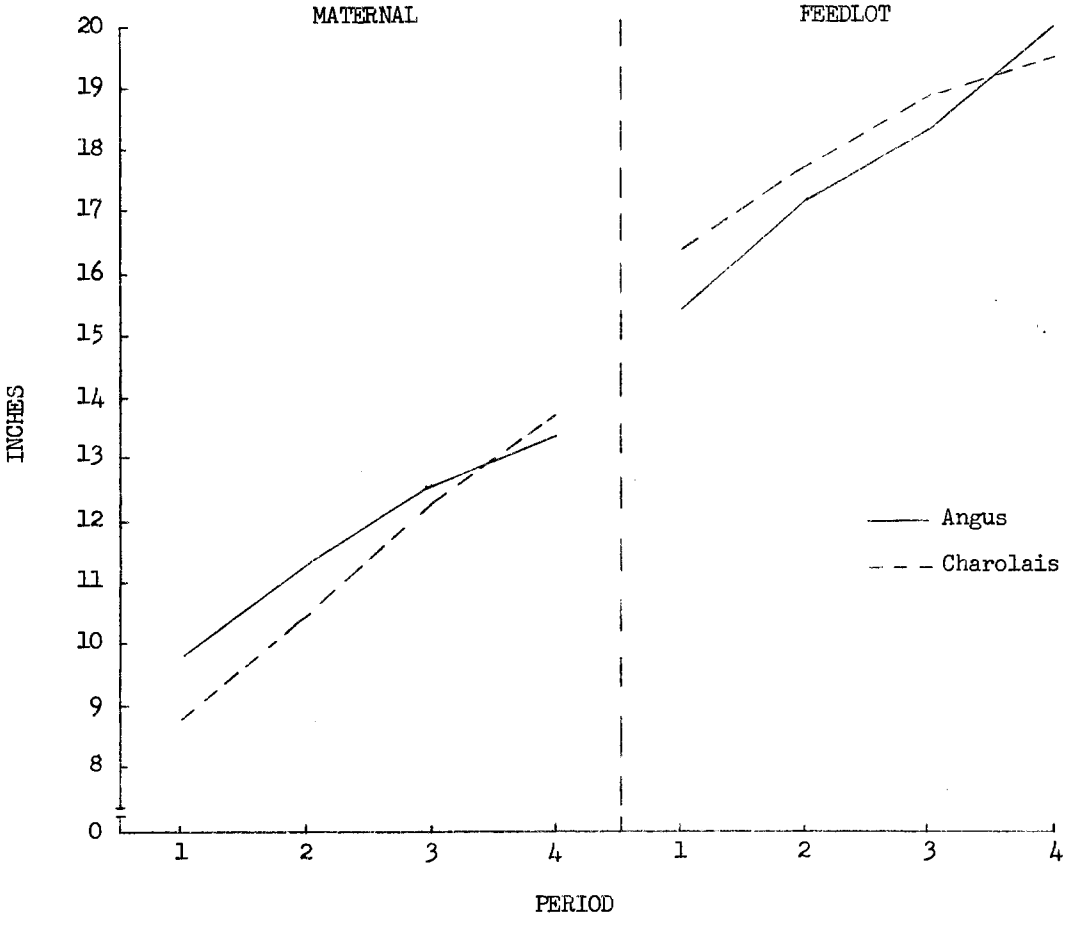

Figure 20. Thickness of Forequarter by Phase and Period

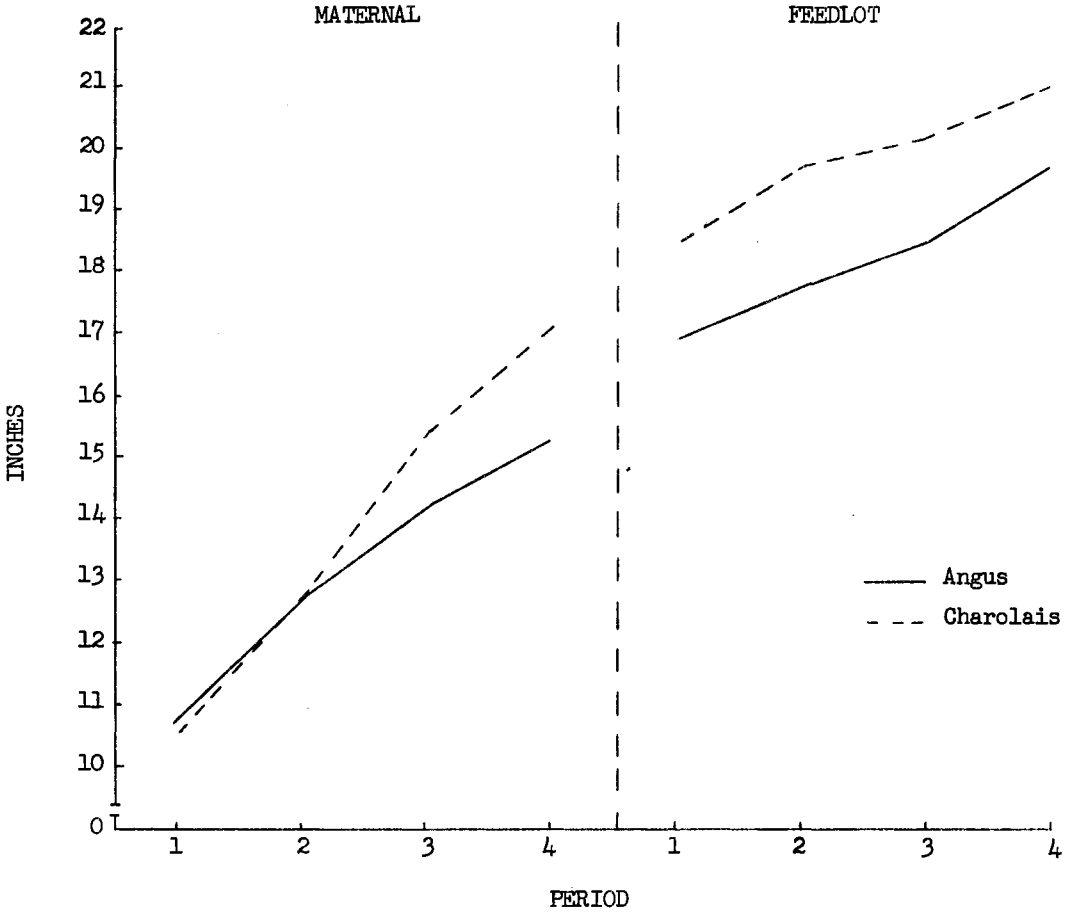

Figure 21. Thickness of Hindquarter by Phase and Period

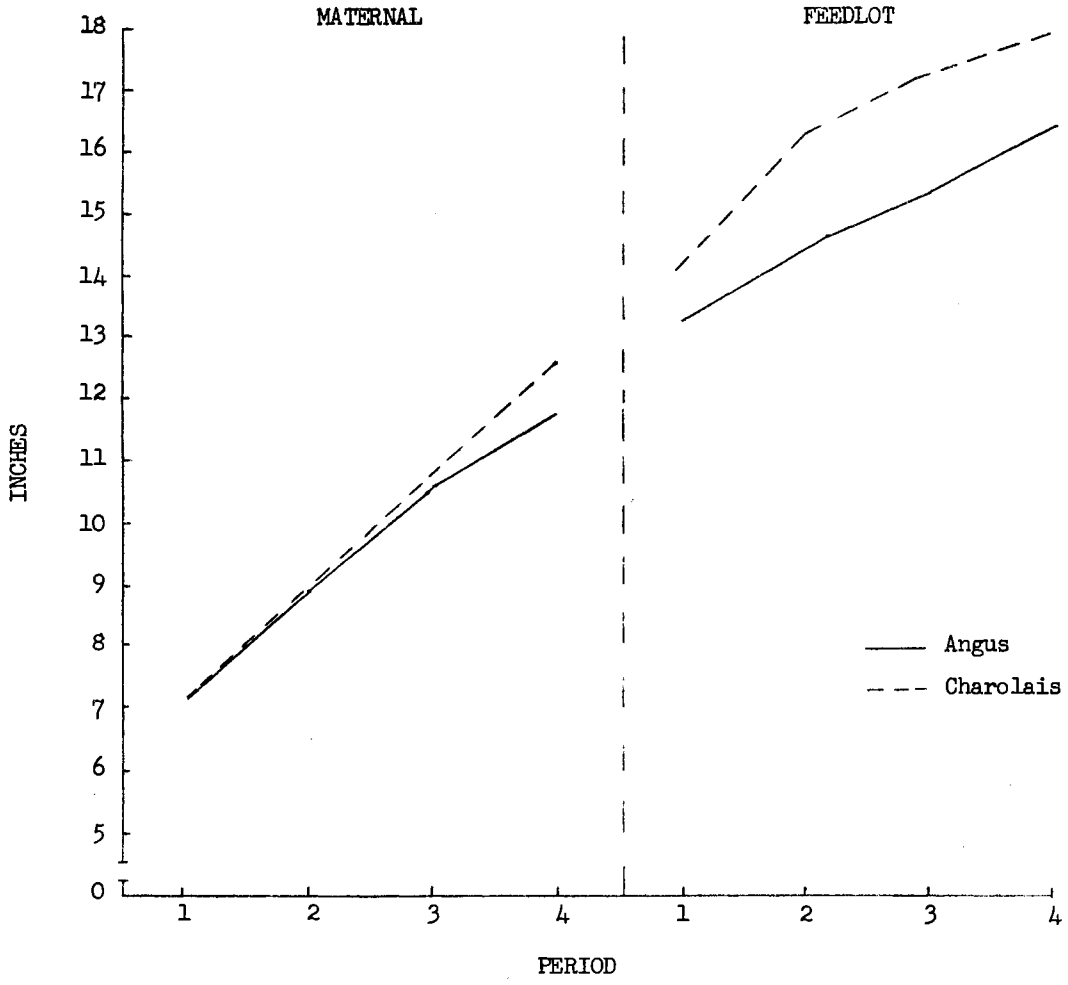

Figure 22. Thickness of Rump by Phase and Period

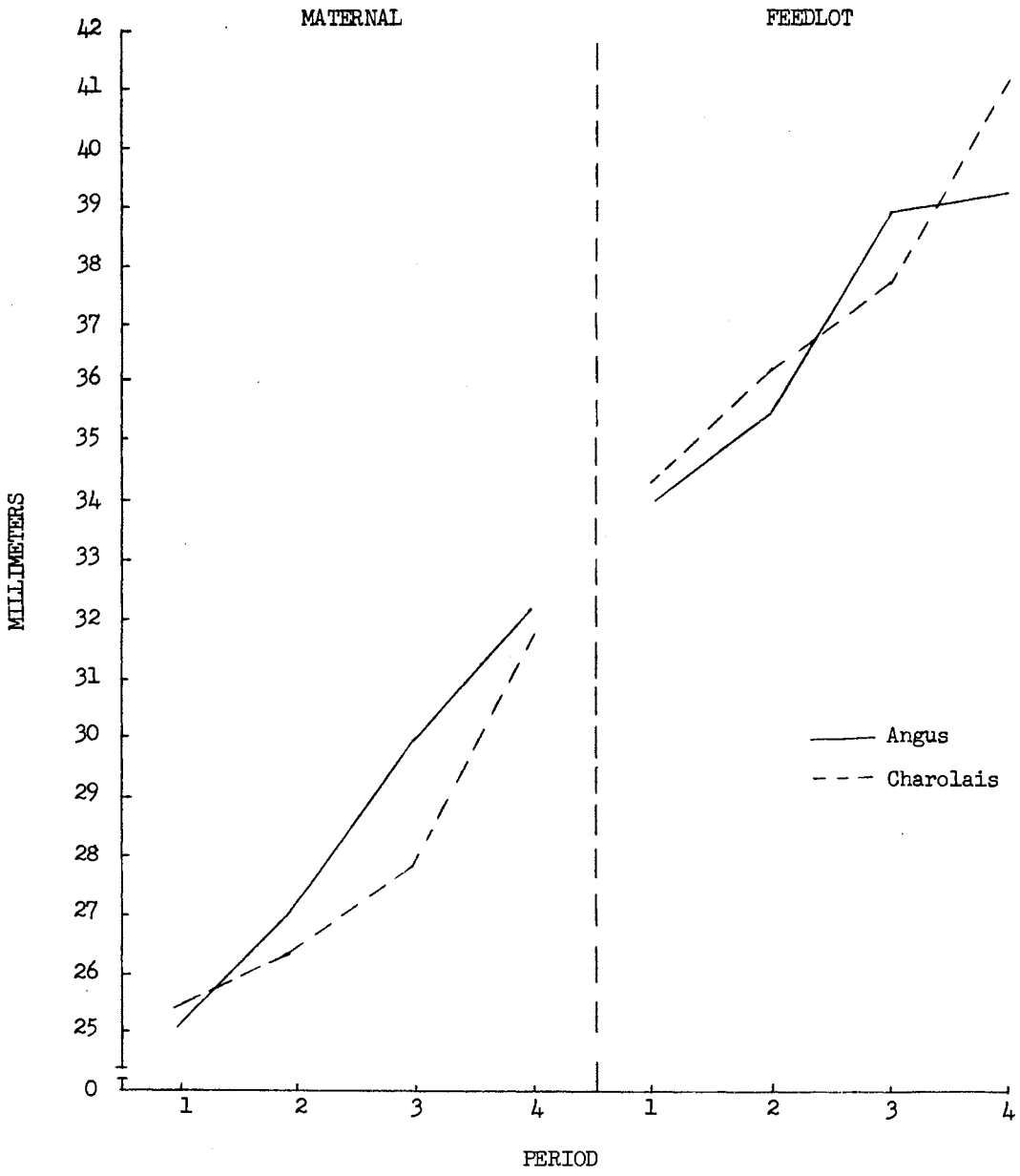

Figure 23. Median Diameter of Metacarpal by Phase and Period

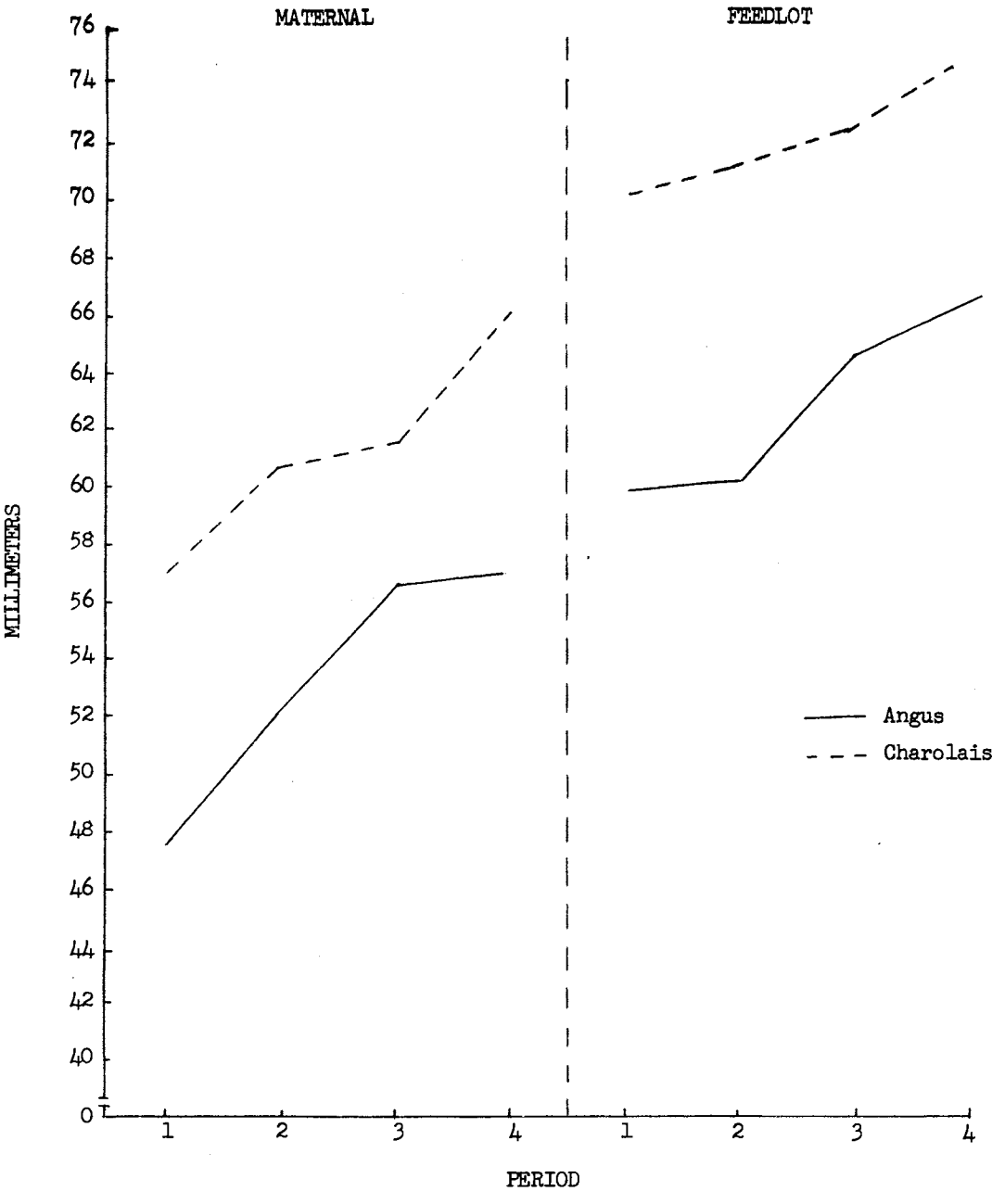

Figure 24. Proximal Diameter of Metacarpal by Phase and Period

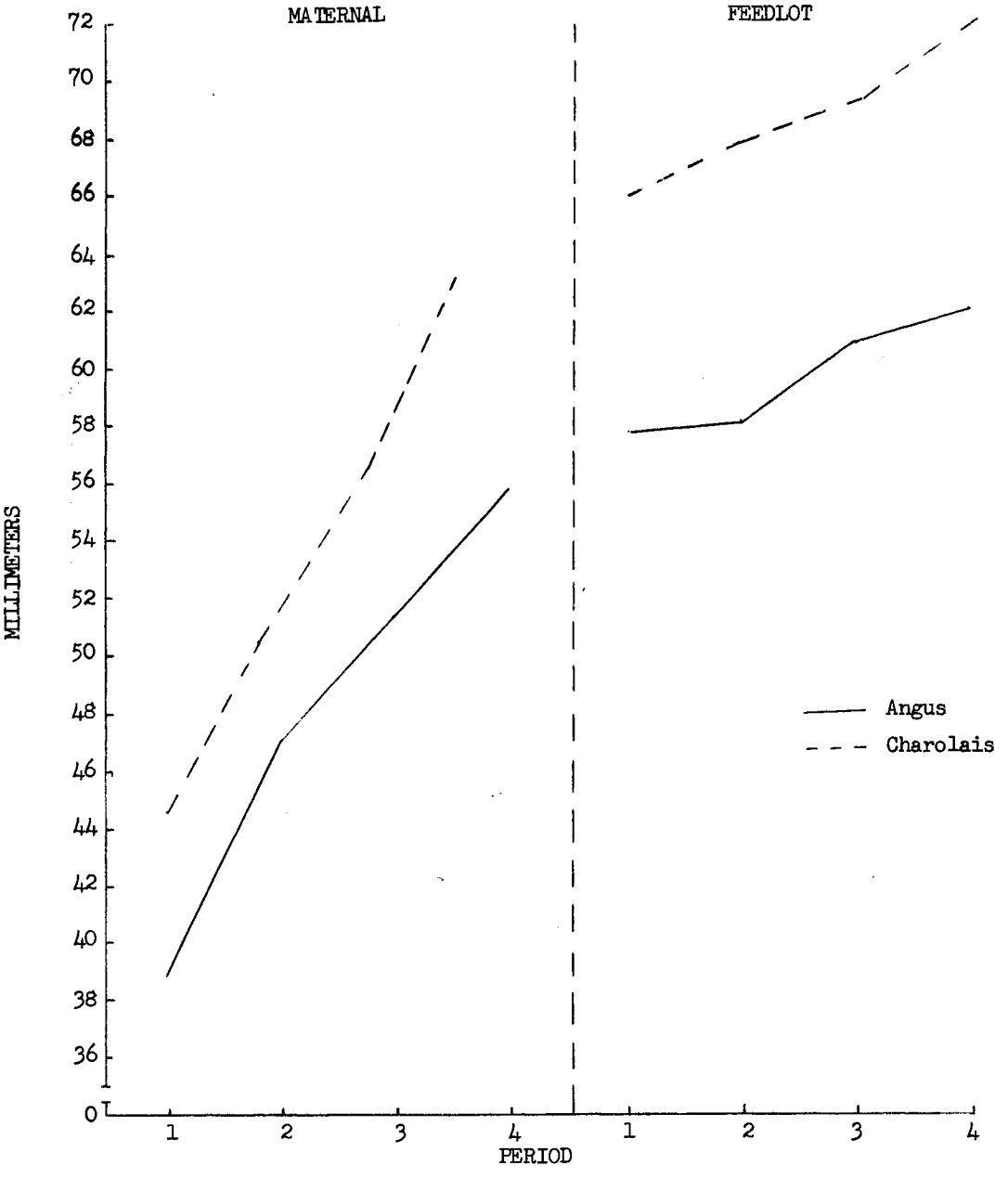

Figure 25. Distal Diameter of Metacarpal by Phase and Period

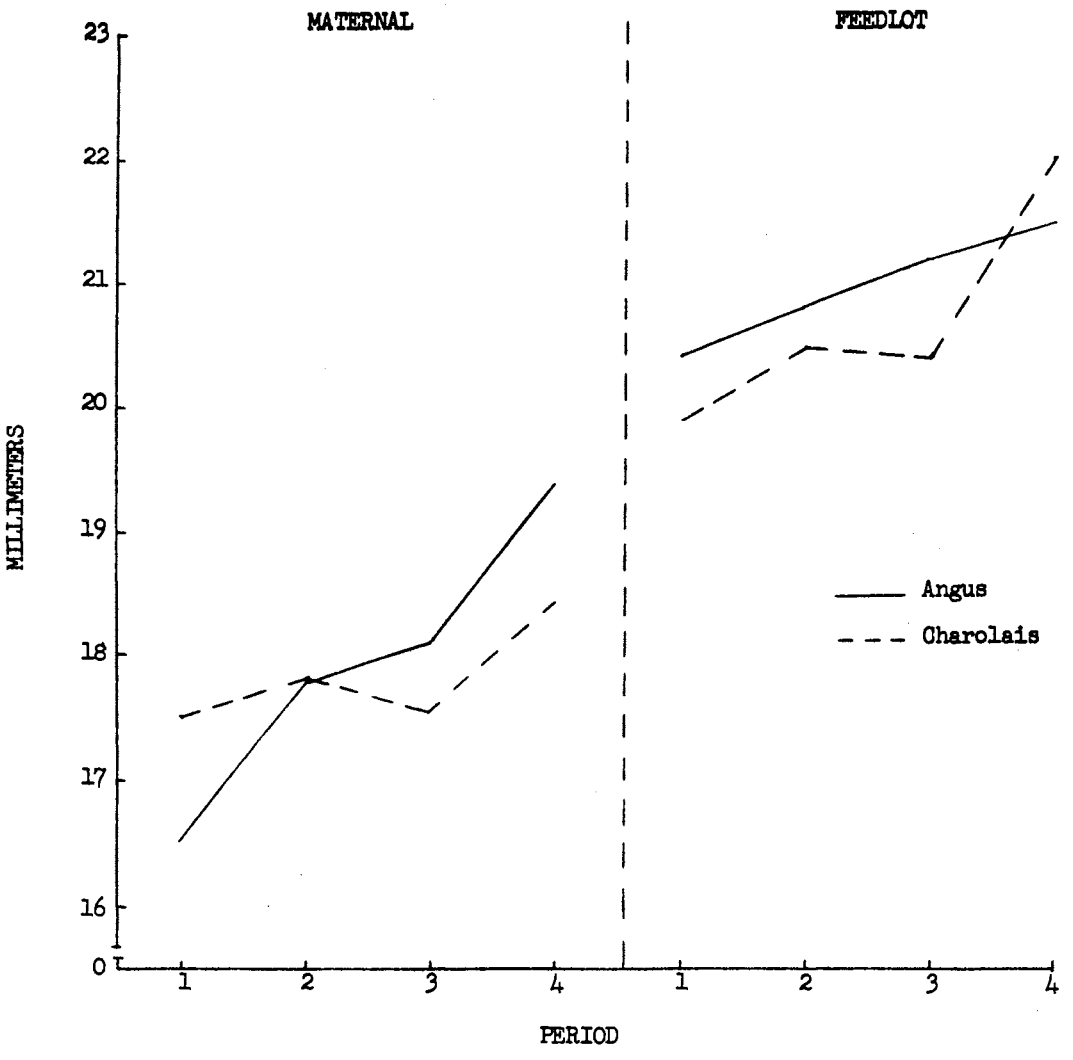

Figure 26. Core Diameter of Metacarpal by Phase and Period

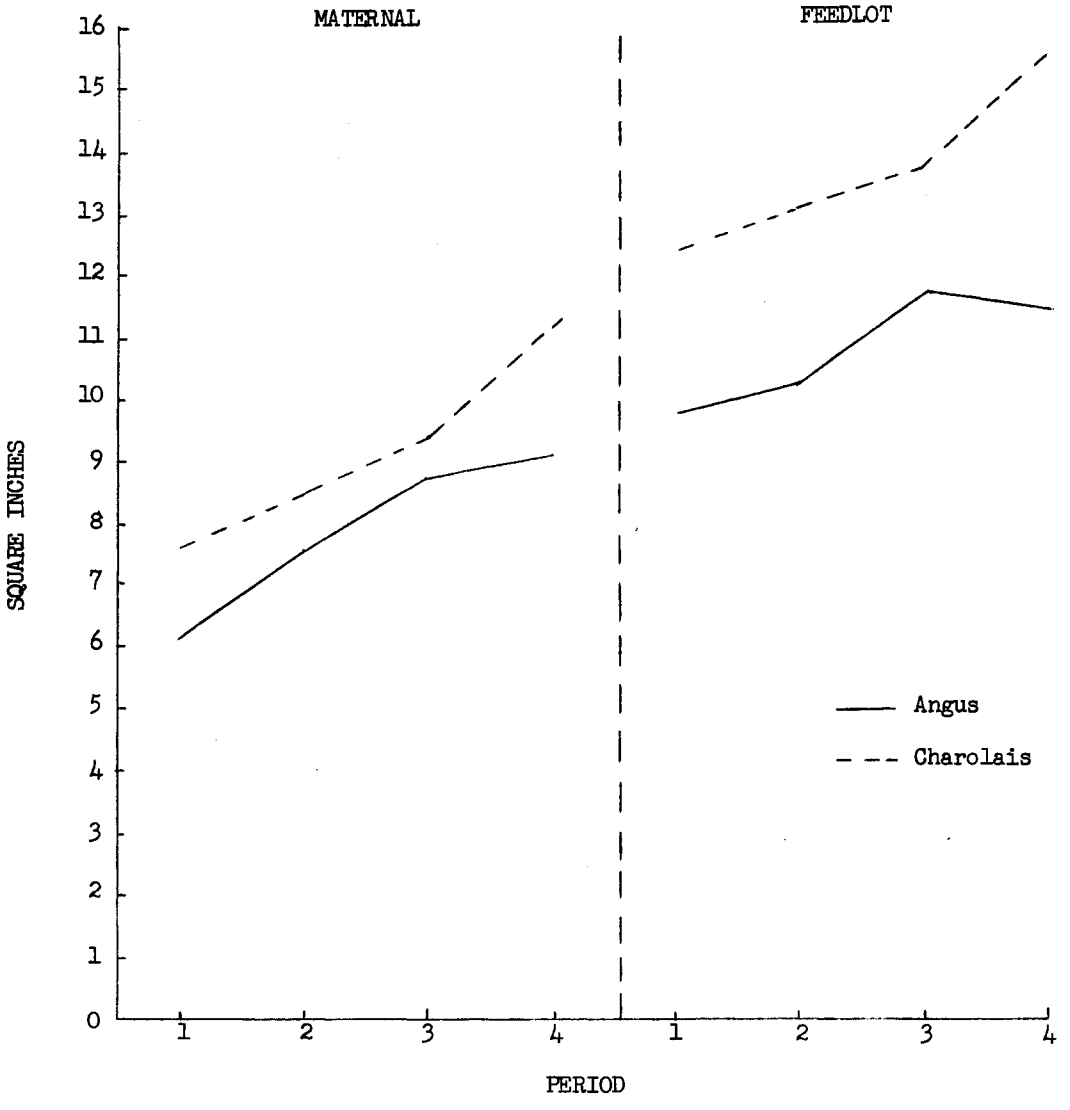

Figure 27. Total Metacarpal Area by Phase and Period

VITA

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Doctor of Philosophy

Thesis: BIOCHEMICAL AND PHYSICAL ESTIMATES OF GROWTH AND DEVELOPMENT IN LARGE SCALE AND SMALL SCALE BOVINE

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