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MUSCLE GROWTH AND MATURITY PARAMETERS
OF BOARS AND BARROWS

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MUSCLE GROWTH AND MATURITY PARAMETERS OF BOARS AND BARROWS

By

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ABSTRACT

Muscle Growth and Maturity Parameters

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The objectives of this study were to evaluate the whole body composition, bone and muscle maturity differences between boars and barrows. Treatments consisted of sex and end weights of (1) barrow to 105 kg, (2) boar to 105 kg, (3) boar to 118 kg, (4) boar to 132 kg and (5) boar to 145 kg. Boars at 105 kg had 45% less backfat, were 2.9% longer and had similar longissimus area as barrows of similar weight. At the same backfat thickness boars were greater than 41.0 kg heavier than barrows. The ratio for total weight to total length of the tibia was greater in the boars (105 kg) than barrows. There was no differences in growth rate between boars and barrows to 105 kg. Boars achieved their maximum daily gain at a weight 24 kg heavier than the weight barrows reached maximum daily gain.

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INTRODUCTION

"The animal breeder requires of the comparative anatomist not only a descriptive statement of what has been done in evolution, but also an indication of how he can best produce the form he requires; it is clear that it is in experimental anatomy or the physiology of anatomy that the solution of these problems will be found. Just as the sciences of chemistry and botany have formed the basis of advancement in soils and crop husbandry respectively, so the science of physiology should form the basis of animal husbandry in the future. Farm animal physiology has as its objective the obtaining of control over the functions of the animal body in order to increase the efficiency in the output of eggs, offspring, milk, meat and wool and to maintain good health throughout a long life-time of high production." These statements by John Hammond (Hammond 1932, 1954) recorded more than fifty years ago suggest that research in animal physiology would become essential for increasing the efficiency of animal production. This concept has been adopted by scientists and the research achievements have continued in achieving a more complete understanding of the physiological control mechanisms, as well as using this knowledge to improve the efficiency of animal production.

The swine industry has adopted genetic principles in performance testing programs to select boars with the genetic ability to sire barrows that will grow efficiently to a desired market weight.

The National Swine Improvement Federation (1981) recommendation to test seedstock to 105 kg is based on the belief that the physylogical growth of boars and barrows is similar. Current research data, however shows that growth and body composition differences do exist between boars and barrows raised to a common weight. Kuhlers et al. (1976) reported that boars had .06 cm less backfat than barrows at 68 kg and .12 cm less backfat at 136 kg. They concluded that to predict the fat depth of barrows at any given weight, boars should be measured at a weight 22.7 kg heavier than barrows. Hines (1966) found no significant differences in the growth rate between boars and barrows carried to similar weights. However, average backfat thickness and percentage primal cuts did vary. This would indiate that a maturity difference may exist between boars and barrows when compared at similar weights.

The research study reported in this manuscript was designed to measure the growth, composition and muscle maturity differences between boars and barrows. The purpose of obtaining these quantitative measures was to accurately determine at which weight the swine industry should test boars, to attain maximum growth and leanness of a 105 kg barrow.

LITERATURE REVIEW

Definition of Growth

The growth phenomenon is one of the primary factors of animal agriculture and a detailed understanding of muscle, fat and bone development during postnatal growth is essential for improving the efficiency of livestock production.

Reviewing the past definitions of postnatal growth will allow a general overview of this area and aid in allowing the complexities to remain in focus. Pomeroy (1955) discussed the definition by Schloss (1911) who defined growth as a "correlated increase in mass of the body in definite intervals of time in a way characteristic of the species." Pomeroy (1955) pointed out that this definition indicates "that growth in weight of an organism is a function of the species, subject to individual variation." The definition does not, however take into consideration that an increase in body mass that is characteristic of a species is dependent on an optimal level of nutrition (Palsson, 1955). The increase in weight until mature size is reached is growth. Development is the change in body conformation and shape during which various functions and faculties come into full being (Hammond, 1940). The increase in weight catagorized as growth is a complex and

highly integrated process, that may be referred to as the production of new biochemical units through metabolic and biological synthesis. In quantitative terms, growth is the increase in living substance and includes one or more of the following three processes: cell multiplication, cell enlargement or incorporation of material taken from the environment (Brody 1945).

Reviewing these concepts allows the realization that growth in the biological sense is more than simply an increase is size. In a living organism, growth is a complex differentiated increase in cell number and cell size, and may be altered genetically and (or) nutritionally.

Methods of Studying Growth

The direction taken to study postnatal growth of animals is generally divided into three separate areas. The first area considered, is the increase of body mass in time. usually described on a whole body basis by the live weight growth curve (Fowler 1968). The construction of live weight growth curves are used extensively for comparative species study and to construct mathematical models of growth prediction (Brody 1945).

The second category that is studied pertains to the change in the form of the animal resulting from differences in the relative growth rates of the component parts of the body (Fowler 1968). This area of growth requires a comprehensive anatomical dissection of experimental animal

carcasses into bone, fat and muscle to provide the documented work necessary. Complete carcass dissection work was utilized in sheep (Hammond 1932) and carried out in pigs (McMeekan 1940 a, b, c). Due to the time consuming, laborous and painstaking work of this procedure, continual effort has led to experiments exploring the possibility of a procedure that would provide composition data, but would not be as time consuming as the entire carcass dissection technique. Hankins and Ellis (1934), established the reality of a high correlation between mean backfat thickness and the chemically determined amount of fat in the carcass. This concept was further studied by Hazel and Kline (1952), who found the average of four backfat measurements supported a .81 correlation with percentage carcass fat. They also developed the steel backfat probe that is still widely used throughout the swine industry for measuring backfat thickness. In a different type of approach to determine the amount of body fat Brown et al. (1951), Whiteman et al. (1953), Pearson et al. (1956) and Morris and Moir (1964) found that specific gravity was more accurate in determining body fat than backfat thickness. Pearson et al. (1956) concluded that the specific gravity technique should be regarded as a useful, although not a necessarily precise method for estimating carcass composition. Aunan and Winters (1952) developed a core technique to determine carcass composition. They removed a core sample between the

fifth and sixth rib of the carcass and found a correlation of .79 between the fat to lean ratio in the core, and the fat to lean ratio in the carcass. After removing the ham from the carcass Smith et al. (1957) separated out the fat and observed a correlation of .89 between the percentage defatted ham and the percentage lean cuts in the carcasses of 300 barrows.

There have been numerous attempts to develop a technique that would similate the accuracy of the total body dissection technique utilized by John Hammond (1932). No other technique has provided a more thorough procedure to record the different components of body composition than the total carcass dissection.

The third and final area studied as a component of growth is at the cellular level. Leblond (1972) proposed three different postnatal cellular growth patterns and a fourth one for muscle. Robinson (1969) has found an increase in the amount of nucleic acids as a function of postnatal growth in myotubes. In studying adipose tissue growth in young pigs, Anderson and Kauffman (1973) have reported the increase in adipose tissue mass up to 2 months was primarily due to an increase in adipose cell number. From 2 to 5 months the increase was due to hyperplasia and hypertrophy however, after 5 months there was continual cell enlargement but no significant increase in cell number.

Working with growing bone Owen, Triffitt and Melick (1973) have observed the formation of new bone by osteoblasts differentiating into osteocytes.

Whole Body Growth

Under normal circumstances a sigmoidal curve is produced when growth of body weight is plotted against time. This relationship of postnatal growth is found to be consistent across species, with only a variation in time (Brody 1945). The first phase of the sigmoidal curve begins with the growth after parturition, and is described as a slow accelerating growth. This phase is followed by a rapid growth phase during which puberty occurs. The rapid growth phase eventually reaches a maximum rate and then levels off at mature weight. Mature weight is maintained with only a slight decrease over time under normal circumstances. Most studies with pigs occur during the period of rapid growth. Clausen (1953) reported that rapid growth occurs to the peak weight of 70 to 80 kg. Doornenbal (1972) referenced work by Oslage and Fliegal (1965) that showed from studying the modern pig (barrows and gilts of Improved German Landrace breeding) that the entire interval from weaning to 130 kg must be regarded as a period of intense growth. Davey and Morgan (1969) and Doornenbal (1972) have also reported that rapid linear growth occurred in swine until 40 wk which represents 130 to 150 kg. The economic importance of rapid growth is clear, due to the high relationship between rapid

gains and efficient feed utilization of relatively lean pigs (Oslage and Fliegal, 1965).

Developmental Patterns

The postnatal development of the differentiated tissues from the prenatal blastocyte, in swine and other animals, matures in the well known order of nervous tissue, bone, muscle and fat (Palsson 1955). Huxley (1932) first studied the differentiation of the various tissue components to whole body growth using the following equation, $Y = aX^b$. Through the use of this equation Huxley was able to predict the weight of an organ or tissue within a species knowing virtually only body weight. The logarithmic conversion of this equation has been used to determine growth coefficients to compare the relative growth rates of carcass components (Tulloh 1964; Elsley et al. 1964; Davies (1974a) and specific muscles and bones (Davies (1974b; Richmond and Berg 1982a; Richmond et al. 1979). With the logarithmic equation Elsley et al. (1964) calculated growth coefficients from data by McMeekan (1940 a, b, c) and Palsson and Verges (1952). Elsley et al. (1964) reported, from these calculations, that body growth followed a developmental pattern of the head and neck maturing first, the forelimb, hindlimb and the thorax being intermediate in development and the pelvis and loin maturing last. The cranial to caudal and proximal to distal development, with hindlimb developing later than forelimb and the lumbar area as the

latest developing is widely supported for muscle and bone growth (McMeekan, 1940 a, b; Davies, 1974b; Richmond et al., 1979; Richmond and Berg, 1982a). Muscle differentiation of swine is postulated (Davies, 1974b; Richmond and Berg, 1982a) to occur at a relative high impetus early in life for muscles essential for basic function of locomotion, while the muscles responsible for greater propulsion and body stability develop later in life. The early differentiation was found to occur before 23 kg live weight by Richmond and Berg (1971c).

Comparing muscle development by breed of swine, Davies (1974b) reported a significant increase in muscle development in the hindlimb and spinal regions, but less development in the forelimb and neck in the Pietrain compared to the Large White. Experimental use of Huxleys' allomentric equation also indicated that the Pietrain was more mature in muscle development than the Large White, at similar body weights (Davies (1974b). These findings indicate that a intraspecies difference exists in muscle development between the Pietrain and Large White.

Classifying the developmental differences of certain muscles in swine, with growth coeffients, Richmond and Berg (1982a) reported that the brachialis was less than 1 and the longissimus and semitendinosus muscles were greater than 1. Davies (1974b) who worked with the Pietrain and Large White disagrees with these findings, and reported a growth

coefficient for the semitendinosus equal to 1. Butterfield and Berg (1966) working with cattle found a growth coefficient for the semitendinosus significantly greater than 1 early in life, but not different from 1 in later phases of growth. Mulvaney (1981) reported that in swine there was a greater impetus for growth in the longissimus at 45 kg than at 22 kg live weight and the semintendinosus and brachialis had less impetus for growth at 45 kg than at 22 kg live weight. Richmond and Berg (1971c) found that differential growth of a certain muscle was also influenced by the sex, reporting that barrows muscle growth differentiation is more prolonged than in gilts.

Bone, Muscle and Fat Development

In addition to anatomical location, developmental differences also occur in the growth rate of the major tissues of the animal body, i.e. bone, muscle and fat. The greatest proportion of bone growth occurs earlier postnatally than either muscle or fat. Fat continues to increase in mass longer throughout body growth than muscle. This pattern was not only demonstrated in swine (McMeekan, 1940a; Cuthbertson and Pomeroy, 1962; Cole et al., 1976) but has also been shown in sheep (Hammond, 1932; Palsson and Verges, 1952) and cattle (Berg and Butterfield, 1976).

Throughout the rapid growth period the impetus of bone growth is maintained at a steady state (McMeekan, 1940a; Berg and Butterfield, 1976). Differential growth of an

individual bone occurs in the order of length followed by thickening (McMeekan, 1940a; Cuthbertson and Pomeroy, 1962). The growth of a single muscle develops in a pattern similar to bone by first lengthening and then thickening (McMeekan, 1940a).

During the rapid growth period the rate of muscle growth exceeds fat deposition. Near the end of this period muscle grows at a slower rate and the incorporation of triglycerides into adipose tissue increases to a rate that is greater than muscle growth. Relative to live body weight, the intercept of fat deposition and muscle accretion has met with disagreement among researchers. Hammond (1933) reported the intercept of fat and lean occurred at 80 kg live weight in the British bacon pig; Clausen (1953) found the intercept to occur at 95 kg for Danish Landrace. Doornenbal (1972) reviewed work by Oslage and Fliegal (1965) that observed with the Improved German Landrace that the ratio of protein to fat does not change from 90 kg to 120 kg live weight. These findings are supported by Witte and Stringer (1969) and Doornenbal (1972). McMeekan (1940a) in a comprehensive study reported that muscle exceeds fat to 24 wk in swine and from then on fat is deposited at a greater rate. In studying bone growth McMeekan (1940a) found that there is a greater quantity of bone than muscle and fat from birth to 4 wk, in swine.

It is widely accepted that as body weight increases percentage carcass yield and fat increase, percentage carcass protein and bone decrease and percent carcass muscle increases to a point and then decreases (McMeekan, 1940a; Buck, 1962; Stant et al., 1968; Richmond and Berg, 1971a; Doornenbal; 1971). McMeekan (1940a) has reported that at birth the pig carcass consisted of 30% muscle and 5% fat. As live weight increased from 52 to 100 kg carcass muscle decreased from 44 to 39% and fat increased from 32 to 43%, respectively. Weiss et al. (1971) in swine observed carcass bone to decrease from 32 to 15% as body weight increased from 1 to 137 kg. Buck (1962) studied percentage lean in barrows and gilts from 68 to 118 kg and found that the percentage lean increased less from 91 to 118 kg than from 68 to 91 kg live weight. At 91 kg live weight, pigs have 84% of the muscle and 66% of the fat present at 114 kg live weight (Richmond and Berg, 1971a). In swine as live body weight increases the carcass measurements of backfat thickness, longissimus muscle area and length increase proportionally (Wallace et al., (1959; Usborne et al., 1968; Meeker, 1973). Buck (1962) and Usborne et al. (1968) reported that as live weight increases daily gain also increases and the efficiency of feed conversion decreases.

Muscle to bone ratios have been shown to be similar at birth for sheep, cattle and hogs, and also at the adult stage (Tulloh, 1964). This suggests that between species,

maturity may have a greater effect on the muscle to bone ratio than body size. Berg and Butterfield (1976) stated that the growth pattern of bone occurs at a steady, but slow rate, while muscle grows relatively fast. Therefore, the ratio of muscle to bone increases with an increase in body weight. Edwards et al. (1980) observed a range of muscle to bone ratios in swine from 2.89 to 5.49, and found that the leaner carcasses had significantly larger muscle to bone ratio.

The sequence of adipocyte development in the different fat depots of red meat animals, from early to late growth, is reported to occur in the order of perirenal, subcutaneous, intermuscular and intramuscular by Lee and Kauffman (1974). Richmond and Berg (1971b) indicated that fat and lean hog carcasses have the same proportion of subcutaneous, intermuscular and perirenal fat. Over a two week period Mulvaney (1981) found a significant increase in the amount of intramuscular fat in the longissimus and the semitendinosus muscles of pigs as early as 45 kg live body weight. Noffsinger et al. (1959) has observed that in swine the thickness of backfat is greater over the shoulder than the loin.

In a comprehensive review Hammond (1932) showed that the plane of nutrition had a profound effect on the amount of fat in the body. The classical work carried out by McMeekan (1940 a, b) demonstrated the effect of nutrition on growth,

by growing inbred Large White pigs along predetermined planes of nutrition that would represent different growth curves. Development of the major body tissues was studied at 16 wk of age and at a final weight of 91 kg live weight. McMeekan concluded that different tissues and organs could be affected by nutrition. Wilson (1954) reexamined McMeekans' data and reportedly found that the varied levels of nutrition primarily affected the development of fat. Fowler and Livingston (1972), Davies (1974a) and Cole et al. (1976) reported that fat deposition is not as closely related to either body weight, carcass weight, or muscle plus bone weight as are muscle and bone growth. Consistent with these findings Richmond and Berg (1971a) found that fat is the major contributor to differences in carcass composition.

Postnatal Muscle Growth

Skeletal muscle is a significant component of postnatal body mass of mammals. The carcass of the new born pig consists of 60% muscle and this level is maintained in the lean type pig to 16 wk of age (Callow, 1948). On a live body basis this muscle mass constitutes 40 to 45% of the weight.

The synthesis of muscle begins at the embryonic stage and originates from the mesoderm (Kelly and Zachs, 1969) as a spindle shaped, mitotically active, mononucleated cell population, termed presumptive myoblasts (Holtzer, 1970). The presumptive myoblast differentiates to a mitotically

inactive myoblast cell that is elongated and capable of myofibrillar protein systhesis (Stockdale and Holtzer, 1961). Myogenesis continues with the fusion of myoblasts to form the multinucleated myotubes. The next stage of myogenic development is the differentiation of myotubes into muscle fibers by the migration of nuclei to the periphery and the bulk synthesis of the myofibrillar proteins, e.g., actin and myosin (Fischman, 1967; Coleman and Coleman, 1968). Continual maturation of the muscle fiber involves synthesis, assembly of the myofibrillar proteins, mitochondrial proliferation, innervation and development of the sarcotubular system.

Growth in living tissue is characterized by two methods, hyperplasia or an increase in cell number and hypertrophy or the increase in cell size. The diploid nuclei located in the myofiber contains a constant amount of deoxyribonucleic acid (DNA) (Mirsky and Ris, 1949; Vendrely, 1955; Leblond, 1972). Enesco and Leblond (1962) studying the muscle nuclei of the rat estimated that each nucleus contained 6.2 pg of DNA. Therefore, in mononucleated cells an increase in DNA content would indicate hyperplasia. Enesco and Puddy (1964) and Leblond (1972) however, have pointed out that skeletal muscle consists of multinucleated cells (myofibers) and a increase in DNA content represents an increase in nuclei number and not necessarily an increase in cell number. Check et al. (1971) discussed how each nucleus within a myofiber has jurisdiction over a definite mass of myofiber

cytoplasm. The incorporation of additional myofibrils increases this cytoplasmic area and increases the cell size by hypertrophy. There may be maximum volume of cytoplasm a single nucleus may control and this physiological cell size concept may be used as a measure of postnatal growth (Moss, 1969; Cheek et al., 1971; Robinson, 1971; Goldspink, 1972).

Extensive documentation that postnatal muscle growth occurs primarily by hypertrophy of myofibers is reported in the literature. McMeekan (1940a) examined the fiber number per bundle in the longissimus of the pig and found no significant increase during postnatal growth. Stickland and Goldspink (1973) supported this previous work in pigs by finding no significant increase of myofiber number in the cross section of the longissimus from 1 to 200 d postnatally. In a different approach using light microscope techniques, Swatland and Cassens (1973) and Swatland (1973) reported that myofiber hyperplasia is completed in the fetal pig by approximately 70 d of gestation. After this time only hypertrophic growth of the individual myofibers was found. In addition to the hypertrophy of the myofiber, determined by an increase in fiber diameter, (Mulvaney, 1981) an increase is reported in total DNA and ribonucleic acid (RNA) and a decrease in DNA and RNA concentration in skeletal muscle of swine, postnatally (Gordon et al., 1966; Robinson, 1969; Gilbreath and Trout, 1973; Tsai et al., 1973; Hakkarainen, 1975; Powell and Aberle, 1975; Harbison

et al., 1976; Swatland, 1977). Considering the mitotically inactive nature of myofiber nuclei the primary source of additional nuclei is the satellite cell. Mauro (1961) first detected the presence of the satellite cell, by electron microscopy, which are located between the plasma membrane and the basement membrane of the myofiber. By thymidine incorporation studies it was determined that the satellite cell is capable of mitosis, after which one or both of the daughter cells fuse with a myofiber, thus contributing additional nuclei (Moss and Leblond, 1971; Snow, 1978). The absolute as well as relative decrease in muscle satellite cell population is reported for the pig, postnatally (Campion et al., 1981).

The decrease in DNA and RNA concentrations with increasing age is most accurately explained as a diluting effect caused by the rapid increase of myofibrils (Goldspink, 1972; Tsai et al., 1973). The increase in total RNA in a tissue during growth is associated with the protein synthesizing potential (Wannamacher, 1972). In postnatal growth of pigs the increase in total RNA was associated with the increase in total protein and muscle weight (Powell and Aberle, 1975).

The amount of RNA synthesized per nucleus is obtained by the ratio of RNA to DNA. Topel (1971) has observed an increase of RNA to DNA ratio in the longissimus of a muscular strain of pigs, and suggested an association of the

ratio of RNA to DNA with protein synthesis. Powell and Aberle (1975), Millward et al. (1975), Ezekwe and Martin (1975) and Hogberg (1976) have also demonstrated the RNA to DNA ratio of muscle is related to protein synthesis capacity. The relationship of protein to DNA and muscle weight to DNA, indicative of physiological cell size, have been found to increase postnatally with age (Robinson, 1969; Powell and Aberle, 1975; Hogberg, 1976).

Bone Growth

Bone is in a constant flux of new mineralization and enzymatic digestion during the growth period and in the mature animal. This activity is referred to as bone remodeling and is due to the presence of osteoblasts and osteoclasts. Osteoblasts are characterized by synthesizing high levels of collagen and providing alkaline phosphatase activity (Rasmussen and Bordier, 1974) responsible for bone mineralization. The osteoclasts contain lysosomal enzymes including acid phosphatase (Vaes, 1968) and are capable of synthesizing a substantial amount of hyaluronic acid (Owen and Shetlan, 1968) which is able to degrade mineralized matrix (Rasmussen and Bordier, 1974).

Bone, as other living tissues, is dependent on adequate nutrition, stimuli and cell type to grow and maintain life. Harris and Innes (1931) have reported that a deficiency of vitamin D or abnormal mineral intake will interfere with

normal cartilage calcification and impair growth. X-ray analysis of long bone growth regions have illustrated transverse lines of growth arrest, due to chronic dietary restriction (Harris, 1933).

Bone growth is also controlled by gonadal hormones. Simpson et al. (1944) reported that testosterone has a stimulating effect on epiphyseal growth. Brannang (1971) has reported the distal bone length of appendages are longer in steers than bulls during the growth period. Wood and Riley (1982) in agreement with this record, have reported that barrows are taller than boars at the same weight.

The precursor cells of bone formation, skeletoblast originate from mesenchymal stem cells during prenatal and postnatal life (Young, 1964; Owen, 1967). The skeletoblast may differentiate into a prechondroblast type I or type II (Stutzman and Petrovic, 1982). The prechondroblast type I cells mature into the chondroblast cells located in the ephiphyseal cartilage of long bones. The original skeletoblast cell can differentiate into a osteoprogenitor cell that can develop into a preosteoblast or a preosteoclast (Petrovic, 1982). With further maturation the osteoblast and osteoclast cells are formed.

The ephiphyseal cartilage located at the junction of the diaphysis and ephiphysis at both the proximal and distal end of a long bone is often referred to as the epiphyseal plate. Under normal circumstances the rapidly growing animal has a

wider epiphyseal plate than slower growing older animals (Sissons, 1956). The proliferative activity of chondroblasts originating from the ephiphyseal plate cartilage, adds new cells increasing the length of bone through a sequence of interstitial growth and endochondral ossification (Dodds and Cameron, 1934). Kember (1960) reported that ephiphyseal cartilage cells labeled with tritiated thymidine demonstrate passage through the ephiphyseal plate towards the diaphysis during mitosis. The passage through the plate is followed by hypertrophic growth and vascularization by blood vessels and connective tissue incorporation (Ham, 1950). Osteoblasts present in this endochondral hypertrophic growth area initiate the mineralization of cartilage remnants (Scott and Pease, 1956) forming trabecular bone. Osteoclast also function in trabecular bone, remodeling areas of the new framework by digesting cartilage remnants (Dodds, 1932).

The mapping of bone growth was first initiated by Hales (1927), who drilled two holes in the diaphysis of a young chicken bone and demonstrated that bone grew by the addition of new bone at the ends. Brash (1934) fed madder to pigs as a method of mapping bone growth. Madder contains alizarin (Payton, 1932) a compound that is incorporated into the growing area of bone (Tapp, 1966). The mapping by tetracycine however, is detected by fluorescence of histological sections (Hansson, 1967).

The appositional formation of bone on a preexisting surface is referred to as membranous ossification and accounts for the thickening of bone during growth. Studies using tritiated thymidine (Young 1962 a, b) have demonstrated that a osteoblast cell population located between the bone surface and periosteum actively deposits lamellar bone on the surface. The osteoblasts are formed by the proliferation and maturation of osteoprogenitor cells located under the periosteum (Owen, 1970). New bone cells are actively formed on the surface and are included in bone lacunae as mature osteocytes. Reabsorption and remodeling of bone by osteoclast is also present in this process (Lee, 1964).

Boar and Barrow Comparisons

Scientific studies comparing growth and composition differences of boars and barrows have been reported in the literature throughout the world. Walstra and Kroeske (1968) reviewing the literature of thirty five articles from ten counties have reported that boars have a higher percentage lean, a lower percentage fat, are longer, have a more favorable feed conversion and a lower dressing percentage than barrows. Turton (1969) emphasizes that castration is as old as the history of domestication of livestock and was adopted to modify the secondary sex characteristics of male animals such as sex drive, body form, composition and the sexual odor or taint in boar carcasses. The Leydig cells of

the seminiferous tubules in the testis secrete the testosterone and other androgens that regulate and maintain the body characteristics and accessory sex organs of the male. Turton (1969) reviewed the data across species of sheep, cattle and hogs and reported that intact males have a greater fore-end development and a higher bone content than castrates. This observation agrees with the review by Prescott and Lamming (1964) that focused specifically on boars.

Growth Rate

The literature on growth rates for boars and barrows have reported no difference in growth rate and that boars grow at a more rapid rate than barrows. The majority of reports demonstrate that boars grow significantly faster than barrows (Bratzler et al., 1954; Piatkowski and Jung, 1966; Blair and English, 1965; Burgess et al., 1966; Siers, 1975; Wood and Riley, 1982). Reports by Blair and English (1965) show an 8.8% greater growth rate in boars, and Wood and Riley (1982) observed at the same final weight boars were 20 d younger. A study on seasonal growth (Siers, 1975) shows a significantly higher growth rate for boars than barrows during the fall. No difference was found in the spring, however. Numerous other researchers have found no significant difference between the growth rate of boars and barrows (Winters et al., 1942; Kroeske, 1963; Hines, 1966; Omtvedt and Jesse, 1968; Hetzer and Miller, 1972; Newell and

Bowland, 1972; Pay and Davies, 1973). Prescott and Lamming (1964) have reported that barrows grew faster than boars. Reviews by Turton 1962 and Wismer-Pedersen (1968) indicate that when no difference resulted in growth rate between boars and barrows, there was a consistent pattern of varied growth. Boars would grow faster than barrows prior to 3 to 4 months while barrows would then grow faster thereafter to 6 to 7 months, resulting in no difference in the growth rate over the entire period. A possible explanation for this observation was proposed by Winters et al (1942) as the onset of puberty, which produces some factors that have a depressing effect on growth. Prescott and Lamming (1964) suggest that the depression in growth rate of boars is due to an increase in nutritional protein requirement that is not provided for in the diet.

Results on the efficiency of feed conversion show that boars are more efficient than barrows (Charette, 1961; Turton, 1962; Teague et al., 1964; Hines, 1966; Pay and Davis; 1973; Siers, 1975; Wood and Riley, 1982). Bratzler et al. (1954), however reported no difference in feed conversion. Blair and English (1965) reported boars to be 7.7% more efficient and Omtvedt and Jesse (1968) demonstrated a 10% improvement in the efficiency of feed conversion for boars.

When feeding different levels of protein Prescott and Lamming (1967) and Wood and Riley (1982) reported that boars have a more efficient feed utilization and growth rate at increased protein levels than barrows. Protein levels of 18% fed until 57 kg and then 16% fed to boars have provided the most beneficial gains (Hays et al., 1966; Newell and Bowland, 1972). Walstra (1969) has shown that ad libitum fed boars are more efficient, but grow slower than ad libitum fed barrows. At restricted intake however, boars grow faster and maintained a more efficient conversion of feed. A possible explanation for this observation may be provided by the studies of Charette (1961), Hines (1966) and Newell and Bowland (1972) who reported boars consumed significantly less feed than barrows, indicating boars more closely regulate their feed intake than barrows. Wong et al. (1968) however, found no significant difference in feed conversion between boars and barrows.

Composition

Studies on composition of boars and barrows are consistent in boars having a greater percentage of muscle and bone, less fat and a lower dressing percentage (Bratzler et al., 1954; Zobriskey et al., 1959; Teague et al., 1964; Prescott and Lamming, 1964; Hines, 1966; Plimpton et al., 1967; Prescott and Laming, 1967; Wismer-Pedersen, 1968; Newell and Bowland, 1972; Fuller, 1980; Wood and Riley, 1982). The lower dressing percentage reported for the boar

may be partially due to the removal of the genitals. Prescott and Lamming (1967) reported boars had 15% greater muscle, 12% greater bone and 24% less fat in the carcass than barrows. Boars also had 3% less dressing percentage and a greater percentage of skin than barrows. Luscombe (1962) has shown that boars have 7% greater muscle and 17% less fat in the carcass than barrows. The rate of protein deposition of boars is 49% greater per day than barrows when compared on an ad libitum fed basis (Wood and Riley, 1982). The ratio of muscle to bone has not been found to be significantly different even though boars possess a greater amount of muscle and bone (Newell and Bowland, 1972; Fuller, 1980; Wood and Riley, 1982). It has also been shown that boars have a greater kidney weight, intermuscular fat and a thicker skin than barrows (Wood and Riley, 1982).

Carcass measurement of backfat thickness has demonstrated that boars are leaner than barrows (Bratzler et al., 1954; Hetzer et al., 1956; Zobrisky et al., 1961; Charette, 1961; Plimpton et al., 1967; Wong et al., 1968; Siers, 1975; Newell and Bowland, 1972). The difference reported by Prescott and Lamming (1964) was that boars were 14% leaner than barrows while Blair and English (1965) reported a 23% difference in leanness. In reviewing literature on sheep and cattle Turton (1969) found a consistent pattern with previous data reported for the boar-barrow comparison. Rams were significantly leaner than

wethers and bull carcasses had less fat than steer carcasses. On a weight basis Kuhlers et al. (1976) demonstrated that at a similar backfat thickness boars are 23 kg heavier than barrows on a live weight basis. Desmoulin (1973) has recorded an increase of 40 kg in live weight, when boars were at the same backfat thickness as barrows. Carcass length is reported to be greater in boars than barrows by Bratzler et al. (1954), Teague et al. (1964), Prescott and Lamming (1964), Hines (1966), Plimpton et al. (1967), Turton (1969), and Froseth et al. (1973). However, Zobrisky et al. (1959), Wong et al. (1968), and Wood and Riley (1982) have found no significant difference in carcass length. Longissimus area has met with similar reports. Bratzler et al. (1954), Zobriskey et al. (1959), Charette (1961), Blair and English (1965), Prescott and Lamming (1967), Pay and Davies (1973) and Siers (1975) have found a significantly larger longissimus muscle area in boars compared to barrows, while Prescott and Lamming (1964), Teague et al. (1964), Hines (1966), and Plimpton et al. (1967) have reported no significant difference in longissimus area.

The endogenous gonadal hormone production in the boar has an effect on muscle development that is not present in the barrow. The androgens of the boar induce the synthesis of protein by regulation of the ribonucleic acids and the protein biosynthesis system at the microsomal level

(Kockakian, 1966). This level of androgen inducement of protein synthesis does not occur at the same magnitude for all muscles, as with the withdrawl of the hormones does not reduce muscle growth to the same extent (Brannang, 1966). LaFlame et al. (1973) working with castrated and intact twin bulls have reported that castration had no significant effect on concentration of DNA, total protein collagen or muscle fiber diameter for the longissimus muscle. Wood and Enser (1982) reported that the moisture content of the longissimus was greater for the boar than the barrow. Staun (1963) studying the boar and barrow found no significant difference in the fiber diameter of the longissimus. This same effect was reported for sheep by Moody et al. (1970) who found no significant difference in the fiber diameter in the semitendinosus or longissumus muscles from rams and wethers that were slaughtered at the same average weight. Reports that are not consistent with these previous findings were reviewed by Brannang (1971). Jasienski (1929) demonstrated that muscle fibers of bulls had a larger diameter than steers and Schilling (1966) reported that the longissimus fiber bundles were 15% smaller in steers, when compared with genetically identical bulls.

EXPERIMENTAL PROCEDURES

Experimental Design

Sixty-five male pigs, representing thirteen litters were used for this research study. The genetic base was derived from purebred Yorkshire or Duroc sires bred to crossbred dams (of Yorkshire, Landrace, Duroc, Hampshire, Chester White breeding). (Breeding records are given in Appendix A.1). All experimental pigs were bred and raised at the Michigan State University Swine Farm. Thirteen replicates were used for the trial. Each replicate consisted of five littermate male pigs selected at 3 wks of age and randomly assigned to the treatment groups of castration or no castration and final slaughter weight of 105 kg, 118 kg, 132 kg or 145 kg. Table 1 summarizes the experimental design.

Table 1 Experimental Design

Replicate (five letter male pigs)	Groups
Pig 1	Castrated (at 3 wk) -slaughter wt-105 kg[a]
Pig 2	Boar -slaughter wt-105 kg[a]
Pig 3	Boar -slaughter wt-118 kg[a]
Pig 4	Boar -slaughter wt 132 kg[a]
Pig 5	Boar -slaughter wt-145 kg[a]

[a]Empty Body Weight

Pigs were started on trial at 4 wk of age and each replicate (5 pigs) were penned together until slaughter time. From 4 wk to 27 kg pigs were raised in a partially slatted nursery with a flush gutter and a hovered sleeping area in an environmentally controlled room at 21 to 29 C. Pigs were fed ad libitum in a 1.22 by 2.44 meter pen allowing .60 square meters of floor space per pig. When pigs within a pen weighed an average of 27 kg the entire replicate was relocated until slaughter weight in a naturally ventilated building with a different pen arrangement. The 2.44 by 2.74 meter solid board partition pen allowed 1.34 square meters of solid concrete floor area per pig. Pigs were fed ad libitum from self feeders and the pens were bedded with straw and cleaned three times weekly. From weaning until 27 kg a 18% protein diet with 1.08% lysine was fed and after 27 kg a 16% protein diet with .92% lysine was fed until slaughter weight was reached. (The diets are listed in Appendix A.2).

Slaughter Procedure and Sample Collection

Final weight was determined on an empty body basis as pigs were allowed to gain 3 to 4% beyond their predetermined slaughter weight. The pigs were then held off feed for 12 to 16 h, weighed and slaughtered. At slaughter time pigs were electrically stunned and bled by severing the carotid artery and jugular vein. At the

cessation of bleeding, pigs were scalded and dehaired in a dehairing machine. Thirty minutes after stunning, the brachialis, semitendinosus and longissimus muscles were removed from the left side of the carcass. The entire brachialis and semitendinosus muscles were removed. The longissimus dorsi was dissected out from the anterior edge of the hip bone to its cranial termination near the first rib. Each muscle was weighed and a subsample of 40 to 50 g was placed in a plastic bag and rapidly frozen in Dry-ice and isopentane. A 2 g sample was also removed from the center of the longissimus for nuclei density analysis. Bone samples were collected from the last seven replicates slaughtered. The tibia-fibula and ulna-radius were removed from the left side of the carcass and freed of all muscle and connective tissue. The bones were placed in polyethylene bags and stored in -30 C blast freezer for later analysis. After muscles and bones were removed the carcasses of pigs from the last five replicates were eviscerated, perirenal fat removed, head removed at the atlas joint and the carcass split longitudinally along the dorsal midline from tail to atlas joint. Carcass weight was recorded and the left side of the carcass was separated into bone, skin and soft tissue (adipose tissue, skeletal muscle and additional connective tissue). Weights were recorded on all three components. The soft tissues were ground in a Toledo Model number 5520 meat grinder through a

4 mm plate, hand mixed and reground through the 4 mm plate a second time. During the course of the second grinding 10 - 5 to 6 g subsamples were collected to comprise a 50 to 60 g sample which was placed in a plastic bag and stored at -30 C.

The right side of the carcass from each pig was chilled for 24 h at 2 C. The carcasses were then measured for length, longissimus area and backfat thickness at the tenth rib by standard procedures (NSIF, 1981). Longissimus area was measured by the grid method, Hillers (1970).

Preparation of Frozen Muscle Sample

The muscle samples collected at slaughter time were powdered in a -30 C walk in freezer. Two different approaches to this technique were outlined by Borchert and Briskey (1965) and Mulvaney (1981). The powdering procedure modified for this analysis consisted of placing the muscle sample in a cloth bag and crushing the sample into approximately 2.0 cm diameter fragments using a rubber mallet. The sample was then placed in a IKA Universalmuhle model M20 high speed impact mill with equal amounts of crushed Dry-ice for 45 to 60 sec. The powdered muscle was then passed through a twenty mesh screen. The remaining muscle fragments were repowdered and sifted through the screen. The powdered muscle sample was mixed and a subsample was placed back in the plastic bag. The bag was

left open for 12 to 16 h to allow the CO_2 from the Dry-ice to escape. Samples were then sealed and stored in the -30 C freezer until analyzed.

The ground samples representing the soft tissues from the dissected carcass side (left side) of replicates nine through thirteen were also prepared in this manner.

Analysis of Muscle Samples

The standard AOAC (1980) methods of analyses for moisture (drying oven), ether extract (Goldfisch), and protein (Kjeldahl x 6.25) were carried out on all the powdered muscle subsamples and the powdered soft tissue subsamples representing carcass composition.

Nucleic acid concentration was determined on all muscle subsamples using the modified Munro and Fleck (1969) method carried out by Mostafavi (1978) and Mulvaney (1981). The details of this procedure are described by Mostafavi (1978) and are outlined in Appendix B.1.

Muscle fiber diameter was determined on subsamples of the powdered muscle from each carcass. The procedure which includes 1.0% gluteraldehyde BSS buffer (Appendix B.2) and .02 M guanidine-HCL buffer (Appendix B.3) was described by Mulvaney (1981) and is presented in Appendix B.4.

Analysis For Nuclei Density

The number of nuclei per unit fiber area was determined on the longissimus sample from the carcasses of eight replicates (replicates 4, 5, 7, 8, 9, 10, 11, 13).

The procedure incorporated into the present study is a modification of the technique utilized by Cardasis and Cooper (1975) on mice. Approximately 2 g of muscle 2.5 cm in length were removed from the center of the longissimus. A 1 mm thick section of fiber was teased from the sample to allow rapid penetration by the 1% gluteraldehyde in .1 M phosphate buffer pH 7.4 (Appendix B.5) solution in which the sample was placed for 1 to 2 h. The sample was removed from the gluteraldehyde solution spread out with blunt forceps and then placed in .02 M guanidine-HCL in .05 M borate buffer pH 9.5 (Appendix B.6). The sample was immediately homogenized at very low speed by a Virtis 45 model Super 30 homogenizer for 4 min. The fibers were spread apart in guanidine solution and then allowed to set at room temperature for 20 min. At the end of 20 min the fibers were removed from the guanidine solution and stained in Mayer Hematoxylin for 45 min. The fibers were then destained by placing them in a .05 M borate buffer solution at pH 8.5 (Appendix B.7) for 55 min. At the end of the destaining period fibers were placed in deionized H_2O for a minimum of 10 min. Twenty fibers were dissected apart from the other fibers and placed on a slide coated with 2% gelatin, one fiber at a time under a Bausch and Lomb model 31-26-84 dissecting microscope. Once twenty fibers were located, the slide was cleaned using a drop of xylene, air dried and covered with a drop of mounting solution and a

cover slip. The slide was viewed through a light microscope at a magnification of 480. A micrometer was located in one eye piece and was calibrated with a stage micrometer for measuring the fiber diameter and the length of the fiber on which the nuclei were counted. Due to the poor staining quality of the fibers it was necessary to separate out at least one hundred fibers to allow for fifty countable fibers. The number of nuclei per unit fiber area for a sample was calculated on the average of fifty fibers. The fiber diameter was measured and the nuclei counted within a 4.83 mm length of the fiber (Diagram in Appendix B.8). Due to the arrangement of nuclei near the outer surface of the fiber the nuclei were counted by a method of focusing from the far side of the fiber to the near side.

Bone Measurements

Due to ossification of the tibia to the fibula and the ulna to the radius specific gravity was calculated for the combined tibia-fibula and the combined ulna-radius. The weight at room temperature and the weight submerged in 0 C water were recorded for each pair of bones to calculate specific gravity (specific gravity = $\frac{(\text{wt in air})}{(\text{wt in air})-(\text{wt in } H_2O)}$). The radius and the tibia were then split in two halves by sawing from the distal to the proximal end. Measurements for total length, length of diaphysis, proximal epiphysis and distal epiphysis were recorded in millimeters. Proximal epiphyseal cartilage width and distal epiphyseal

cartilage width were recorded as the average of five measurements (Diagram B.9).

Statistical Analysis

The data were analyzed using the procedure of Least-squares (Harvey, 1960). The model used was:

$Y_{ijk} = u + t_i + l_j + e_{ijk}$

Y_{ijk} = an observation for any of the traits considered

u = an effect common to all individuals for a given trait

t_i = effect of the ith treatment, i= 1...5

l_j = effect of the jth litter j= 1...13

e_{ijk} = an effect unique for each individual

For a solution of the generalized equations, the restraints $\Sigma t = O$ and $\Sigma l = O$ were imposed to make all the equations independent.

RESULTS AND DISCUSSION

Live Body Weight

The average live body weights for groups I through V are listed in table 1. There was a significant linear increase ($P<.01$) in the live weights of the boars, groups II through V. No significant difference was found between the live weight of the barrows and the boars groups I and II, respectively. The similar dressing percentage (Table 1) between groups II and I is in contrast to other studies (Hines, 1966; Plimpton et al., 1967; Wood and Riley, 1982). Prescott and Lamming (1967) found that barrows had a 3% greater dressing percentage than boars. A trend did occur in this study for a 1% greater dressing percentage in the barrows.

Carcass Measurements

The carcass measurements of tenth rib backfat thickness (Table 2) was less ($P<.01$) in group II than group I. The greater leanness in the boar, than barrow at similar live weight is substantiated in the literature (Bratzler et al., 1954; Charette, 1961; Plimpton et al., 1967; Siers, 1975).

The 45% reduction in tenth rib backfat in boars than comparable weight barrows (groups II and I, respectively) is greater than the 14% reported by Prescott and Lamming (1964)

Table 1. Average Final Live Weight and Dressing Percentage of Each Group

Group	I	II	III	IV	V		Level of Significance	
Sex	Barrows	Boars					P Value	
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Live Weight, kg[a]	104.3	104.1	118.1	130.9	145.5	5.01	.01	.98
Dressing Percentage, %[b]	74.7	74.1	74.8	73.9	74.5	2.04	.74	.50

Sex comparison - barrows and boars at 105 kg

EMS - error mean square

[a]Linear response for boars from 105 to 145 kg $P<.01$

[b]Measurement on replicates 9, 10, 11, 12 and 13

Table 2. Mean Carcass Measurements of Each Group

Group	I	II	III	IV	V		Level of Significance	
Sex	Barrows	Boars					P Value	
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Carcass Length, cm[a]	82.8	85.2	87.9	89.8	91.6	12.94	.01	.09
Longissimus Area, cm^{2}[ac]	31.7	31.8	34.5	38.3	41.4	9.57	.01	.94
Tenth Rib Backfat, cm[ab]	2.84	1.95	2.19	2.39	2.72	.21	.01	.01

Sex comparison - barrows and boars at 105 kg

EMS - error mean square

Linear response for boars from 105 to 145 kg, [a]$P<.01$

Quadratic response for boars from 105 to 145 kg, [b]$P<.01$, [c]$P<.05$

and the 23% less backfat in the boar compared to the castrate, reported by Blair and English (1965). The 2.84 cm tenth rib backfat thickness of the barrow is even greater than the 2.72 cm average measurement of the boars in group V. When compared on a live weight basis the tenth rib backfat thickness in the barrow is greater than the boars weighing 41.4 kg more. This 41.4 kg weight difference between boars and barrows is greater than the 22.7 kg difference reported by Kuhlers et al. (1976), the weight difference at which boars had fat thicknesses similar to barrows.

A greater ($P<.09$) carcass length in the boar (group II) than the barrow (group I) was also found and is consistent with past work (Bratzler et al., 1954; Hines, 1966; Turton, 1969; Froseth et al., 1973). The boar carcasses in this study were 2.9% longer than the barrow carcasses. Some studies reported no differences in carcass length between boars and barrows (Zobriskey et al., 1959; Wood and Riley, 1982). There was no significant difference in longissimus area (Table 2) between boars and barrows slaughtered at similar weights (groups II, and I, respectively). No differences in longissimus area were reported by Prescott and Lamming (1964), Teague et al. (1964), Hines (1966) and Plimpton et al. (1967).

In contrast, other studies have shown that boars had a larger longissimus area than barrows (Blair and English, 1965; Pay and Davies, 1973; Siers, 1975). Blair and English

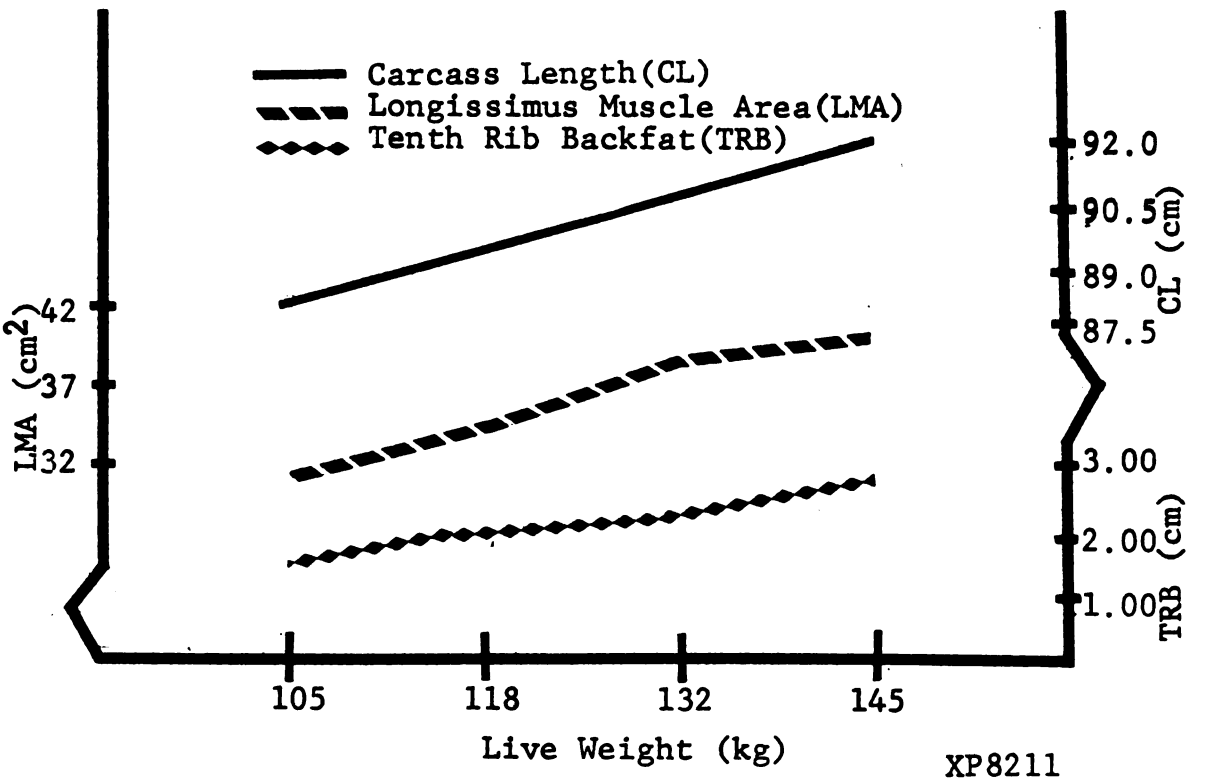
(1965) reported that boars had 14% more longissimus area while Siers (1975) found the boars had 15% more longissimus area than the barrow.

Average longissimus area and tenth rib backfat thickness increased with the live weight increase in groups II through V (Figure I). Carcass length increased ($P<.01$) linearly at a rate of .15 cm/kg of live weight gain. A significant ($P<.05$) quadratic inrease was found for longissimus area from groups II to V. The most rapid increase in longissimus area over this weight range was .30 cm^2/kg of live weight increase from 118 to 132 kg, while the slowest rate of increase in longissimus area was .19 cm^2/kg of live weight increase from 105 to 118 kg. Both a linear and quadratic increase ($P<.01$) was found for tenth rib backfat thickness in the boars of groups II to V. A constant rate of .017 cm increase/kg of gain in tenth rib backfat thickness occurred in the boars from 105 to 132 kg. From 132 to 145 kg a more rapid rate of increase for tenth rib backfat thickness of .023 cm/kg of gain was found.

Muscle Chemical Composition

There were no significant differences in the brachialis (Table 3), semitendinosus (Table 4) or longissimus (Table 5) fat free muscle weight between boars (group II) and barrows (group I) at 105 kg. As previously mentioned, the longissimus area between groups II and I was also similar. There was however, a trend for a greater brachialis ($P<.10$)

Figure I: The Carcass Measurements Of Boars From 105 to 145 kg, Live Weight.



Equations of Graphs in Appendix E.1

Table 3. Mean Brachialis Muscle Weight, Fat Free Muscle Weight, Total Fat, Percentage Moisture, Protein, Fat and Fiber Diameter by Group

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Muscle Weight, g[a]	101.8	112.6	121.8	129.1	143.3	91.18	.01	.12
FFM Weight, g[ac]	97.8	109.1	118.4	125.5	139.0	90.44	.01	.10
Mosture, %	75.1	76.4	76.9	76.2	76.2	1.22	.33	.01
Protein, %	20.6	20.2	20.4	20.4	20.7	1.57	.75	.38
I Fat, %[b]	3.97	3.17	2.86	2.74	2.88	1.25	.03	.09
Total I Fat, g	3.99	3.49	3.45	3.81	4.26	1.86	.37	.35
Fiber Diameter, μm	66.5	65.5	68.2	64.1	68.0	31.23	.40	.69

FFM - fat free muscle

Sex comparison - barrows and boars at 105 kg

I fat - intramuscular fat

EMS - error mean square

Linear response for boars from 105 to 145 kg, [a]P<.01, [b]P<.02

Quadratic response for boars from 105 to 145 kg, [c]P<.01

Table 4. Mean Semitendinosus Muscle Weight, Fat Free Muscle Weight, Total Fat, Percentage Moisture, Protein, Fat and Fiber Diameter by Group

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Muscle Weight, g[a]	397.2	441.9	460.3	509.5	567.5	2621.8	.01	.15
FFM Weight, g[bd]	376.8	425.6	443.8	493.5	547.4	2620.5	.01	.12
Moisture, %	73.7	75.4	75.4	75.4	75.1	1.24	.60	.01
Protein, %	20.5	20.4	20.8	21.2	20.7	1.67	.42	.81
I Fat, %[ac]	5.21	3.76	3.55	3.08	3.42	2.14	.09	.02
Total I Fat, g	20.4	16.3	16.4	15.9	20.0	37.85	.10	.10
Fiber Diameter, μm	74.6	71.2	74.3	74.3	71.2	24.90	.23	.10

FFM - fat free muscle

Sex Comparison - barrows and boars at 105 kg

I Fat - intramuscular fat

EMS - error mean square

Linear response for boars from 105 to 145 kg [a]P<.01, [b]P<.08

Quadratic response for boars from 105 to 145 kg [c]P<.09, [d]P<.01

Table 5. Mean Longissimus Muscle Weight, Fat Free Muscle Weight, Total Fat, Percentage Moisture, Protein, Fat and Fiber Diameter by Group

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Muscle Weight, g[ac]	2164	2155	2395	2633	2908	42495.6	.01	.95
FFM Weight, g[ab]	2105	2101	2341	2574	2850	42746.2	.01	.98
Moisture, %	73.8	74.5	74.4	74.2	74.7	1.19	.95	.16
Protein, %	22.7	22.4	22.5	23.1	22.8	1.95	.67	.62
I Fat, %	2.81	2.51	2.31	2.25	1.97	2.12	.97	.60
Total I. Fat, g	59.1	53.4	53.8	58.6	58.3	1304.1	.96	.68
Fiber Diameter, µm	83.8	84.1	87.1	89.6	89.7	30.23	.09	.90

FFM - fat free muscle

Sex Comparison b Barrows and boars at 105 kg

I Fat - intramuscular fat

EMS - error mean square

Linear response for boars from 105 to 145 kg, [a]P<.01

Quadratic response for boars from 105 to 145 kg, [b]P<.01, [c]P<.02

and semitendinosus ($P<.12$) weight in the boars (group II) as compared to the barrows (group I). A quadratic increase ($P<.01$) is present for the fat free muscle weight of the brachialis, semitendinosus and longissimus with live weight increases (groups II to V, Figure II). The increase over the live weight range for each muscle was .72 g/kg for the brachialis, 2.94 g/kg for the semitendinosus, and the longissimus increased 18.1 g/kg of live weight gain from 105 to 145 kg (groups II to V).

The quadratic relationship for fat free muscle weight of the longissimus and the semitendinosus agrees with the differential growth rate of individual muscles reported by Richmond and Berg (1982a) and Davies (1974b). The brachialis is characterized as an early developing muscle, the semitendinosus as an intermediate maturing muscle and the longissimus as a late developing muscle (Richmond and Berg, 1982a; Davies, 1974b). In this study a rapid increase in growth occurred in the semitendinosus fat free muscle weight in the boars from 118 kg to 132 kg (groups III to IV). The most rapid increase in the longissimus fat free muscle weight occurred between 132 and 145 kg (group III to V). The brachialis data in this study does not agree with the work of Richmond and Berg (1982a) and Davies (1974b) as the most rapid increase of fat free brachialis muscle weight did not occur until the period from 132 to 145 kg (group III to V).

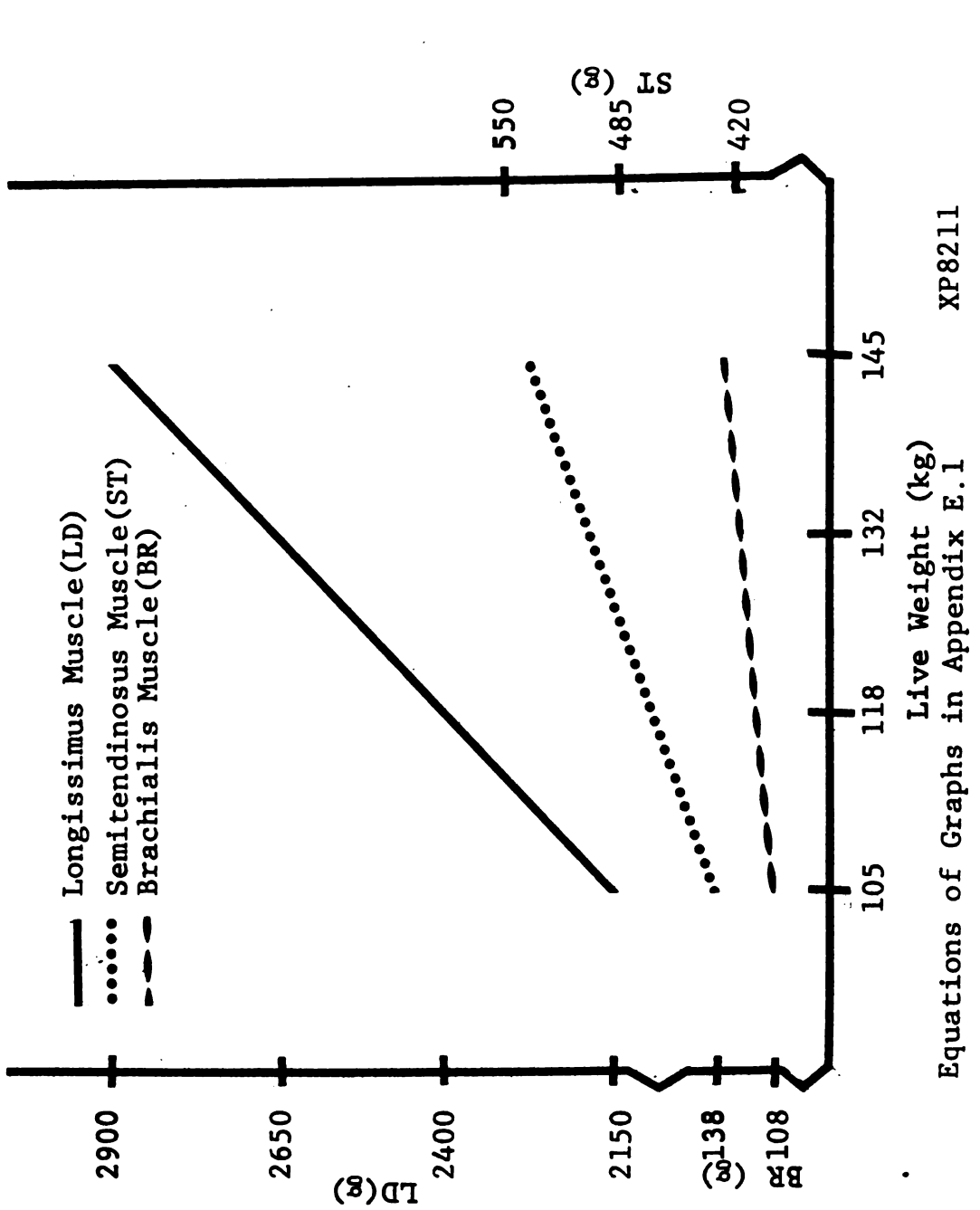


Figure II: The Fat Free Muscle Weight Increase Of The Brachialis, Semitendinosus And Longissimus Muscles In Boars From 105 to 145 kg, Live Weight.

Equations of Graphs in Appendix E.1

The percentage of moisture was greater ($P<.01$) in group II than in group I for the brachialis and semitendinosus muscles but was not significantly different for the longissimus. The percentage moisture of boars (group II) was 2% greater in the brachialis, 2% greater in the semitendinosus and 1% greater in the longissimus, than in similar weight barrows (group I). No significant difference was found in the percentage moisture for the brachialis, semitendinosus or the longissimus from groups II to V.

Protein concentration was constant in the three muscles from pigs in groups I and II and thus, no significant differences were found between these groups. Similarly no significant difference was observed in the protein percentage for the brachialis, semitendinosus and longissimus muscles of boars from 105 to 145 kg (groups II to V).

The percentage intramuscular fat was significantly greater in the brachialis ($P<.09$) and semitendinosus ($P<.02$) of group I as compared to group II. Barrows (group I) had .8% more intramuscular fat in the brachialis and 1.45% more in the semitendinosus muscles than the boars (group II). There were no significant differences in longissimus intramuscular fat between boars and barrows taken to the same endpoint weight of 105 kg (group II and I, respectively). Total intramuscular fat of the brachialis and longissimus also was not significantly different for

treatment groups II and I. Total intramuscular fat weight of the semitendinosus was 25% larger ($P<.10$) in group I than in group II. The percentage intramuscular fat decreased from groups II to V at a significantly linear rate in the brachialis ($P<.02$) and a significant quadratic rate in the semitendinosus ($P<.09$). No significant difference was observed in the total intramuscular fat for the brachialis, semitendinosus or the longissimus from groups II to V. Likewise no difference was found in the percentage intramuscular fat in the longissimus over the weight range from 105 to 145 kg (group II to V).

Forbes (1968) reported that with an increase of fat free muscle there is a decrease in moisture percentage while the percentage of protein increases. During development this rate of increase eventually reaches a plateau. The relationship between protein and fat accretion rates was found by Bailey and Zobrisky (1968) and Searle et al. (1972) to occur at a constant rate during early postnatal growth but at heavier body weights the rate of fat deposition is greater than the rate of protein accretion. Over a two week period at 45 kg live weight Mulvaney (1981) reported that the brachialis, semitendinosus and longissimus of boars deposited fat at a more rapid rate than protein accretion. He also observed significant decreases in water content. The pattern reported by Forbes (1968) in relation

to percentage moisture and protein was present in the comparison of groups II and I. The boars (group II) had a greater percentage of moisture and a lower protein concentration than barrows (group I) in the brachialis, semitendinosus and longissimus fat free muscle mass. With development, Forbes (1968) found that protein concentration increased while moisture decreased. Applying this concept to this study, barrows appeared to be further along in muscle development than boars of similar weight (105 kg). The development from groups II to V indicate that the percentage of moisture in the brachialis, semitendinosus and longissimus had plateaued since no significant different was noted between groups. The decrease in percentage of intramuscular fat from group II to V indicates that fat may be mobilized possibly as an energy source or that a diluting effect occurred by a faster rate of myofibrillar protein accretion than for fat deposition.

A greater semitendinosus fiber diameter occurred in boars (group II) than in barrows (group I). The greater fiber diameter of the semitendinosus from boars is not consistent with the similar fat free muscle weight of boars and barrows at 105 kg. This difference may be due to biological difference from littermate replication as the greater fiber diameter of the semitendinosus muscle approached significance ($P<.10$) but no significant difference existed for the fiber diameter in the longissimus

or brachialis muscle between boars and barrows (group II vs group I). Swatland and Cassens (1973) demonstrated that hyperplasia of muscle fibers is completed prenatally and that postnatal growth occurs exclusively by hypertrophy. This indicates that if the same number of fibers are present in two muscles and fat free muscle weight is similar then fiber diameter should be similar. This concept is supported in the present study since fiber diameter was significantly ($P<.09$) different for the longissimus in the boars from 105 to 145 kg (group II to V). Although there was a consistent increase in the fiber diameter from groups II through V, it was not a significant linear response. Fiber diameter of the semitendinosus or brachialis muscles from groups II to V did not differ significantly even through fat free muscle weight of the brachialis and semitendinosus increased.

Muscle Nucleic Acid Measurements

The nucleic acid analysis of the brachialis, semitendinosus and longissimus are listed in Tables 6, 7 and 8, respectively. Due to the high variation, there were few significant differences between groups. Trends are present that are consistent with other reports (Hakkarainen, 1975; Harbison et al., 1976). No significant difference existed in DNA concentration for the brachialis, semitendinosus or longissimus muscles from groups II through V. There was a trend for decreased DNA concentration as live weight increased from 105 to 145 kg in all three muscles of boars.

Table 6. Mean Brachialis Nucleic Acids and Muscle Weight by Group

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Muscle Weight, g	101.8	112.6	121.8	129.1	143.3	91.18	.01	.12
DNA Concentration, µg/g	752.5	743.4	738.9	712.5	698.8	1203.27	.88	.83
Total DNA, mg	75.2	83.3	88.9	91.5	99.1	231.0	.58	.22
RNA Concentration, µg/g	1210.2	1163.0	1206.4	1185.7	1157.4	7742.5	.66	.17
Total RNA, mg[a]	123.7	130.8	146.9	152.6	165.2	223.4	.01	.41
RNA/DNA	1.61	1.56	1.63	1.66	1.66	.74	.87	.85
Protein/DNA	273.8	271.7	276.1	286.3	296.2	2.54	.92	.90
Mus. Wt. (µg)/Nucleus	8.42	8.38	8.50	8.76	8.97	1.88	.94	.81

Sex Comparison - barrows and boars at 105 kg

Nucleus- 6.2 pg DNA

EMS - error mean square

[a]Quadratic response for boars from 105 to 145 kg, P<.08

Table 7. Mean Semitendinosus Nucleic Acids and Muscle Weight by Group

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Muscle Weight, g	397.2	441.9	460.3	509.5	567.5	2621.8	.01	.15
DNA Concentration, µg/g	507.2	554.3	542.0	519.1	524.0	1284.0	.73	.28
Total DNA, mg	197.1	244.5	246.7	265.4	291.1	2716.2	.65	.04
RNA Concentration, µg/g	1183.7	1151.6	1139.9	1183.7	1098.7	9889.4	.61	.43
Total RNA, mg[a]	472.1	510.1	525.1	605.6	622.1	6532.1	.02	.33
RNA/DNA	2.33	2.08	2.10	2.28	2.10	0.29	.61	.24
Protein/DNA	404.2	368.0	383.8	408.4	385.0	1.08	.65	.45
Mus. Wt. (µg)/Nucleus	12.50	11.20	11.56	11.90	12.10	7.52	.71	.26

Sex Comparison - barrows and boars at 105 kg

Nucleus- 6.2 pg of DNA

EMS - error mean square

[a]Linear response for boars from 105 to 145 kg, P<.07

Table 8. Mean Longissimus Nucleic Acids and Muscle Weight by Group

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Muscle Weight, g	2164	2155	2395	2633	2908	43746.2	.01	.98
DNA Concentration, µg/g	458.6	462.4	454.2	441.9	423.3	990.1	.92	.92
Total DNA, mg	998.9	1009.6	1082.3	1156.1	1207.5	6750.4	.50	.91
RNA Concentration, µg/g	1139.9	1256.5	1165.0	1162.2	1115.3	4038.1	.32	.14
Total RNA, mg	2484.4	2745.1	2810.5	3072.0	3240.7	36187.1	.54	.30
RNA/DNA	2.48	2.72	2.56	2.63	2.63	.93	.73	.23
Protein/DNA	494.9	484.4	495.4	522.7	538.6	3.98	.98	.98
Mus. Wt. (µg)/Nucleus	13.43	13.25	13.73	14.15	14.93	.96	.99	.95
Nuclei Number/mm^3	7.406	7.384	7.696	7.193	7.461	.245	.98	.94

Sex Comparison - barrows and boars at 105 kg

Nucleus- 6.2 pg of DNA

EMS - error mean square

A trend for a constant decrease in RNA concentration was also observed for the longissimus and semitendinosus muscles of groups II through V. This result of decreasing muscle DNA and RNA concentration with increasing live weight due to growth has been reported in other studies involving pigs (Robinson, 1969; Tsai et al., 1973; Hakkarainen, 1975; Harbison et al., 1976). Work by Tsai et al. (1973) and Hakkarainen (1975) demonstrated that the decrease in muscle DNA and RNA concentration was due to the increased accretion of myofibrillar proteins in myofibers causing a diluting effect of myonuclei. In all three muscles total DNA and RNA trended to increase with live weight gains from 105 to 145 kg in boars. This increase is referred to as a trend since no significant differences occurred with the exception of total RNA in the brachialis and semitendinosus muscles. Total RNA in the brachialis and semitendinosus increased significantly ($P<.01$, $P<.02$, respectively) over the weight range from 105 through 145 kg. This increase resulted in a significant linear response for the brachialis ($P<.05$) and the semitendinosus ($P<.07$) for total RNA over the weight range of 105 to 145 kg. Harbison et al. (1976) reported that total DNA and RNA continued to increase with live weight gain in pigs from 23 to 118 kg. The increase in total DNA appears to precede the increase in total RNA and additional protein accumulation (Hakkarainen, 1975). The increase in

total RNA is a prelude to increased protein accretion (Hakkarainen, 1975) and may be used as an indirect measure of protein synthesizing machinery (Wannamacher, 1972). The source of the additonal DNA is from the incorporation of daughter nuclei of satellite cells into the myofiber (Mauro, 1961; Moss and Leblond, 1971; Snow, 1978).

In this study there was a greater ($P<.04$) amount of total DNA in the semitendinosus in boars (group II) than in barrows (group I, 244.5 vs 197.1 mg, respectively). No significant differences occurred for any of the other nucleic acid measurements between groups II and I.

The ratio of RNA to DNA has been used as a indicator of protein synthesis capacity by Powell and Aberle (1975) and Millward et al. (1975). The ratio of RNA to DNA was constant in all groups in this study. No significant difference was found between the RNA to DNA ratio for the three muscles in barrows and boars at 105 kg live weights.

The physiological cell size concept reported by Moss (1969) does not vary since a significant difference was not observed for the protein to DNA ratio or the fat free muscle weight to nuclei ratio between groups I and II or from groups II to V for the brachialis, semitendinosus or the longissimus.

No significant difference was found in nuclei density in the longissimus myofibers (Table 8). There was no difference in nuclei density of the longissimus myofiber

between groups I and II ($P<.94$) or groups II through V ($P<.98$).

Carcass Composition Data

The greater muscle mass of boars compared to barrows as reported by Prescott and Lamming (1967), Fuller (1980), and Wood and Riley (1982) was not found in the present study (Table 9). No significant difference in fat free muscle was observed between groups II and I. However, there was a difference ($P<.01$) in total fat of the carcass between groups II and I and this agrees with past studies (Wismer-Pedersen, 1968; Newell and Bowland, 1972). Pigs of group I had 25.4% fat (Figure III) in the carcass compared to 17.1% in group II carcasses. The 26.6% less fat in group II compared to group I was greater than the 24% difference between boars and barrows reported by Prescott and Lamming (1967).

The total fat in the barrow carcasses of group I at 105 kg was the same amount as the total fat in the carcasses of the boars of group V at 145 kg (Table 9). The 41.0 kg difference in live weight between groups I and V is closely associated with the 40 kg weight difference in live weight when boars had the same fat content as barrows as reported by Desmoulin (1973). As previously observed in this study, barrows had similar tenth rib backfat thickness as boars weighing 41.2 kg more. There was a significiantly ($P<.01$) greater weight of carcass skin and total bone in the

Table 9. Carcass Composition of Fat Free Muscle, Fat, Bone and the Ratio of Fat Free Muscle to Bone for Groups I, II, III, IV and V.

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
FFM, kg[b]	41.5	45.2	52.5	56.1	62.1	75.50	.01	.48
Total Fat, kg[cd]	19.6	13.1	14.9	18.2	19.9	7.79	.01	.01
Total Bone, kg[a]	10.7	11.9	12.7	14.4	15.3	.74	.01	.01
Total Skin, kg[a]	5.50	6.27	7.68	8.25	10.54	.47	.01	.01
FFM/Total Bone	3.86	3.81	4.13	3.90	4.05	.215	.05	.30
Carcass Weight, kg	77.3	76.4	87.7	96.8	107.7	9.10	.01	.94

FFM - fat free muscle

Sex Comparison - barrows and boars at 105 kg

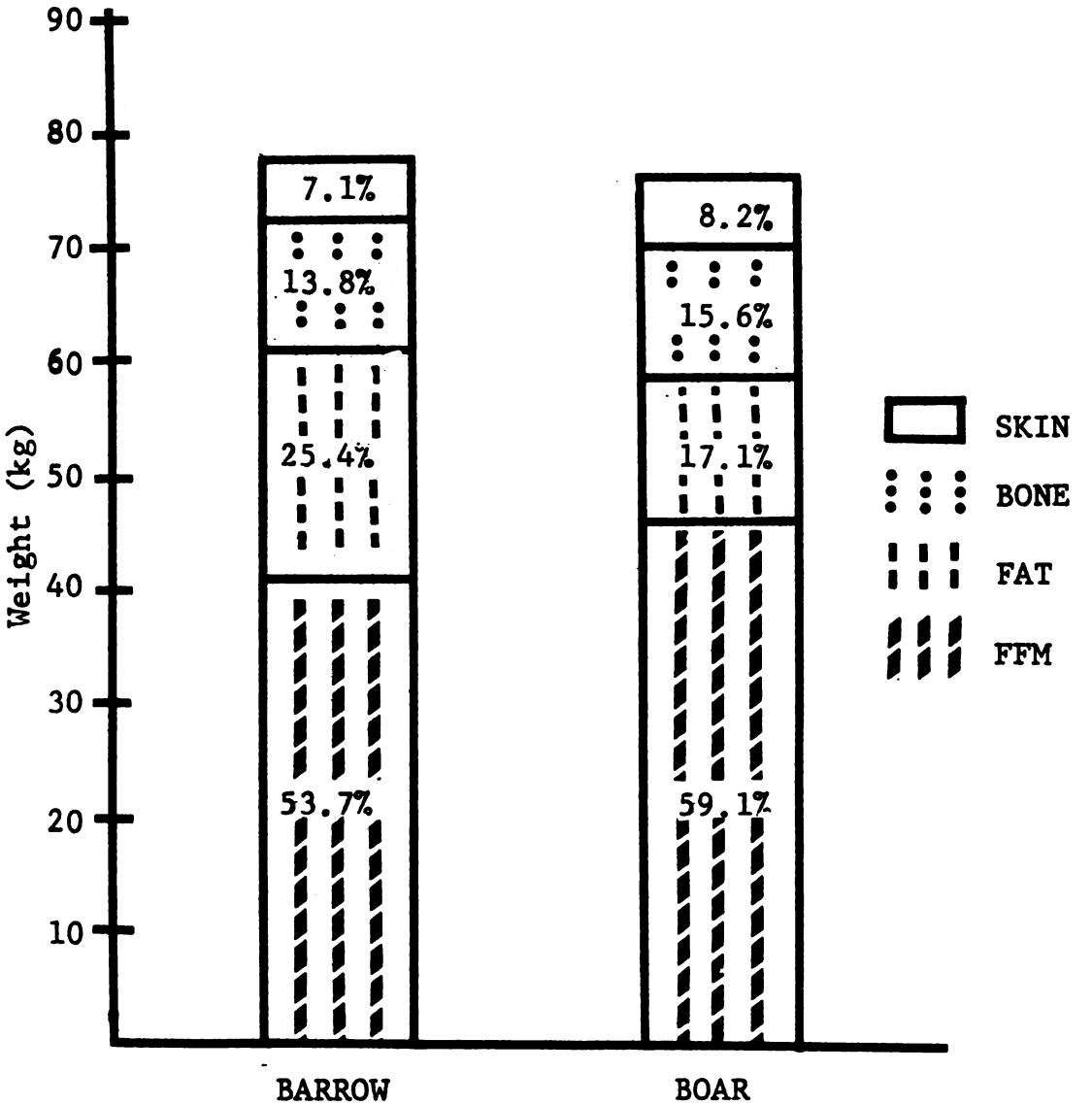
Data from replicates 9, 10, 11, 12 and 13

EMS - error mean square

Linear response for boars from 105 to 145 kg, [a]$P<.01$, [b]$P<.05$, [c]$P<.08$

Quadratic response for boars from 105 to 145 kg, [d]$P<.06$

Figure III: Average Carcass Compostion Of The 105 kg Boars And 105 kg Barrows.



FFM - Fat Free Muscle

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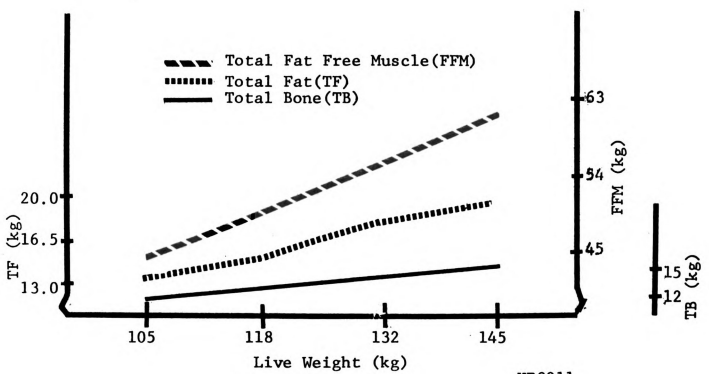
carcasses of group II as compared to group I (Table 9). The 11% greater weight of total bone in boars (group II) than barrows (group I) is in close agreement with the 12% greater carcass bone in boars compared to barrows of similar live weight as reported by Prescott and Lamming (1967). The 14% greater carcass skin weight of group II, than of group I may be best explained by the greater skin thickness of boars compared to barrows reported by Wood and Riley (1982). The ratio of fat free muscle weight to total bone weight between groups II and I was similar in the present study and is in agreement with other studies (Newell and Bowland, 1972; Fuller, 1980).

The average fat free muscle weight for the boars for groups II through V was increased ($P<.01$) with live weight gain (Figure IV). A significant linear increase was observed. There was a 37% (Table 9) increase in fat free muscle from 105 to 145 kg in boars or a .41 kg increase of fat free muscle/per kg of live body weight increase. Total fat weights of groups II to V increased at a quadratic rate ($P<.06$). Total fat increased 52% from groups II through V. The most rapid increase in total carcass fat in boars occurred between 118 and 132 kg at a rate of .236 kg/kg of live weight. From 105 to 118 kg and from 132 to 145 kg the total fat in boars increased at a rate of .129 kg/kg of live weight gain. Total bone and total skin increased at a significantly ($P<.01$) linear rate from groups II to V.

Figure IV: Total Fat Free Muscle, Total Fat And Total Bone In Boars From 105 to 145 kg, Live Weight.



Equations of Graphs in Appendix E.1

Total bone increased 3.3% (Table 9) over the live weight range from 105 to 145 kg or a .083 kg increase of total bone/per kg of live weight gain. Total skin of the carcass increased at a constant rate of .104 kg/kg of live weight from 105 to 145 kg. On a percentage basis total skin (68%) showed the greatest percentage increase while carcass fat (52%) was at a greater percentage than either fat free muscle (37%) or carcass bone (29%) over the weight range from 105 to 145 kg (Table 9).

The increase ($P<.05$) in the ratio of fat free muscle (Table 9) to total bone from treatment groups II to V indicates that the rate of fat free muscle growth continued to increase at a greater rate than carcass bone, over this live weight range. On a percentage basis total bone (P .08) decreased significantly from groups II to V. The decrease in percentage total bone, even though total bone weight increased from treatment groups II to V, was due to a greater rate of increase in fat free muscle and total fat over this weight range. The 9.3% decrease in total bone from 105 to 145 kg live weight was within the range of a 16% decrease in carcass bone reported by Weiss et al. (1971) in swine from 1 to 137 kg live weight. No significant difference was observed for percentage total skin from groups II to V.

Tibia and Radius Data

Measurements of bone development were recorded on the tibia (Table 12) and radius (Table 13).

Table 10. Mean Percentage Bone and Skin on the Carcasses of Groups I, II, III, IV and V.

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Total Bone, %	13.8	15.5	14.5	14.8	14.2	0.95	.08	.01
Total Skin, %	7.1	8.2	8.7	8.5	9.7	0.41	.61	.11

Data from replicates 9, 10, 11, 12 and 13

Sex Comparison - barrows and boars at 105 kg

EMS - error mean square

Table 11. Mean Soft Tissue Weight, Percentage Moisture, Fat and Protein in the Carcasses of Groups I, II, III, IV and V.

Group	I	II	III	IV	V		Level of Significance	
Sex	Barrows	Boars					P Value	
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Tissue Weight, kg	61.1	58.3	67.5	74.3	81.8	8.51	.01	.67
Moisture, %	51.4	59.7	59.6	58.4	58.1	.68	.01	.01
Fat, %	32.1	22.4	22.1	24.5	24.3	.90	.01	.01
Protein, %	15.6	17.2	17.6	16.6	16.9	.70	.04	.02

Data from replicates 9, 10, 11, 12 and 13

Sex Comparison - barrows and boars at 105 kg

EMS - error mean square

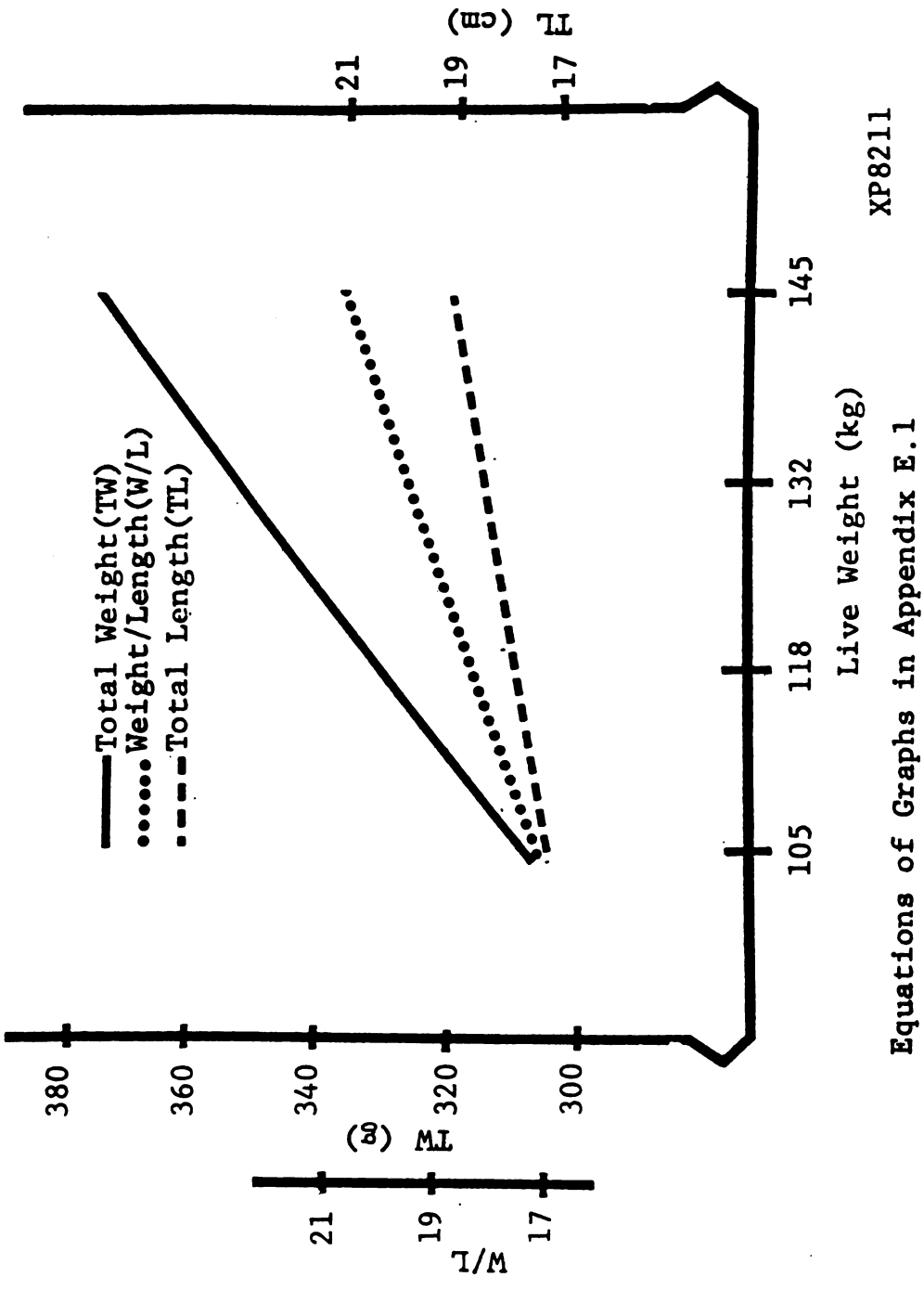


Figure V: Total Weight, Ratio Of Weight To Length And Total Length Of The Tibia.

Equations of Graphs in Appendix E.1

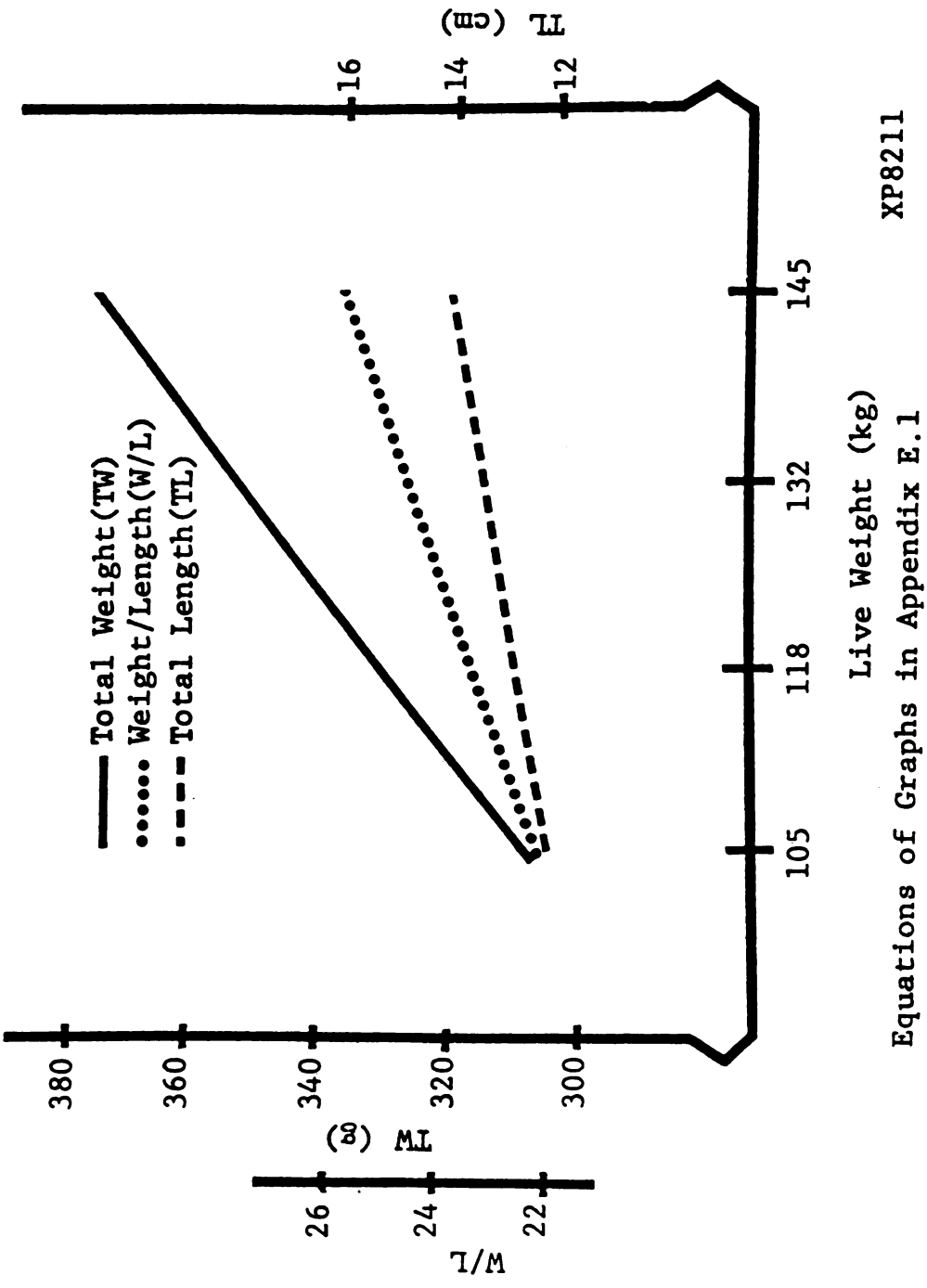


Figure VI: Total Weight, Ratio Of Weight To Length And Total Length Of The Radius.

Equations of Graphs in Appendix E.1

Total weight of the tibia was greater ($P<.03$) for boars (group II) than for barrows (group I). The radius weight of boars (group II) and barrows (group I) was not significantly different. However, a trend for a higher radius weight in boars was observed ($P<.11$). The measurements of total length were consistent for the two bones between boars (group II) and barrows (group I). Work by Brannang (1971) in cattle for bone weights showed similar results due to castration. Steers had lighter ($P<.01$) ulna and radius weights than bulls. Brannang (1971) found a greater bone length of the radius and tibia in castrates which conflicts with the data in this study. The ratio of total weight to total length is a measure of bone thickness. In group II the ratios of total weight to total length for the tibia and radius were 17.7 and 22.9, respectively. In group I the same ratios for the tibia and radius were 15.0 and 20.9, respectively, A greater tibia and radius total weight is observed in group II over group I. The greater tibia and radius weight in group II is consistent with the greater total carcass bone weight that is found for group II compared to group I (Table 9). The difference in total weight, and no difference in total length between groups II and I, indicates that the greater total weight of the bones is due to increased bone thickness. This is supported by the higher total weight to total length of the tibia and radius for group II compared to group I.

A significant linear increase in total weight of the tibia (Figure V) and radius (Figure VI) was found as the live weight increased from 105 to 145 kg. Over this weight range there was a linear increase ($P<.01$) in the total length of the tibia (Figure V) and radius (Figure VI). When the ratio of total weight to total length was plotted for the tibia (Figure V) and radius (Figure VI) the ratio continued to increase from group II through group V. The increase of this ratio substantiates that total weight is increasing at a greater rate than total length for both the tibia and the radius. The 13% increase in the tibia ratio and 16% increase of the radius total weight to total length ratio, points out that the growth of the tibia and radius over the live weight range of 105 to 145 kg in boars was due more to an increase in bone thickness rather than an increase in bone length.

No significant difference was observed for specific gravity of the tibia or the radius between groups II and I. Therefore the density of the tibia or radius in boars and barrows is not different. However specific gravity calculated for the tibia and radius from groups II through V was not constant. While no difference was observed for the tibia from 105 to 145 kg (groups II to V) in boars, there was a difference ($P<.07$) in specific gravity of the radius. The 23% increased (Table 11) in the specific gravity of the radius from groups II to V was neither linear or quadratic.

No differences were observed for any epiphyseal measurements of the tibia (Table 12) or the radius (Table 13). There was however, a trend for a decrease of the tibia and radius epiphyseal cartilage widths at both the proximal and distal ends for groups II through V. The decrease in the epiphyseal cartilage widths indicates closure was occurring in the epiphyseal cartilage and that growth rate of bone length, for the tibia and radius was decreasing in boars as they increased from 105 to 145 kg live weight.

Diaphysis length of the tibia and radius did not differ between groups II and I. There was a difference ($P<.01$) in diaphysis length of the tibia and the radius from groups II to V. A consistent, but nonlinearly significant increase of the tibia and radius diaphysis length was observed as boars increased from 105 to 145 kg. The increase in diaphysis length and total length of boars from groups II to V along with no increase in epiphyseal length of the tibia and radius supports the work of Dodds and Cameron (1934) and Kember (1960) who found that the increase in bone length was due to a lengthening of the diaphysis, or bone shaft rather than an increase in epiphyseal length. The 6.7% increase in diaphysis length is consistent with the 6.7% increase in total length of the radius, of groups II to V. The tibia increased in total length by 6.5% while the diaphysis length increased by 10% from groups II to V. The percentage increase in the diaphysis length is considerably greater than that of total increase of the tibia.

Table 12. Effect of Sex and Liveweight Change In Boars on Tibia Bone Measurements.

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Total Bone Weight, g[ad]	268.8	320.0	329.0	344.2	385.0	350.7	.10	.03
Specific Gravity[a]	1.31	1.30	1.32	1.32	1.33	.01	.30	.29
Total Length, cm[d]	17.8	18.1	18.6	19.0	19.3	.50	.01	.37
P - Epiphyseal Length, cm[b]	1.71	1.76	1.72	1.72	1.59	.05	.71	.64
D - Epiphyseal Length, cm[c]	1.08	1.11	1.04	1.04	.83	.04	.69	.78
P - Epiphyseal Cartilage Width, mm[b]	1.76	1.78	1.74	1.64	1.57	.08	.75	.92
D - Epiphyseal Cartilage Width, mm[c]	1.43	1.56	1.66	1.46	1.48	.09	.47	.43
Diaphysis Length, cm	15.0	15.2	15.9	16.3	16.8	.60	.01	.57

[a]Combined tibia and fibula
[b]Proximal end
[c]Distal end
Sex Comparison - barrows and boars at 105 kg
EMS - error mean square
[d]Linear response for boars from 105 to 145 kg, P<.01

Table 13. Effect of Sex and Liveweight Change In Boars on Radius Bone Measurements.

Group	I	II	III	IV	V		Level of Significance P Value	
Sex	Barrows	Boars						
Weight, kg	105	105	118	132	145	EMS	Boars	Sex
Total Bone Weight, g[ad]	274.4	309.0	327.0	336.0	382.0	146.17	.01	.11
Specific Gravity[a][d]	1.31	1.29	1.32	1.31	1.32	0.01	.07	.41
Total Length, cm[d]	13.1	13.5	14.0	14.2	14.4	.36	.01	.30
P - Epiphyseal Length, cm[b]	1.10	1.13	1.09	1.03	1.15	0.01	.23	.57
D - Epiphyseal Length, cm[c]	1.92	2.00	2.07	2.07	2.17	0.03	.88	.50
P - Epiphyseal Cartilage Width, mm[b]	1.06	1.13	1.02	1.03	1.00	0.04	.62	.49
D - Epiphyseal Cartilage Width, mm[c]	1.74	1.78	1.69	1.61	1.69	0.05	.60	.71
Diaphysis Length, cm	10.1	10.4	10.8	11.0	11.1	.34	.01	.46

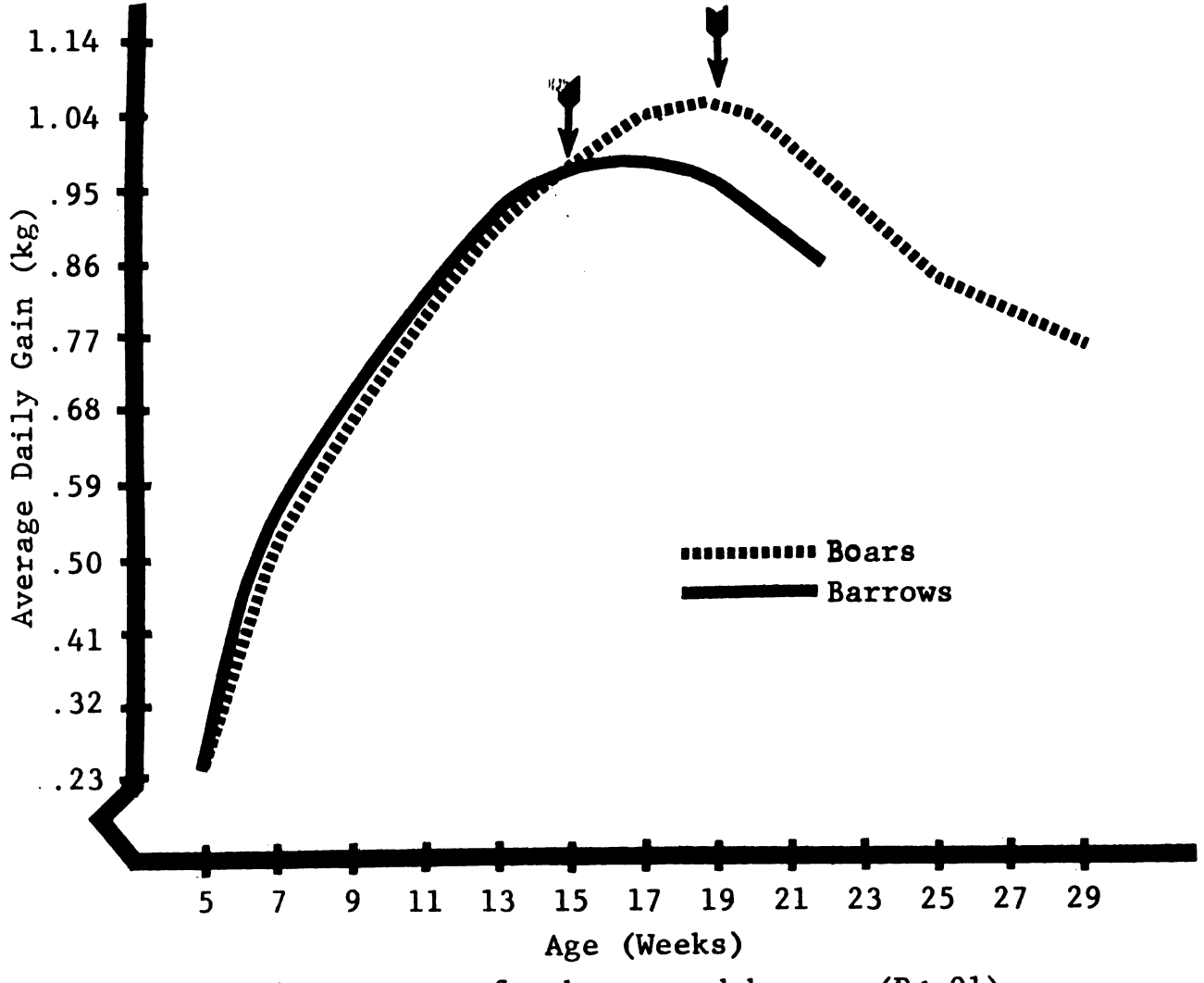
[a]Combined radius and ulna
[b]Proximal end
[c]Distal end
Sex Comparison - barrows and boars at 105 kg
EMS - error mean square
[d]Linear response for boars from 105 to 145 kg, P<.01

Growth Rate of Boars and Barrows

The growth rate of the boars in groups II through V were analyzed as one group and compared to the growth rate of the barrows of group I. From 5 wk of age to 105 kg the average daily gain of the boars and barrows was .782 kg and .796 kg, respectively. No significant difference in average daily gain between boars and barrows was observed (Figure VII). Winters et al. (1942), Kroeske (1963), Hines (1966), Omtvedt and Jesse (1968), Hetzer and Miller (1972a), Newell and Bowland (1972) and Pay and Davies (1973) also found no difference in growth rate between boars and barrows. In contrast other studies have shown a greater rate of growth in boars than barrows. Winters et al. (1942) indicated that the onset of puberty in boars had a depressing affect on growth rate. The aggressive sexual behavior that occurs among some boars after puberty was observed in only 2 boars in this study. They demonstrated aggressivenes to mount other pigs in the pens.

Average daily gain plotted in Figure VII illustrates that barrows had a slightly faster rate of gain than boars to 15 wk of age. At 15 wk the rate of gain for barrows was highest, however the rate of gain for boars did not peak until week 19. The final weight at which boars and barrows are compared may be a possible explanation for the inconsistent data for growth rates between these sex groups. Studies in which boars and barrows were grown to weights

Figure VII: The Average Daily Gain Of Boars And Barrows From 5 to 29 Weeks Of Age.



Quadratic response for boars and barrows ($P<.01$)

greater than the weight at which barrow gains level off undoutedly show a difference in gain between boars and barrows while experiments terminated prior to this weight generally may show no difference in growth rate. Genetic ability for growth rate varies throughout the swine population, thus the rate of gain of all barrows may not reach maximum at 15 wk of age. The data in this study does indicate that the anabolic effects of the testosterone in the boars results in an increase in average daily gain that reaches maximum at a live weight that is 24 kg more than the live weight at which the barrow attains its maximum rate of gain.

The increase in live weight at 2 wk intervals for barrows and boars is graphed in Figure VIII. A very consistent rate of increase in live weight occurred for boars and barrows until week 23 or approximately 105 kg, live weight. The increase in boars live weight continued to increase at a steady rate to about 27 wk and then it appears to have leveled off.

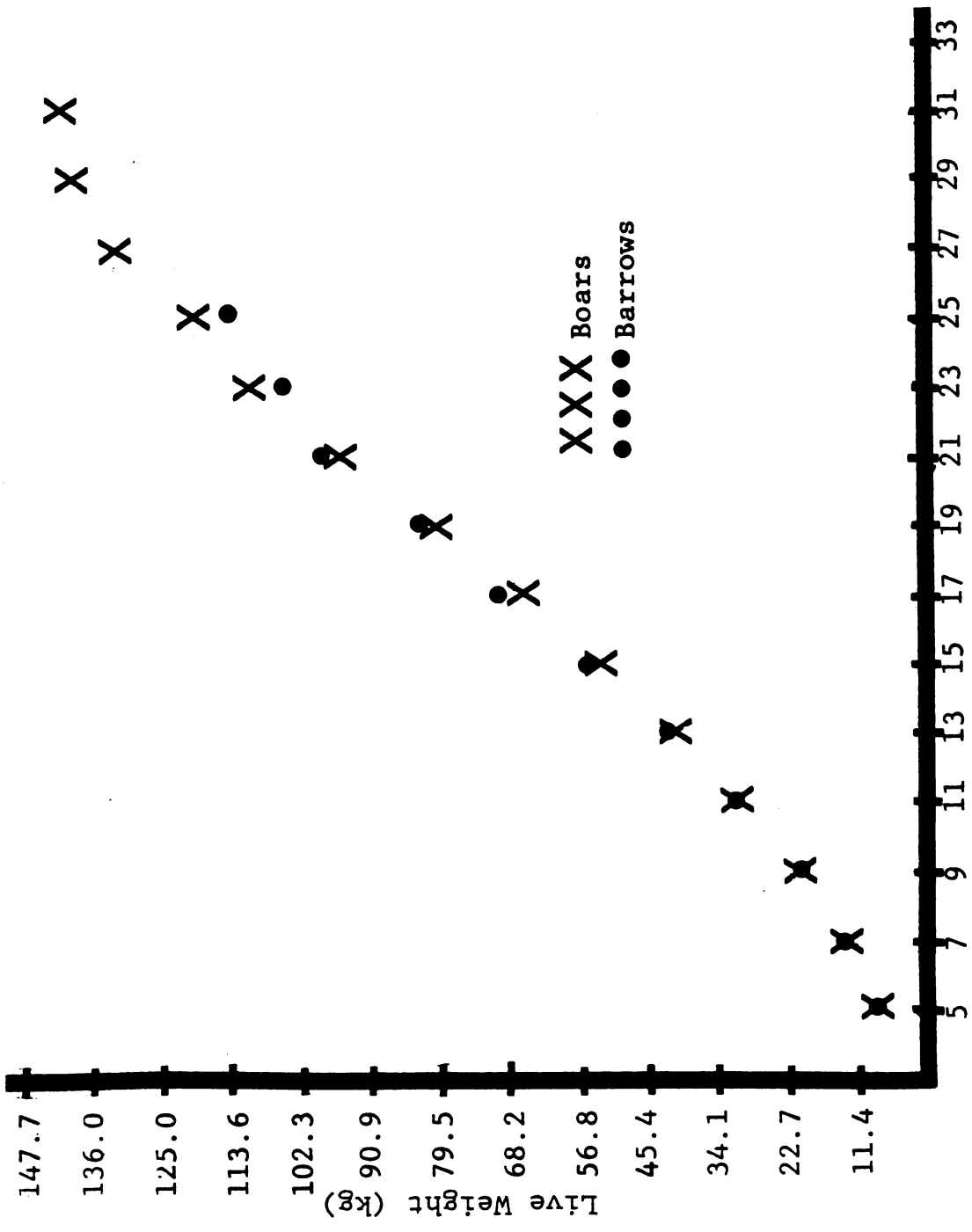


Figure VIII:Growth Curves Of Barrows And Boars.

Quadratic response for boars and barrows(P<.01)

SUMMARY

1) Average live weight of the barrows in group I was not different from that of the boars in group II. The 13.6 kg weight difference was statistically significant between groups II, III, IV and V. A linear increase was also observed from groups II to V.

2) Tenth rib backfat thickness was 45% less in group II (boars) than in group I (barrows). When boars and barrows had the same backfat thickness boars were greater than 41.0 kg heavier (group V boars) than barrows.

3) A 2.9% greater carcass length was found in boars than in barrows, however no significant difference occurred in longissimus area between groups I and II.

4) The three carcass measurements consisting of length, tenth rib backfat thickness and longissimus area continued to increase with live weight increase in boars from groups II to V. The rate of increase was linear for

carcass length, while the quadratic response for longissimus area and tenth rib backfat indicated that the increase in longissimus area was leveling off between 132 to 145 kg and the deposition of tenth rib backfat thickness was beginning to accelerate.

5) The brachialis, semitendinosus and longissimus muscles in the barrows of group I and the boars of group II did not differ in average weight or average fat free muscle weight. These three muscles continued to increase in a quadratic response as live weight increased for the boars in group II to V.

6) A greater percentage of intramuscular fat and less moisture was found in barrows than the boars indicating that barrows were further along in their development than boars at a similar live weight.

7) Total DNA in the semitendinosus of the boars (group II) was greater than that found in the barrows (group I). Total RNA increased with a quadratic response in the semitendinosus and brachialis from the boars as live weight increased from 105 to 145 kg.

8) The comparison of the barrows and the boars from group I and II, respectively, resulted in no difference in dressing percentage, fat free muscle or in the ratio of fat free muscle to total bone. Boars carcasses had 26.6% less fat, 11% more bone and 17% more skin than barrows at 105 kg live weight.

9) With the increase of live weight from groups II to V the fat free muscle mass and the ratio of fat free muscle to total bone increased at a consistent rate. Total fat and total skin from the boars over this weight range increased linearly while total bone increased in a quadratic response. The increase of fat free muscle to live weight for boars increased over the weight range from groups II to V by 16% while total fat increased 6.6% and bone increased 3.2%. This greater rate of increase of fat free muscle in boars than fat indicates that even at 145 kg boars are continuing to deposit muscle at a more rapid rate than fat.

10) On a percentage basis the boars of group II had a greater percentage of bone and skin than the barrows of group I. Barrows however, had a higher percentage of fat.

11) Total moisture decreased 1.3% and total bone decreased 1.3% in boars over the weight range from 105 to 145 kg.

12) No difference was found in total length of the tibia or the radius in the boars (group II) and barrows (group I) at similar live weight. A difference was observed in total weight of the tibia between boars and barrows indicating that the greater bone weight of boars, compared to barrows was due to a greater thickness of bone.

13) Total bone weight and length of the radius and tibia increased linearly in boars from 105 (group II) to 145 kg (group V). The ratio of bone weight to bone length for the radius and tibia increased over this weight range, indicating that bone weight was increasing at a greater rate than bone length, or that the increase in bone weight from 105 to 145 kg in boars was primarily due to an increase in thickness.

14) A consistent trend for a decrease in the epiphyseal cartilage width in the radius and tibia in boars from 105 (group II) to 145 kg (group V) indicates that closure of the epiphyseal cartilage was occurring.

15) No difference was found in the average daily gain of boars or barrows up to 105 kg.

16) The point at which average daily gain reached a plateau was different between boars and barrows. In this genetic pool, barrows leveled off in gain at 15 wk and boars at 19 wk. When the average daily gain from 15 to 19 wk was used to calculate the actual weight difference, boars were approximately 24 kg heavier than barrows when the peak gain per day was reached. Researchers that have reported a difference in growth rate between boars and barrows may possibly have measured gain to a weight that was beyond the point of maximum average daily gain for barrows. Other studies where no difference in gain existed between boars and barrows may have preceded this point.

APPENDICES

APPENDIX A.1

Breeding Records

Replicate	Litter No.	Sow No. and Breeding		Boar and Breeding
1	106	163-2	Ch-D	Trump-D
2	103	138-2	D-L	Jackson-Y
3	105	126-1	Y-ch	Billy-Y
4	124	167-2	D-Y	Motorhead-D
5	203	Y11-2	Y	Motorhead-D
6	121	164-2	Ch-H	Billy-Y
7	102	138-4	D-L	Genesis III-Y
8	103	138-3	D-L	Genesis III-Y
9	107	117-1	Ch-Y	Genesis II-Y
10	108	139-3	Y-H	Trump-D
11	114	107-3	Y-D	Trump-D
12	130	188-1	Y-D	Rail III-D
13	137	203-1	Y-L	Boran-D

Ch-Chester White; D-Duroc; H-Hampshire; Y-Yorkshire;
L-Landrace

APPENDIX A.2

MSU Swine Diet

Ingredients, kg	Starter	Boar Test Station
Ground Shelled Corn	530	680
Soybean Meal (48%)	159	186
Oats	91	---
Dried Whey	91	---
Dicalcium Phosphate	14	16
Calcium Carbonate	9.1	12
Salt	2.3	2.7
MSU-VTM Premix	4.5	5.4
Selenium-Vit. E premix	4.5	4.5
L-Lysine	2	1.4
Aureomycin 50	--	0.5
ASP-250	2.2	
Calculated Analysis		
Metabolizable energy (Kcal)	1400	1431
Protein (%)	18.3	16.8
Lysine (%)	1.08	.92
Calcium (%)	.91	.87
Phosphorus (%)	.71	.68

APPENDIX B.1

Modified Munro and Fleck (1969)

Nucleic Acid Determination

I. Procedures for Extracting Muscle and Liver Nucleic Acids

A. RNA

1. Weigh .2 gm powdered muscle (.1 g powdered liver) in a corex tube add 2 ml of deionized H_2O and then stopped & vortex.
2. Add 5 ml of cold 2.5% $HClO_4$, stopper & vortex and let stand in ice for at least 10 min.
3. Centrifuge for 15 min at 17,000 RPM (RC2-B Sorval, SS-34 roter) or 34,800 xg.
4. Discard supernatant.
5. Break up pellet, (with an applicator stick), add 5 ml cold 1% $HClO_4$, stopper and vortex.
6. Centrifuge for 15 min at 17,000 RPM.
7. Discard supernatant.
8. Break up pellet and add 4 ml of .3 N KOH, stopper and vortex, (Put tape over stopper to prevent from popping off).
9. Incubate for 1 hr at 37C.
10. Place on ice for 5 min.
11. Add 5 ml cold 5% PCA, stopper vortex and let stand in ice for 15 min.
12. Centrifuge for 10 min at 17,000 RPM.
13. Decant supernatant into graduated test tubes.
14. Break pellet, add 5 ml of 5% PCA, stopper, vortex, centrifuge at 17,000 RPM and decant supernatant into graduated test tubes (step 13).
15. Repeat step 14 (save pellet for DNA).
16. Bring the volume up to 20 ml. This is the RNA Fraction.

3. Add .1 ml of Acetaldehyde solution to each tube and vortex.
4. Place marbles on top of tubes and incubate overnight at 30C (water bath).
5. Cool to room temperature and read at 595 nm.

B. DNA

1. Break up the pellet from step 15, add 5 ml of 10% PCA, stopper and vortex.
2. Place marbles on top of tubes and digest at 70C for 25 min.
3. Remove from water bath and place in ice for 5 min. Then stopper and vortex.
4. Centrifuge for 10 min at 17,000 RPM.
5. Decant supernatant into graduated tubes.
6. Break up pellet and add approximately 4.75 ml of 10% PCA, stopper, vortex and centrifuge for 10 min at 17,000 RPM.
7. Decant supernatant into tubes (step 5) and bring the vol up to 10 ml. (discard remaining pellet)

II. Colorimetric Procedures for Nucleic Acid Determinations

A. RNA

1. Pipet (2 ml volumetric) 2 ml from each RNA tube into 16 mm test tubes (do everything in duplicate). Also set up the blank (using 2 ml of 5% PCA) and the standards (2 ml of each standards; 12.5, 25, 37.5 and 50 µg/ml).
2. Add 2 ml of 1% orcinol reagent to each tube (must be made up just prior to use) and vortex.
3. Place marbles on top of tubes and place the rack in boiling water for 30 min. Cool by placing rack in running cold water for 5 min.
4. Read at room temperature at 680 nm.

B. DNA

1. Pipet (2 ml volumetric) 2 ml from each DNA tube into 10 mm test tubes (do everything in duplicate). Also set up the blank (2 ml 10% PCA) and the standards (2 ml of each standard; 12.5, 25, 37.5 and 50 µg/ml).
2. Add 2 ml of 4% Diphenyl Amine to each tube.

SOLUTIONS FOR COLORIMETRY

A. RNA

1. Make RNA Standards up in 5% PCA.
   a. 12.5 mg RNA/250 ml 5% PCA 50 µg/ml
   b. 37.5 ml of (a) + 12.5 ml 5% PCA = 37.5 µg/ml
   c. 25 ml of (a) + 25 ml 5% PCA = 25 µg/ml
   d. 12.5 ml of (a) + 37.5 ml 5% PCA = 12.5 µg/ml

2. 1% Orcinol
   a. Make 10% $FeCl_3$ (W/V) in 6 N HCl.
   b. Take 5 ml of (a) and dilute to a l with 6 nc HCl (gives a 0.05% $FeCl_3$ sol.)
   c. *Make 1% Orcinol by adding 100 ml of (b) to 1 gm Orcinol in a volumetric flask and stirring vigorously with a magnetic bar for about 20 min. *(Must be made just prior to use).

B. DNA

1. Make DNA Standards up in 10% PCA
   a. 12.5 mg DNA/250 ml 10% PCA = 50 µg/ml
   b. 37.5 ml of (a) + 12.5 ml 10% PCA = 37.5 µg/ml
   c. 25 ml of (a) + 25 ml of 10% PCA = 25 µg/ml
   d. 12.5 ml of (a) 37.5 ml 10% PCA = 12.5 µg/ml

2. Diphenyl amine reagent (W/V)
   a. 4 gm Diphenyl Amine/100 ml Glacial Acetic Acid

3. Acetaldehyde solution
   a. 0.4 ml Acetaldehyde concentrate/250 ml H_2O

KEEP ALL SOLUTIONS IN A COLD ROOM

APPENDIX B.2

Gluteraldehyde - BSS Buffer

- 1% gluteraldehyde in BSS Buffer
- BSS Buffer:
  - Mix the following compounds with dionized water and bring final volume up to 1 liter:

8.0076 g NaCl
.2013 g KCl
.1110 g $CaCl_2$
.2033 g $MgCl_2$
.0207 g NaH_2PO_4
.1931 g Na_2HCO_3
.5041 g $NaHCO_3$
.9909 g glucose

APPENDIX B.3

Guanidine - HCl Buffer

Make a: 1) .02 M guanidine - HCl solution
2) .05 M boric acid - KOH buffer

Mix to a pH 9.5

APPENDIX B.4

Fiber Diameter

1. Weigh approximately 200 mg of powdered muscle sample in 5 ml beaker.
2. Add 2 ml of 1% gluteraldehyde - BSS buffer.
3. Refrigerate at 4C for 1 hr.
4. Pipett off liquid portion and discard liquid.
5. Add 2 ml of .02 M guanidine-HCl buffer and allow to stand at room temperature for .5 hr.
6. Pipett off .02 M guanidine-HCl buffer and discard.
7. Add 2 ml of BSS buffer plus 2 drops of methylene blue.
8. Gently shake at 4C for at least 2 d.
9. Remove breaker from shaker and homogenize for 30 sec using a Virtis 45 model Super 30 homogenizer.
10. Put one to two drops of mixture on microscrope slide-add cover slip.
11. Measure diameter of 50 fibers at a total magnification of 400.

APPENDIX B.5

1% Gluteraldehyde in .1M Phosphate Buffer pH 7.4

- 1% gluteraldehyde in Phosphate Buffer
- Phosphate Buffer
  1. Mix 13.9 g $NaHPO_4 \cdot 7H_2O$ in 1000 ml
  2. Mix 26.8 g $Na_2HPO_4 \cdot 7H_2O$ in 1000 ml
  3. Add 19 ml of solution 1to 81 ml of solution 2 and dilute with H_2O to a total of 200 ml.

APPENDIX B.6

Guanadine-HCl in Borate Buffer pH 9.5

- Add .02 M Guanadine - HCl to Borate Buffer until a pH 9.5 is reached.

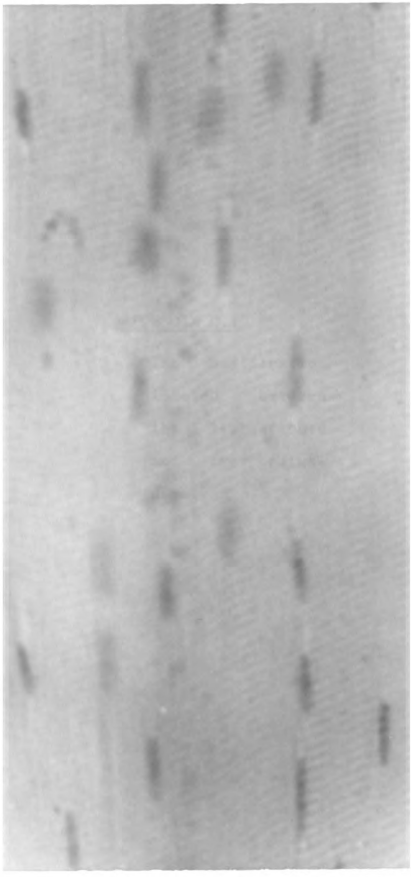
APPENDIX B.7

.05M Borate Buffer pH 8.5

1. Mix 31.0 g Boric acid in 1000 ml.
2. Mix 47.6 g Borax in 1000 ml.
3. Add 50 ml of solution 1 to 14.5 ml of solution 2 and dilute with H_2O to a total of 200 ml.

APPENDIX C.1

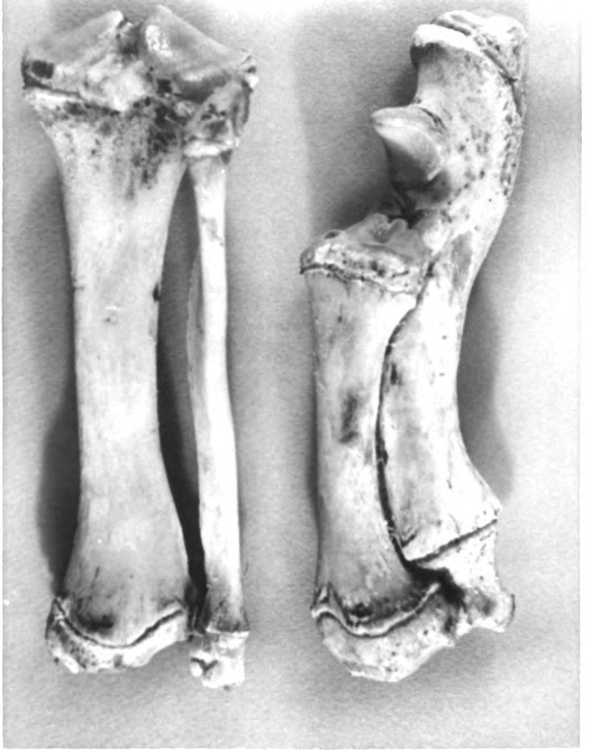
Nuclei counting in longissimus fiber.



APPENDIX D.1

The ossification located between the tibia-fibula and the raius-ulna.

TIBIA- FIBULA RADIUS - ULNA

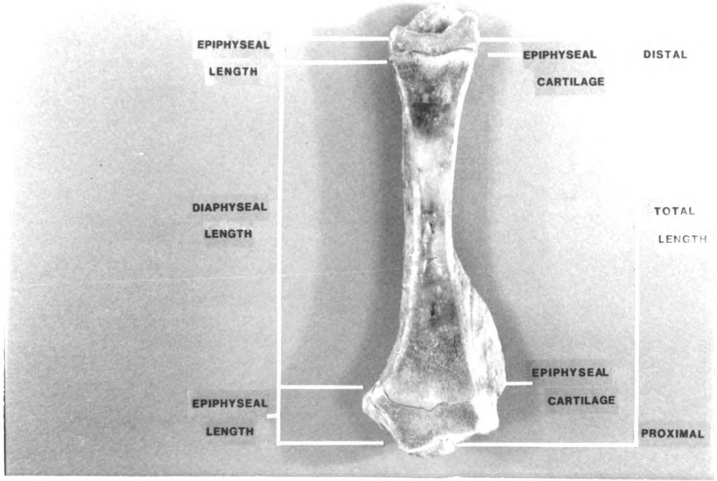


APPENDIX D.2

Measurements recorded on the Tibia.

BONE MEASUREMENTS

TIBIA

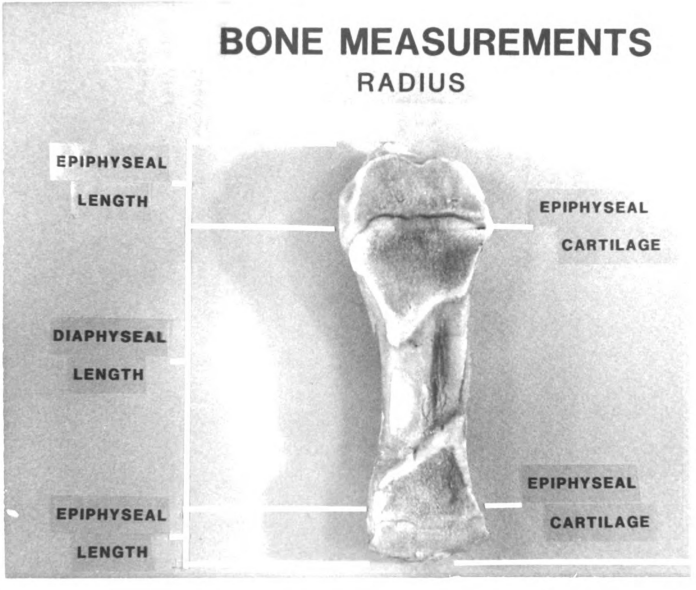


APPENDIX D.3

Measurements recorded on the Radius.

BONE MEASUREMENTS

RADIUS



APPENDIX E.1

Equations to Graph Figures

a - intercept
b - linear regression coefficient
c - quadratic ugression coefficient
d - absicca value (105 kg=2, 118 kg=3, 132 kg=4, 145 kg=5)

Linear response = $a + (b)(d)$
Quadratic response = $a + (b)(d) + (c)(d^2)$

Figure I

Carcass Length = $80.14 + (2.26)d$
Longissimus Muscle Area = $32.32 + (-.684)d + (.555)d^2$
Tenth rib Backfat = $3.84 + (-1.105)d + (.183)d^2$

Figure II

Longissimus Muscle = $2247.60 + (91.98)d + (124.4)d^2$
Semitendinosus Muscle = $437.34 + (14.78)d + (24.21)d^2$
Brachialis Muscle = $112.21 + (3.73)d + (4.99)d^2$

Figure IV

Total Fat Free Muscle = $35.06 + (5.20)d$
Total Fat = $12.90 + (1.21)d + (.691)d^2$
Total Bone = $9.50 + (1.17)d$

Figure V

Total Weight = $252.49 + (25.78)d$
Total Length = $17.37 + (.396)d$

Figure VI

Total Weight = $253.38 + (24.21)d$
Total Length = $12.85 + (.330)d$

Figure VII

Graphed on mean values

Figure VIII

Graphed on mean values

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