COMPARISON OF PERFORMANCE, COMPOSITION AND ENERGY PARTITIONING BETWEEN MAINTENANCE, PROTEIN AND FAT IN BOARS AND BARROWS

By

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ABSTRACT

COMPARISON OF PERFORMANCE, COMPOSITION AND ENERGY PARTITIONING BETWEEN MAINTENANCE, PROTEIN AND FAT IN BOARS AND BARROWS

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In Experiment I of this study the effect of perinatal androgens on growth, carcass composition and selected bones and muscles were assessed. Treatment groups were: 1) intact boars, 2) boars castrated at birth and 3) boars castrated at 6 wk of age. Boars castrated at birth compared to those castrated at 6 wk had lower teres minor weight. Serum testosterone concentrations in boars increased to 1.6 ng/ml at 3 wk and then decreased to a low concentration at 6 wk that did not increase consistently again until 15 wk of age (2.2 ng/ml). Compared to castrates, boar carcasses had 9% greater fat-free muscle, 29% less fat, 11% more bone and 25% more skin weight. In Experiment II growth rate, feed intake, efficiency of gain of boars, barrows and gilts did not differ prior to 71 kg. From 71 to 105 kg boars and gilts had lower feed intakes than barrows and boars had greater gain/feed than barrows and gilts. Boars and gilts had larger longissimus areas, longer carcasses and more muscle than barrows. In Experiment III digestible energy

(DE), metabolizable energy (ME) and nitrogen corrected ME (ME_N) were compared for 85 kg boars and barrows at four intake levels of a similar diet. DE, ME and ME_N of the diet were all greater in boars than in barrows. Boars had greater nitrogen retention, nitrogen digestibility, apparent biological value and net utilization of protein than barrows. In Experiment IV, energy partitioning of boars and barrows where compared by the comparative slaughter method. Initial slaughter pigs weighed 70 kg and additional pigs were provided varying levels of feed intake during a 5 wk feeding trial. Retained energy, protein and fat were calculated and data were expressed on both body weight $(BW)^{.66}$ and $BW^{.75}$ bases. Boars retained more protein and barrows retained more fat and total energy. Boars tended to have higher maintenance energy requirements while barrows tended to have greater efficiency of total energy retention.

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Introduction

The future challenge to animal production agriculture is to meet production demands with a steadily decreasing budget of feed energy (cereal grains) and fossil energy (Fredeen and Harmon, 1983). The production of edible food products from animals and the interest to improve that efficiency originated when man changed from hunter to herder. Narrower profit margins for producers and the dwindling energy supply have merited even a keener focus on efficiency. Feed energy is by far the greatest input in animal production agriculture. The improvement of animals' efficiency to convert feed energy to food should result in substantial energy conservation and economic returns to producers. In meat producing species efficiency means a concentrated effort on the production of lean meat and not fat. Fat is considered a by-product which must be trimmed off and discarded by the consuming public (Breidenstein and Carpenter, 1983).

Improving animals' use of feed energy has been studied for many generations (Lavoisier, 1777). Lavoisier was the first to depart from the phlogisticated theory and equate life as a combustive process, so that metabolism of organisms may be studied under similar theory. In discussion of animal energetics, Kleiber (1975) simulates

life to fire. Through this association, generalizations are discouraged and clarification stressed to better understand energy metabolism. Therefore, energetics is the science that deals with the laws of energy and its transformations. The first two laws of energy are fundamental and merit emphasis. The first law states that energy can never be created or destroyed but only transformed by the flow of energy as heat or work (Metzler, 1977). This law assertains only the initial and final energy states of the system. In animal systems the energy equivalent of work, maintenance energy plus dissipated heat must equal energy generated from the oxidation of consumed nutrients (Brody, 1945). The second law is concerned with transformation of energy: in this process molecules become disordered and energy flows from a higher to a lower energy state (Metzler, 1977). There are limitations of complete conversion into work however, and kinetic energy (heat) is lost in the energy transformation. In animals this energy is lost as heat and dissipated from the body into the environment (Brody, 1945).

In rapidly growing animals energy is primarily stored in body tissues as protein and fat. Many different factors can intervene to prevent maximum efficiency of converting feed energy to protein and fat. For example, the efficiency of energy conversion in body tissues can be altered by environmental temperature outside the thermoneutral zone (Phillips and MacHardy, 1982),the type (fat, carbohydrate, protein or fiber) of dietary energy source (Schiemann et

al., 1961) or the proportion of protein to fat deposition (Blaxter, 1980). This thesis will focus on how the efficiency of utilizing dietary energy for growth in swine is affected by variation in deposition of body protein and fat.

It is important to first recognize that heat of combustion of protein and fat differ. Heat of combustion of protein has been shown to be 5.57 to 5.69 kcal/g and for fat 9.354 to 9.512 kcal/g (Garrett et al., 1959; Brouwer, 1965). Differences also have been found in the conversion of dietary energy to protein and fat energy. The Agricultural Research Council (ARC, 1981) summarized data on the efficiency (kcal/kcal) of protein deposition that ranged from .35 to .80 and averaged .56. Efficiency of fat deposition ranged from .62 to .92 and averaged .74 (ARC, 1981). The conversion of energy to grams of protein and fat provides a different result. Based on the gross energy and the efficiencies of protein and fat summarized by the ARC (1981), 10.5 kcal of ME are required to deposit 1 g of protein and 12.8 kcal ME/g of fat in growing pigs, thus resulting in less energy required to deposit a gram of protein than fat.

During rapid growth the relationship of total protein to fat deposition has been found to vary with age (figure 1) in sheep (Searle, Graham O'Callaghan, 1972) rats (Zucker and

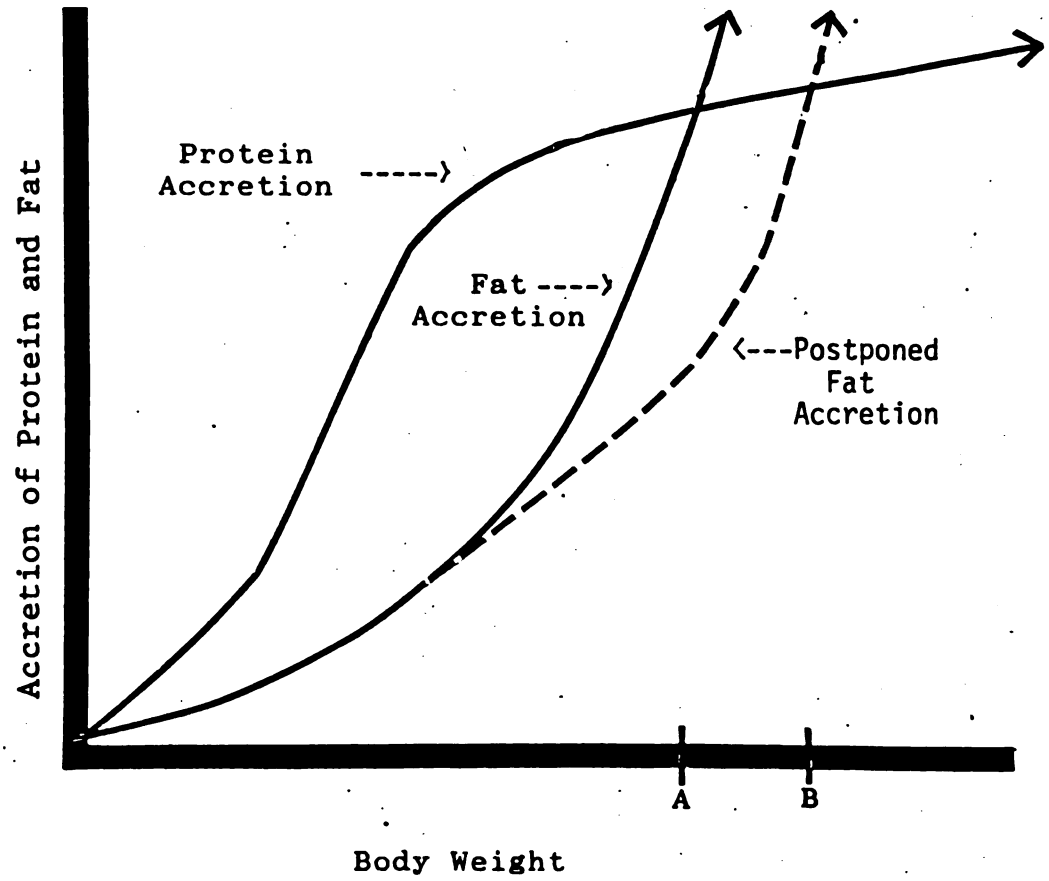


Figure 1. Idealized plot of fat and protein accretion versus body weight. Relocation from A to B indicates the relationship of protein and fat accretion if propensity for fattening was postponed. (Modified after Bergen, 1974).

Zucker, 1963) cattle and pigs (Bailey and Zobrisky, 1968). Early in life protein accretion is more rapid than fat deposition. However, the rate of protein accretion decreases with advancing age only to be surpassed by a greater rate of fat deposition. With fat considered a by-product, the ratio of protein to fat deposition in early growth is more favorable than the ratio found in later growth. It would be advantageous in meat animal production to lengthen the period where protein accretion is greater than fat deposition (figure 1). Postponement of the acceleration of fat deposition, through better understanding of the mechanisms that divert energy to fat synthesis rather than protein accretion, has important implications in animal agriculture (Bergen, 1974).

Improved quality of diets and crossbreeding schemes have improved the efficiency of gain and delayed fattening in livestock. Further improvement has been demonstrated through anabolic hormone implants, primarily in beef cattle. Applications of anabolic compounds for use in swine are needed. Agricultural companies have committed resources to produce synthetic compounds that will delay fattening when administered to animals. A widely studied compound is a *B* adrenergic agonist produced by American Cyanamide Company, Cimaterol (CL 263,780). Cimaterol administered (Dalrymple et al., 1984; Moser et al., 1984, 1986; Jones et al., 1985) to swine has delayed the propensity for fattening and increased the percentage of lean gain. However, Cimaterol

has not consistently decreased energy required for live weight gain. Jones et al. (1985) found improved feed to gain in swine fed Cimaterol but Moser et al.(1984,1986) demonstrated no difference from untreated controls. Inconsistent results along with increased foot lesions in Cimaterol fed pigs (Moser et al., 1984, 1986; Jones et al., 1985) indicate that further work is required before practical use can be considered. Another problem is that none of these synthetic compounds has yet been approved by the Food and Drug Administration for use in domestic livestock feeds.

Delayed fat deposition also has been found in intact male swine (boars) compared to castrates (barrows). Numerous reviews have shown that boars have a greater percentage of lean to fat, are 10 to 20% more efficient in overall live weight gain and consume less feed per day than barrows. Therefore, castration of boars increases feed intake and more consumed energy is diverted to fat deposition and less to protein accretion. The differences in performance between boars barrows indicates that natural androgens in the boar may be more effective in delaying fattening than Cimaterol. Characterization of the effects of androgens should lead to methods for improving efficiency of gain through postponement of fat deposition.

The effects of castration have been studied relative to the action of specific androgens. Mulvaney (1984) focused on the testicular androgen, testosterone, and compared in

vitro rates of protein synthesis and degradation, and adipose tissue lipogenic and lipolytic activities between boars, barrows and barrows administered testosterone or dihydrotestosterone. In vitro methods suggested that testosterone increased muscle growth by increasing rates of protein synthesis more than degradation. There was no difference in protein synthesis in semitendinosus muscles of barrows administered dihydrotestosterone or testosterone (Mulvaney, 1984). Barrows given exogenous testosterone deposited protein and fat proportional to boars but the total amount of protein and fat accretion was less in testosterone treated barrows compared to boars. It was suggested that fattening may be reduced through a reduction in fatty acid synthesis and lipoprotein lipase activites with only subtle increases in hormone sensitive lipase activity (Mulvaney, 1984). These results (Mulvaney, 1983) and those of others (Breuer and Florini, 1965; Florini, 1970; Grigsby et al., 1976) indicate that testosterone may increase energy utilization for protein synthesis to a greater extent than for fat deposition. Androgen concentration has been found to increase in boars during the perinatal period and following puberty (Colenbrander et al., 1978; Martin et al., 1984). The anabolic effects of androgens relative to the perinatal stage of development have not been documented.

The first objective of this investigation was to determine if high perinatal androgen concentrations

(Colenbrander et al., 1978) affect the expression of protein and fat deposition during subsequent growth in boars and barrows. Second, the objective was to determine if stage of development alters performance differences between boars and barrows. The final objective was to determine if castration of boars affects the partitioning of energy between maintenance, protein and fat deposition, or alters the efficiency of protein and fat deposition. Before testing the final objective, it was necessary to establish if metabolizable energy of the diet differed between boars and barrows.

Literature Review

Differences in composition between boars and barrows have been documented since the passage "a boar will have more meat on him than a hog" was printed in Fritzherbert's Husbandry, published in 1523 (Fuller, 1980). However, meat from boars has had limited acceptance due to a sexual odor described as urine or perspiration like (Craig and Pearson, 1959). Association of 5-androst-16-ene-3-one with sex odor in cooked boar meat (Patterson, 1968) has stimulated work to prevent the odor (Mottram, Wood and Patterson, 1982; Brooks et al., 1983). Odor levels have varied due to rearing conditions, growth rate as well as age (Walker, 1980; Patterson,1982). Although the persistent odor of boar meat has limited consumer acceptance, research has been active to assess the advantages of intact boars compared to castrates (barrows) for meat production. Differences in composition, growth rate and efficiency of gain have been reviewed extensively (Turton, 1962; Prescott and Lamming, 1964; Walstra and Kroeske, 1968; Wismer-Pederson, 1968; Martin, 1969; Turton, 1969; Field, 1971; Kay and Houseman, 1975; Fuller, 1980; Galbraith and Topps, 1981: Seideman et al., 1982; Knudson, 1983; Mulvaney, 1984). Walstra and Kroeske (1968) after an extensive literature review on the comparison of boars to barrows concluded the following: boars have a more favorable feed efficiency, greater carcass

length, less backfat thickness, lower percentage of carcass fat and higher percentage of carcass lean, increased percentage of primal cuts and a decreased dressing percentage than barrows. Growth rate differences were not found to be consistent among reports (Walstra and Kroeske, 1968). Advantages in growth rate of boars over barrows was suggested to be dependent on a greater dietary protein for boars to maximize growth (Speer et al., 1957; Prescott and Lamming, 1964; Hays et al., 1966). In addition to dietary protein, level of daily food intake (ad libitum vs restricted), body weight and breed are suggested to affect boar-barrow comparisons (Winters et al., 1942; Turton, 1969; Fuller, 1980).

In the remaining discussion the differences found for boar versus barrow comparisons for gain/feed and carcass fat will be reviewed. The primary focus will be on the importance of body weight or age affects on boar-barrow comparisons, and dietary protein required to maximize differences. The final area to be discussed is the utilization of dietary energy for maintenance and accretion of protein and fat in boars and barrows, and the methods used to assess differences in energy partitioning.

Boar Versus Barrow Comparisons

Composition. Castration of boars promotes early maturity (Palsson, 1955). The earlier maturing barrow has

greater backfat thickness and total fat in the carcass relative to boars (Bratzler et al., 1954; Hetzler et al., 1956; Charette, 1961; Teague et al., 1964; Hines, 1966; Plimpton et al., 1967; Prescott and Lamming, 1967; Wong et al., 1968; Texier et al., 1970; Omtvedt and Jesse, 1971; Newell and Bowland, 1972; Froseth et al., 1973; Desmoulin, 1973; Siers, 1975). The mean backfat measurement noted by Martin (1969), Turton (1969) and Wismer-Pederson (1968) from 15 different citations was 3.0 cm for boars and 3.6 cm for barrows (Field, 1971); a difference of 17%. More recently backfat thickness of boars was found to be 17% less at 68 kg (Wood and Esner, 1982), 21% less at 90 kg (Newell and Bowland, 1972) and 31% less at 105 kg (Knudson et al., 1985a) live weight compared to castrates. The 31% difference in backfat thickness corresponded to 33% less total carcass fat in 105 kg boars reported by Knudson et al. (1985b). Carcass muscle was increased 3% (Field, 1971; Wood and Riley, 1982) and 5% (Seiderman et al., 1982) in boars relative to barrows. A similar pattern was found for carcass bone with boars having 2% (Field, 1971), 5% (Wood and Riley, 1982), 11% (Knudson et al., 1985b) and 12% (Prescott and Lamming, 1967) greater total carcass bone than barrows. Therefore, the largest difference found in carcass composition between boars and barrows was the percentage fat.

Efficiency of Gain. In most studies the amount of feed per unit live weight gain was found to be less in boars compared to barrows. In a review of 22 citations, Walstra and Kroeske (1968) reported conversion of feed to gain for boars and barrows was equal in three studies and in the other 19 boars were superior to barrows in efficiency. This relationship of contrasting results was also found in more recent studies. Omtvedt and Jesse (1968), Wong et al. (1968), Walstra (1969), Texier (1970), Newell and Bowland (1972), Froseth et al. (1973), Pay and Davis (1973), Siers (1975), Luce et al. (1976), and Wood and Riley (1982) have reported an advantage in feed efficiency for boars of approximately 9%, while only one study reported no difference between boars and barrows (Campell and King, 1982). The greatest advantage in feed efficiency of boars was found to be 19.5 % (Wood and Riley,1982). A 9 to 10 % difference was generally found in other reports.

Weight and Age Effects. Fuller (1980) recognized that the endocrine changes accompanying sexual development may effect growth rate of boars compared to barrow. In data from Witt and Schroder (1969) boars had superior growth rates than barrows only after 50 kg live weight. The differences were even more pronounced at weights above 70 kg and these results have recently been confirmed (Hansson, 1974; Knudson et al., 1985a).

Colenbrander et al. (1978) measured serum testosterone concentration in boars and barrows and found that after 19 wk of age serum testosterone concentrations remain elevated in boars at pubertal concentrations until the end of the experiment at 24 wk. Martin et al. (1984) also found elevated testosterone concentrations in boars by 19 wk of age. This age corresponded to work by Allrich et al. (1982) in which elevated testosterone concentrations were shown in boars by 130 d of age (18.4 wk) or approximately 65 kg body weight. Recognizing that age and/or weight may affect boar-barrow comparisons Mulvaney(1984) assessed composition and efficiency of gain differences at 38 and 88 kg. The 38 kg live weight was selected to correspond to prepubertal and 88 kg live weight to postpubertal stages of growth. Boars demonstrated an advantage of 20 to 23% in efficiency of live weight gain at 38 and 88 kg compared to barrows. The difference in percentage carcass fat however, was greater at the heavier weight. Boars had 15% less carcass fat at 38 kg and 21% less at 88 kg, than barrows. Testosterone administration to barrows was also found to decrease fat deposition similar to that of boars (Mulvaney, 1984) indicating that testosterone may play a major role in compositional differences of boars and barrows.

Blair and English (1965) assessed gain and efficiency of gain and found that prior to 54 kg boars gained 6.3% faster and had 7.7% greater feed efficiency than barrows. These differences increased after 54 kg with an 8.8%

advantage in weight gain and 14.2% in feed efficiency for boars relative to barrows. Pay and Davis (1973) found that prior to 55 kg, efficiency of gain did not differ but from 55 to 90 kg boars were 11% more efficient than barrows. The comparison of nitrogen retention also has been found to differ for boars and barrows relative to live weight. Nitrogen retentions of Pietrain boars and barrows were similar at 60 kg, but differed by 18% at 80 kg (Eckhout et al., 1971).

Backfat thickness differences of boars and barrows, relative to live weight have been found (Hetzler et al., 1956) to follow a pattern similar to carcass fat comparisons found by Mulvaney (1984). At 68 kg, boars had 5.3% less backfat than barrows and by 102 kg live weight this difference increased to 11% (Hetzler et al., 1956). Cahill et al. (1960) found that at 45 kg boars and barrows did not differ in backfat thickness, but at 95 kg boars were 17% leaner.

Therefore, boars have generally been found to have a greater difference in gain, backfat and efficiency of gain relative to barrows at heavier weights. These differences are associated with the high serum pubertal testosterone concentrations in boars. The effect of elevated serum perinatal testosterone (Colenbrander et al., 1978; Martin et al., 1984) on these parameters is difficult to characterize as time of castration is not documented in these studies.

Protein Requirements. The results from previous experiments have indicated that for maximum performance and percentage lean, boars respond to a higher level of dietary protein (amino acids) than barrows (Charette, 1961: Hays et al., 1966; Hines, 1966; Prescott and Lamming, 1967; Walstra, 1969; Newell and Bowland, 1973; Campbell and King, 1982; Wood and Riley, 1982). The National Research Council (NRC, 1979) has listed dietary protein requirements for barrows (and gilts) at 13 to 14% crude protein during the growing to finishing periods. A recent cooperative study by a North Central Regional (NCR-42) subcommittee has shown that for maximum gain and percentage muscle, barrows required a 14% crude protein diet (fed corn-soybean meal diet, percentage lysine .84 to .61) in the finishing period (Cline, 1984). No recommended protein requirements of growing boars are provided by the NRC (1981). Past studies have shown that boars respond with increased performance when fed a higher percentage of dietary protein than that required by barrows, but recommended feeding levels have not been summarized. Those studies that have shown that boars require a greater percentage of dietary protein than barrows will be discussed next. The amount of dietary protein required by boars for maximum performance also will be discussed.

Fuller (1980) has suggested that the statement: boars require greater dietary protein than barrows, is incorrect. Boars retain a greater percentage of dietary nitrogen than barrows when fed a similar diet (Piatkowski and Jung, 1966).

Therefore, to have nitrogen retention equal to barrows, boars need less protein (Fuller, 1980). However, at low protein intake (13.5%, .59% lysine) boars and barrows have been found not to differ in nitrogen retention, but when dietary crude protein was increased to 20.6% (lysine, 1.20%) boars retained more nitrogen than barrows (Holmes et al., 1980). Therefore, boars have been suggested to have a greater metabolic capacity to utilize increased dietary protein compared to barrows. Speer et al. (1957) supported this concept in a different context. For maximum growth and efficiency of gain, boars required a higher concentration of protein than that fed to maximize performance of barrows (Speer et al., 1957).

Most work supports increased gain and percentage lean when dietary protein was increased (Prescott and Lamming, 1964; Hays et al., 1966; Walstra, 1969; Newell and Bowland, 1972; Luce et al., 1976; Reinhard et al., 1976; Traverner et al., 1977; Wood and Riley, 1982; Tyler et al., 1983). However, there have been reports in which boars have not responded to increased percentage of dietary protein (Wong et al., 1968; Pay and Davis, 1973) or amino acids (Hines et al., 1975). These diets may have already contained adequate protein for maximum performance. Campbell and King (1982) suggested that response to dietary protein may be confounded with differences in energy intake for boars and barrows.

At restricted energy intake (5.8 Mcal/d for 65 kg pig) growth rate of boars, increased with the increase in

dietary protein from 17 (.86% lysine) to 21% (1.06% lysine, Campbell and King, 1982). However as percentage protein was increased at restricted energy intake, decreased growth was found for barrows (Campbell and King, 1982). With ad libitum energy intake (8.49 Mcal/d) 21% protein promoted maximum growth and efficiency of gain for boars, but had no beneficial effect on barrows relative to a 17% crude protein diet (Campbell and King, 1982).

In a discussion of the dietary protein level that has supported maximum performance of boars, Newell and Bowland (1972) found that maximum gain in boars required the feeding of 18% dietary protein until 90 kg. Hays et al. (1966) reported that prior to 57 kg, 18% protein was required for most rapid gain, but thereafter only 16% protein was required. Luce et al. (1976) found maximum gain for boars when 20% dietary crude protein was fed from 23 to 56 kg and 18% protein from 57 to 100 kg. These levels of protein also supported maximum gain in a later study (Tyler et al., 1983). Traverner et al. (1977) reported maximum gain for boars fed 19.6% crude protein from 20 to 70 kg.

Percentage lean cuts were maximized when an 18% protein diet was fed to boars (Reinhard et al., 1976). The level of crude protein required for maximum longissimus muscle area was 19.1% crude protein (Tyler et al., 1983). Hayes et al. (1966) found that percentage lean in boar carcasses was optimum when 20% protein was fed prior to 57 kg and with 18% protein thereafter. This dietary protein sequence also has

resulted in minimum backfat thickness in boars (Luce et al., 1976). Traverner et al. (1977) used percentage lean in the ham of boar carcasses to assess composition and found maximum ham leanness when 21% protein was fed.

Feeding a 20% crude protein diet to boars prior to 55 kg has been found to provide the greatest gain/feed (Luce et al., 1976; Reinhart et al., 1976; Tyler et al., 1983). Traverner et al. (1977) reported 19.3% protein maximized gain and feed efficiency for 20 to 79 kg pigs. However, when gain to feed ratio was recorded for boars from 55 to 100 kg no advantage was found by feeding greater than 16% dietary protein (Pay and Davis, 1973; Luce et al., 1976; Reinhart et al., 1976; Tyler et al., 1983).

Through efforts concentrated on percentage dietary lysine rather than crude protein, Batterham et al.,(1985) found that maximum efficiency of gain and growth were found at .8% lysine for 80 kg boars. Campbell et al. (1984) found that .83 to .9% dietary lysine supported the most rapid growth rate for boars. Dietary lysine concentrations are considered to be .1 to .2% higher for maximum percentage carcass lean than for growth rate (ARC, 1967). If the percentage dietary lysine found by Campbell et al. (1984) and Batterham et al. (1985) for maximum growth were increased .1 to .2% it would correspond to the percentage lysine in an 18 to 20% crude protein corn-soybean meal diet that has supported maximum percentage carcass muscle in boars (Luce et al., 1977).

Dietary protein fed at concentrations greater than 18 to 20% may not be beneficial and may decrease performance. Boars fed 23% protein (1.24% lysine) compared to boars fed 21% protein had decreased growth rate (Campbell and King, 1982). In a more recent study 45 to 90 kg boars fed 23% crude protein (1.24% lysine) had 3.4% lower gain and required 4.4% more feed for gain compared to a 18.6% protein diet (.99 lysine; Campbell et al., 1985). Decreased gain and efficiency were also found when gilts were fed 25 and 27% protein (1.45 and 1.59% lysine) compared to 16% protein diets from 23 to 59 kg (Cooke et al., 1972). Just-Neilson (1980) reported that net energy per unit of metabolizable energy decreased in association with increases in concentration of dietary crude protein that ranged from 13 to 24%. Therefore, an 18 to 20% crude protein diet with 1.0 to 1.1% lysine (corn-soybean meal diet) should provide for maximum gain and percentage muscling in growing boars.

Energy Metabolism

Research on energy metabolism in swine has greatly increased in the last 28 yr since the formation of the International Symposium on Energy Metabolism in 1958. The limited research prior to that time was evident from the lack of discussion in the 1958 review of 50 yr of progress in swine nutrition by Hanson (Seerly and Ewan, 1983).

Current knowledge on energy metabolism indicates that growing animals require energy for three major metabolic processes: protein accretion, fat deposition and maintenance (Van Es, 1977). The amount of energy required for protein and fat deposition has been widely studied, relative to environment and other conditions. Comparisons of energy required for protein and fat deposition in sheep, rats and swine are shown in table 1. A factor that has not been widely studied in relation to affect on energy is castration of males. Studies on energy metabolism in swine have provided energy requirements and partitioning of energy in castrated male swine (barrows). However, the assessment of energy metabolism of boars is limited in the areas of relative energy value of feedstuffs fed to boars and also for the partitioning of that energy. A greater understanding of the energy utilization by boars compared to barrows would indicate if possible dietary adjustments are needed for feeding boars. Comparison of energy utilization may also provide a better understanding of why barrows are less efficient than boars in the conversion of feed to lean gain.

The following discussion will focus first on reviewing the general nomenclature used in energy metabolism. Secondly, the effects that energy substrates, environmental temperature and metabolic body weight have on energy partitioning will be discussed. Next, the methods used to measure energy partitioning and the amount of energy

Table 1. LITERATURE ESTIMATES OF THE ENERGY COSTS OF PROTEIN (b_P) AND OF FAT (b_F) DEPOSTION

b_P, Mcal/kg	b_F, Mcal/kg	Species	Source
7.07	14.97	Sheep	Kielanowski (1965)
7.51	11.65	Pigs	Kielanowski (1965)
11.5		Pigs	Kielanowski and Kortarbinska (1970)
15.96	12.96	Pigs	Kielanowski and Kortarbinska (1970)
16.25	11.44	Sheep	Orskov and McDonald (1970)
(10.9)[a]	(13.6)	Pigs	Oslage et al. (1970)
11.65	16.26	Pigs	Sharma and Young (1970)
14.62	15.73	Pigs	Sharma and Young (1970)
13.1	12.4	Pigs	Thorbek (1970)
12.1	13.7	Pigs	Close and Mount (1970)
7.43	12.05	Pigs	Burlacu et al. 1973)
9.8	13.6	Pigs	Close et al. (1973)
7.6	12.5	Rats	McCracken and Weatherup (1973)
10.5	13.5	Pigs	Gadeken et al. (1974)
45.6	10.2	Sheep	Rattray et al. (1974)
27 to 54	11 to 12	Sheep	Rattray and Joyce (1976)
8.6	9.5	Pigs	Burlacu et al. (1976)
(13.3)	(14.6)	Rats	Pullar and Webster (1974)
12.6	12.8	Rats	Pullar and Webster (1977)
11.9	12.4	Pigs	Thorbek (1977)
(8.0)	(13.4)	Pigs	Close (1978)
12.2		Pigs	Reeds et al. (1980)

[a] Values in parentheses are adapted from published estimates of kp and kf as: $b_P = 1/kp \times 5.7$ Mcal/kg; $b_F = 1/kf \times 9.5$ Mcal/kg.

(Modified from Tess et al., 1984b).

required for protein and fat accretion will be reviewed. The last area will be a discussion of those studies that have included a comparison of energy partitioning between boars and barrows.

Energy Nomenclature. The principal system and nomenclature to describe the partition of energy in animals has been adopted and published by the NRC (1981). Detailed definitions of energetic terms and a diagram (figure 2) of the system were provided in that publication (NRC, 1981). A summary of these definitions have been discussed by Seerley and Ewan (1983) and Baldwin and Bywater (1984). Intake energy is the gross energy of the consumed feedstuff multiplied by total consumption. Gross energy is the energy released as heat after complete oxidation of the feedstuff. Gross energy reflects the energetic equivalents of the protein, fat and carbohydrate constituents of the feedstuff.

Total intake energy (IE) minus gross energy of the feces is defined as digestible energy (DE) and is considered the energy that is absorbed. Metabolizable energy (ME) is energy available in the feedstuff for the animals' metabolism, and is IE minus energy lost in the feces (FE), urine (UE) and combustible gases (GE): ME = IE - (FE + UE + GE). Three of these factors (IE, FE and UE) are readily measurable. GE is difficult to quantify in pigs and generally found to be .6 (Close and Mount, 1978) to 2% (Bowland et al., 1970; Just, 1980) of IE and is therefore

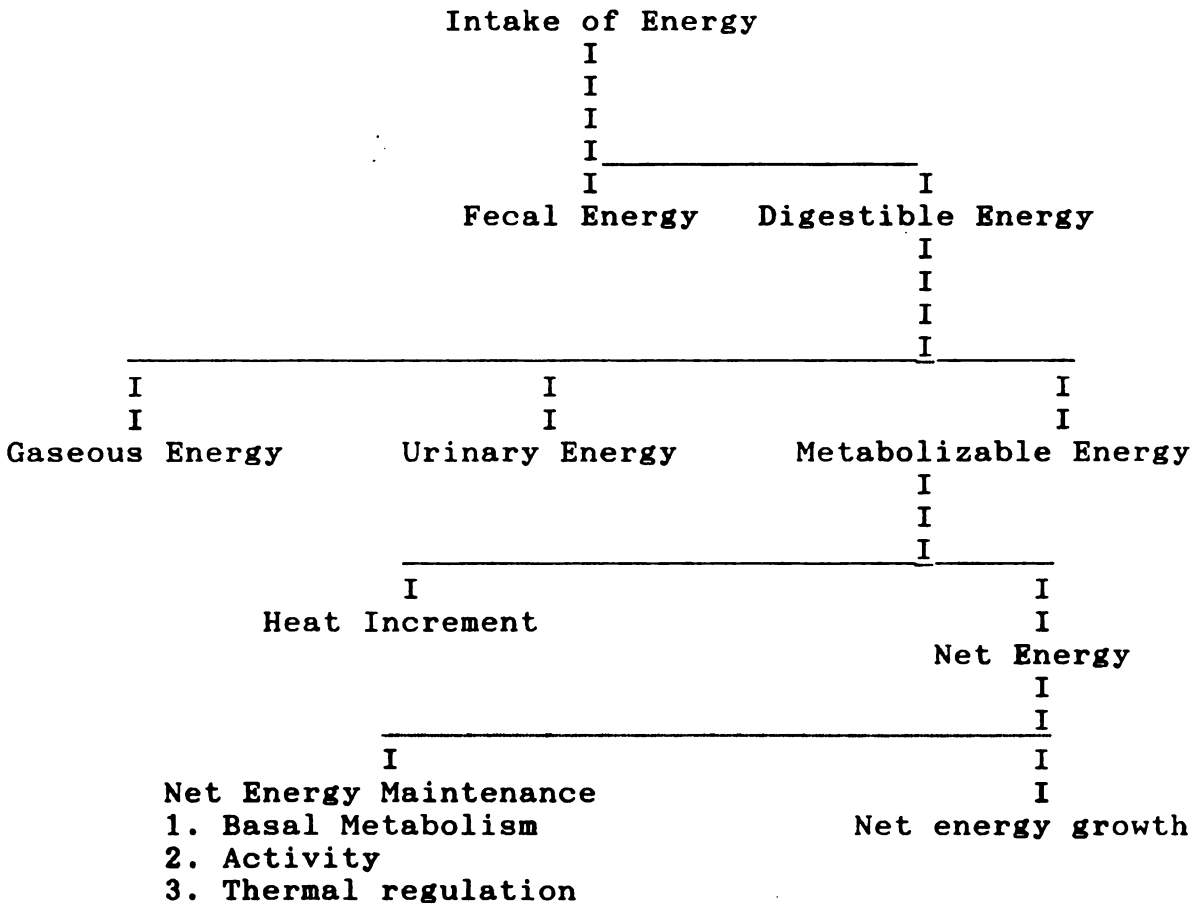


Figure 2. Energy Utilization (Adopted from Seerley and Ewan, 1983).

frequently not measured or considered in ME evaluations. ME is available for metabolic processes in the animals' system and further partitioned to net energy and heat increment (HI), Net energy is then partitioned between net energy of maintenance (NE_m) and net energy of growth (NE_g).

The NE_m is the energy expended to sustain life processes of an animal and the energy associated with minimal movement and consumption of food and water. The NE_g is the recovered energy (RE) in growing animals equivalent to retained energy in tissues (protein, fat, carbohydrate). Heat production (HP) of the animal in a thermoneutral enviroment is the sum of HI and NE_m. The partition of ME is therefore: ME = HP + RE or ME = HI + NE_m + NE_g.

Substrate Energy Availability. The total energy available for intermediary metabolism of the animal's system varies with the type of substrate constituents of which dietary metabolizable energy consists. The energy digested from feedstuffs consists of organic components that are further hydrolyzed to metabolizable energy and passed to the blood in the form of monosaccharides (mainly glucose, fructose), fatty acids and amino acids. These components vary in their ATP forming capacity in intermediary metabolism and in fat synthesis. The amount of ME required for the production of a mole of ATP from 1 mol of ADP was found (Armstrong,1969) to be 17.8 kcal of ME from starch, mono- and dissacchrides; 18.5 kcal from fat (fatty acids)

and 22 kcal from protein (amino acids). Nehring (1967) has also characterized a difference in efficiency of these energy sources based on a carbohydrate standard (100 %). ATP forming capacity of casein (protein source) was 78% and stearic acid (fat source) was 95% relative to glucose (carbohydrate source). Similar reports were found when, ME from protein produced 20% less ATP than ME from starch (Schiemann et al., 1971; VanEs et al., 1967). This difference was suggested to be due to a higher heat production from protein. It is important to emphasize that before oxidation of the carbon skeleton of protein, the amino acid must be deaminated and converted to urea. This process requires ATP and also should be considered a factor for the lower net ATP produced from protein (VanEs, 1977). The most widely used swine diets have carbohydrates as the energy source so that variation of results due to energy substrates is generally not expected.

Environmental Temperature. As a homeothermic organism, environmental temperature will affect the energy available for retention in the pig. A lower and upper critical temperature provides a zone of thermal neutrality at which the pig's heat loss is minimal and consequently energy retention is maximal (Close and Mount, 1978a). The theory of a fixed zone of thermoneutrality (Mount, 1974), has been modified by VanEs (1977) which he stated is dependent on production and activity level. Pigs have also

been found to modify their effective environmental temperature on heat production by behavior such as huddling when penned together (Mount and Holmes, 1967).

The point that heat production was reported to be dependent on environmental temperature (Brody, 1945) has lead to further research on the specific effects of temperature. Unless feed intake was increased when environmental temperature was below thermoneutrality, growth rate decreased as a result of increased heat loss, leading to a reduction in metabolizable energy available for growth (LeDividich and Noblet, 1982). In a hot environment (40 C), feed intake has been markedly reduced (Heitman and Hughes, 1949). Feed consumption has not been found to be affected within a thermoneutral temperature of 22 to 30 C for growing-finishing age pigs (Morrison and Mount, 1979). Moderate increases in temperature above that range have depressed feed intake (Ingram, 1968). For pigs 3 to 9 wk of age the zone of thermoneutrality was reported to be from 22 to 28 C, and for each 1 C decline in temperature growth rate decreased 12.2 g (LeDividich and Noblet, 1982). Close (1978) found 22.5 C to support mean efficiency of protein and fat deposition for growing-finishing pigs over a temperature range of 10 to 30 C. For similar age pigs 25 C has supported the most rapid growth and greatest feed efficiency (Fuller, 1965). At 25 C efficiency of energy retention was .67. When temperature decreased to 10 C efficiency was increased 18% to .79 but when temperature

increased to 30 C, efficiency only decreased 3% to .65. (Close, 1978). To maintain similar energy retention below the zone of thermoneutrality (20 to 25 C) .65 g diet/kg of bodyweight were needed for each 1 C difference (Close and Mount, 1978b). This decrease of 1 C in temperature without additional intake decreased growth 17.8 g/d in 20 to 90 kg pigs (Fuller and Boyne, 1971). Pigs raised at temperatures below the zone of thermoneutrality have had a greater reduction in fat accretion than protein (Close et al., 1978). Nitrogen retention is also reported to be lower at 10 C than at 22 C (Berschauer et al., 1983).

Therefore, even though the zone of thermoneutrality has generally been found to range from 20 to 25 C for growing-finishing age pigs (Fuller, 1965; Close and Mount, 1978b), efficiency of energy deposition was only decreased 3% at 30 C and feed intake was not decreased until temperatures exceeded 30 C.

Metabolic Body Weight. Basal metabolism also affects the availability of energy for retention in tissue. Basal metabolic energy is required to sustain life and differs in animals relative to body weight. It has long been recognized that fasting heat production is proportional to body weight which is used to express data (Brody 1945). However, the exponent of body weight dictating the relationship has been found to vary when considering inter- to intraspecies comparisons. Rubner (cited by Klieber,

1961) in the 1800's first noted that fasting metabolism or basal metabolism was not a linear function of body weight either within or between species, but rather, varied as an approximate function of surface area, body weight$^{2/3}$. Brody (1945) and Klieber (1975) have reported that body weight (BW) to the .73 and .75 power, respectively, accurately estimated metabolic body weight. Both authors noted the best empirical fits to data within species were obtained with exponents other than .75. This also has been noted by Thonney et al. (1976). Heusner (1982a, 1982b) described the use of BW$^{\cdot 75}$ as an artifact that has been used to fit data to a straight line through use of averages. A data set of seven species that included data used by Kleiber (1932, 1961) were analyzed by Thonney et al. (1976). When considered as a single population, a BW exponent of .752 to .766 for basal metabolism supported a 99.9% confidence interval. However, when species and sex were entered as a source of variation no common exponent could adequately represent all populations. In fact, exponents for sex varied within species and were higher in male than female chickens and humans. This difference was suggested to be due to more adipose tissue in females that has been found to decrease total heat production (Keys et al., 1973). The attempt to remove the effect of BW by dividing by BW$^{\cdot 75}$ may add a bias. At lighter weights, heat production was found to be underpredicted and was overpredicted at heavier weights (Thonney et al., 1976). To correct for that bias,

BW was suggested to be considered as a covariable. If a curvilinear relationship was expected between response variables and BW, BW^2 or log BW may be added to the model as the covariable (Thonney et al., 1976).

Studies with pigs also suggest that the .75 exponent of BW is questionable. In a review of metabolic body size for growing pigs, Brown and Mount (1982) found a wide range in reported exponent values. Generally, however, the exponent values used to calculate the metabolic body weight for growing pigs have been less than .75. From previously reported data (Fuller and Boyne, 1971; Close and Mount, 1978), Brown and Mount (1982) developed the following equation for maintenance requirement: maintenance heat production (KJ/d) = 711 $BW^{.64}$. Brown and Mount (1982) have reported that although there is considerable variation between different sets of results, a lower value in the order of .60 may be the most applicable. In a review by Close and Fowler (1982) they reported the exponent .63 to calculate metabolic body weight for growing pigs. The exponent .63 provided the most favorable statistical fit to previously reported data (Fuller and Boyne, 1972; Holmes, 1974; Gadeken et al., 1974). The following equation for 5 to 90 kg pigs was calculated: metabolizable energy of maintenance (KJ/d) = 719 $BW^{.63}$ (Close and Fowler, 1982). This equation is consistent with the derivation reported by Brown and Mount (1982). Therefore, the BW exponent of 2/3, originally suggested by Rubner (Klieber, 1961), may be more

accurate for expressing data on a metabolic body weight basis for growing pigs than the traditional exponent, 3/4.

Methods to Assess Energy Partitioning. Different methods have been employed in the assessment of energy metabolism of the whole animal. Techniques have ranged from calorimetry in chambers through indirect and direct methods to comparative slaughter for the determination of net energy for maintenance and growth. Other nonchamber methods have been used for individual animal calorimetric measurements through use of a hood and mask (Brockway, 1978). Heart rate also has been used as an index of oxygen consumption and energy expenditure to determine energy metabolism of animals; but prior calibration of the individual animal's relationship between heart rate and oxygen consumption has been required (Brockway and McEwan, 1969). All of these methods are useful in their application and are based on certain assumptions. In the following discussion the chamber calorimetry and the comparative slaughter methods will be dicussed. The prediction of energy partitioned to maintenance, protein and fat using multiple and linear regression of metabolizable energy (ME) intake on retained energy will also be presented.

Indirect calorimetry (Verstegen et al., 1973) and direct calorimetry (Pullar and Webster, 1977) have been used to estimate maintenance requirement. Indirect calorimetry is based on the relationship between the amount of heat

produced from oxidation of feed or body constituents and the amounts of oxygen consumed and carbon dioxide produced in an open or closed circuit (Blaxter, 1971). Direct calorimetry measures heat of combustion of feed ingested and excreta produced in either an adiabatic or conduction chamber (Blaxter, 1971). Indirect respiration calorimetry has been widely used in animal energetics (Garrett and Johnson, 1983). Past use of those techniques (Thorbek and Aersoe, 1958), the major innovations over the past 25 yr in automation and more accurate methodolgy have been described by Garrett and Johnson (1983). Energy retention has been determined in chambers utilizing balance studies and the collection of urine and feces. Total energy retention may be calculated and separated into energy retained as protein and fat through nitrogen collection. A standard value of 6.25 has been used to convert nitrogen to protein and then a standard energy value of 5.69 kcal/g (Brouwer, 1965) is used to calculate total protein energy retained (Holmes et al., 1982). The final calculation to determine energy retained as fat, is the difference between total energy retained and protein energy retention. This method provides the advantage of numerous measurements on the same animal and the short trial duration of only 7 to 10 d (Garrett and Johnson, 1983).

The comparative slaughter method in energetics studies is based on varying levels of a diet fed to animals and then determining energy retention as the difference between final

and initial slaughter animal body energy (Kielanowski, 1966). Regression of energy retention on ME intake then is used to calculate efficiency of energy retention and maintenance (ME intake at zero retained energy, Blaxter and Wainman, 1966). This method provides the advantage that animals can be fed more feed than the amount of feed that can be fed in indirect calorimetry methods and the rates of performance are more nearly representative of normal performance in the livestock industry. The comparative slaughter method has the disadvantage of long trial periods to accurately determine body energy storage in the final slaughter group compared to the initial group of animals (Garrett and Johnson, 1983). Large whole body grinders are required and sacrifice of the animals prevents additional measurements on the same animal. There also is the increased expense of lost carcass value with whole body composition studies.

Armsby (1917) and, Kellner and Kohler (1900; cited by Blaxter, 1966) provided much of the first work on animal energetics. Both, investigated the efficiency of energy utilization in relation to feed intake and energy retention. Armsby and Kellner indicated a higher efficiency of net energy below maintenance than above. More recent studies with cattle have indicated a similar relationship (table 2).

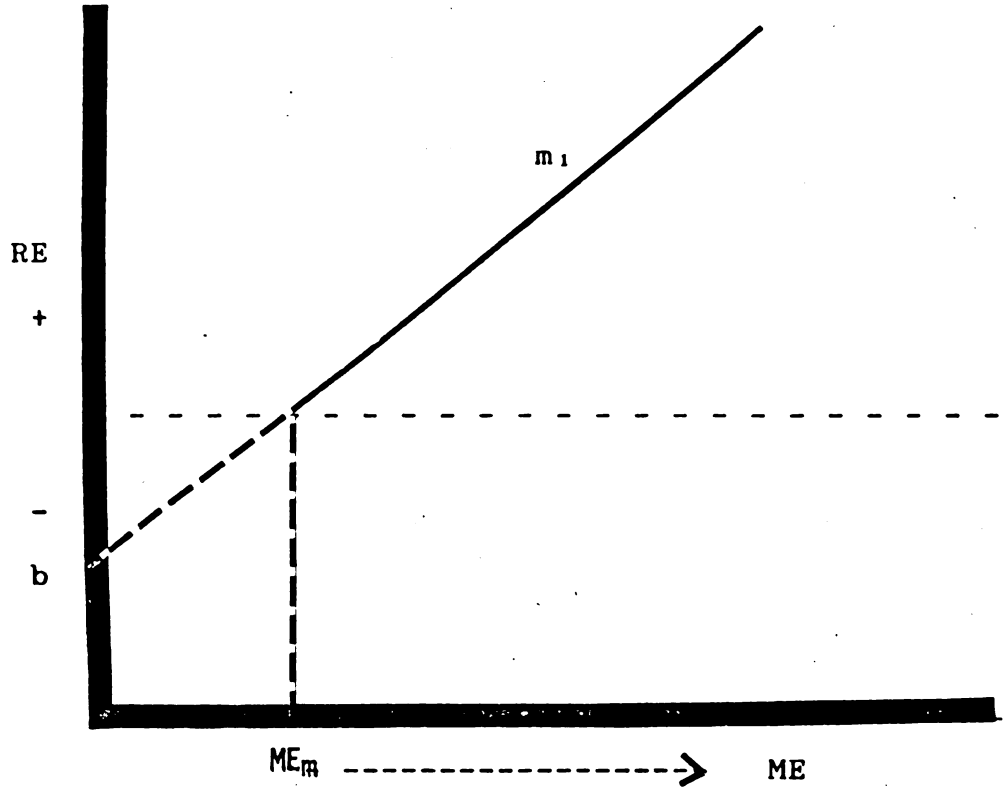
Table 2. EFFICIENCY OF ME UTILIZATION (%) AS DETERMINED BY CALORIMETRIC (ARC, 1980) AND COMPARATIVE SLAUGHTER TECHNIQUES (GARRETT, 1980)

	ME concentration of diets, kcal/g				
Item	2.0	2.25	2.5	2.75	3.0
Maintenance					
Calorimetric	66	68	70	72	74
Comparative slaughter	57	62	64	66	68
Growth and fattening					
Calorimetric	36	40	45	49	54
Comparative slaughter	30	36	40	43	46

(Modified from Garrett and Johnson, 1983).

However, Forbes and Swift (1946) extrapolated a level of fasting heat production directly from measurements made for feed intakes above maintenance on energy retention. This method was later adopted by Blaxter and Wainman (1961). The regression of ME intake on energy retention was demonstrated (Blaxter and Wainman, 1966) as a simple linear regression ($y = bx + c$). The assumption was made that efficiency of energy retention does not differ when compared above or below maintenance. The use of different levels of ME intakes to vary retained energy and then to use retained energy to predict ME of maintenance is not a direct linear relationship but an inverse relationship. The original linear regression must be converted to the inverse linear regression because the calculated ME of maintenance from retained energy reverses the dependent and independent variables (Gill, 1978). The retained energy becomes the dependent variable and ME intake the independent variable. At zero retained energy the inverse linear regression is used to calculate ME by dividing the negative of the intercept by the slope ($x = -b/c$). This method also provides a prediction of fasting heat production as the positive intercept (figure 3).

Another method used to calculate maintenance energy requirements was the multiple regression equation that also estimates energy partitioned to protein and fat. Kielanowski (1966) first proposed the factorial comparative slaughter method with the theory that intake of metabolizable energy



ME_m = Maintenance energy requirement

m_1 = Efficiency of ME used for gain

b = Extrapolated fasting heat production

Figure 3. Calculation of maintenance energy, fasting heat production and efficiency of ME used for gain from the regression of metabolizable energy intake on retained energy (Modified from D.E. Johnson, 1981)

was partitioned over the sum of three factors: maintenance, total cost of protein accretion and total cost of fat accretion. This method has been used more recently by Old and Garrett (1985) in cattle and in swine by Holmes et al. (1982). In the multiple regression method, metabolizable energy (ME) has been considered the dependent variable and protein and lipid accretion the independent variables (Fowler et al., 1980). The regression equation is: $ME = ME_m + k_p P + k_f F$, where ME is measured as kcal/day. ME_m is the energy required for maintenance (kcal/day), P is the energy retained as protein (kcal/day) and F is the energy retained as fat (kcal/day). The values of k_p and k_f are the amount of ME required for protein and fat deposition (kcal/kcal deposited), respectively; while $1/k_p$ and $1/k_f$ are the efficiencies of protein and fat deposited, respectively.

Fowler et al. (1980) recognized that the factorial approach provides the opportunity of calculating maintenance requirement and deposition of protein and fat at any level of performance specified by the factors. Limitations of the factorial method also were listed: 1) factorial method assumes constant efficiencies of tissue accretion 2) estimates were made using constants in which independent variables are in themselves correlated and 3) the relative meaning of maintenance estimate was questioned. Kotarbinska and Kielanowski (1967) also recognize that comparative slaughter allows for a degree of inaccuracy due to variability of composition in the initial slaughter pigs

relative to what final slaughter pigs were at the start of the experiment. Another limitation is the calculation of ME of maintenance from the multiple regression equation with ME intake as the dependent variable and retained energy as the independent variable. As described earlier for linear regression, to calculate ME of maintenance, ME intake should be considered the independent variable and retained energy of protein and fat as the dependent variable. The result is that the maintenance requirement calculated by the multiple regression method is generally found to be higher than calculated by the inverse linear regression method (Fowler, 1980). No methods are available to calculate inverse multiple regression (Personal communication, Gill, 1985).

The level of dietary intake can also provide an inaccurate measure of protein and fat deposition if energy intake is below maintenance requirement. Close and Mount (1978) indicated that at energy equilibrium, in fact, there was substantial lipid mobilization and 4 to 7 g/d of nitrogen were accumulated in 35 kg pigs. Fuller et al. (1976) found similar results and suggested that this level of nitrogen retention represented a quarter to one third of potential nitrogen retention. Therefore, the concept of maintenance relating to an animal in energy equilibrium neither losing or gaining energy is merely hypothetical (Close and Fowler, 1982).

Energy of Protein and Fat Accretion. Following the ME used for the heat of activity, digestion and basal metabolism, the remaining available ME is measured as energy in protein and fat. Pullar and Webster (1977) have described the energy cost of protein and fat deposition as the increment of dietary energy required to promote a defined increment in body protein and fat. The phrase "defined increment of body protein and fat" from this definition merits further discussion. Energetic efficiency of converting kcal of ME to kcal of energy in protein or fat favors a more efficient conversion to fat (Pullar and Webster, 1977). However, when the amount of energy required to deposit a gram of protein and fat are considered, less energy was required for protein deposition in most cases shown in table I. The greater energy required for a gram of fat deposition, may be due to a greater energy density in fat than protein.

Energy content or heat of combustion (gross energy) of protein and fat are reported by Garrett et al. (1959) to be 5.57 and 9.354 kcal/g, respectively. Brouwer (1965) found higher energy levels of 5.69 kcal/g of protein and 9.39 kcal/g for fat. Later, Orskov and McDonald (1970) demonstrated lower values than Garrett et al. (1959) at 5.347 kcal/g for protein and 9.18 kcal/g for fat. However, the average energy content of protein and fat from these three reports are similar to the original values of 5.535

and 9.315 kcal/g, respectively, reported by Garrett et al. (1959).

The synthesis of protein is found predominantly in skeletal muscle and represents 35% of total protein synthesis. Viscera and digestive tract represents 26% and skin accounts for only 12% of total protein synthesis (Edmunds et al., 1980). The relative deposition in skeletal muscle is even greater as it accounts for 72% (Edmunds et al., 1980) of total protein and this protein accretion is associated with water at a ratio of .33 to .25 (VanEs, 1977). Therefore, on a wet fat-free basis, muscle tissue contains 1.38 to 1.11 kcal/g, calculated from the average protein energy content of muscle (Garrett et al., 1959; Brouwer, 1965; Orskov and McDonald, 1970).

Net accumulation or accretion of protein in muscle is the difference between synthesis and degradation (Garlick, 1980). In young fast growing pigs, synthesis is greater than degradation. With increasing age however, the balance between synthesis and degradation decreases to an adult level after which zero net protein accumulation occurs (Waterlow et al., 1978). Theoretical calculation for efficiency of protein deposition from ME ranged from .90 (Schiemann et al., 1961) to .93 (Blaxter, 1962). These efficiencies vary considerably from .56, calculated from studies measuring efficiencies of protein deposition in pigs (review: Close and Fowler, 1982; ARC, 1981). Other reported values are listed in table 3. Blaxter (1971) suggested that

the differences between theoretical and actual efficiencies of protein accretion were due to protein turnover. The first theoretical stoichiometric calculations of energetic efficiency of protein deposition ignore the turnover of body protein (Blaxter, 1971). Reed et al. (1980) suggested that protein turnover cannot account for all of the difference between theoretical and actual efficiencies. Others (Kielanowski, 1976; Pullar and Webster, 1977; Close, 1978; Fowler et al., 1980) have proposed that the variation in $1/k_p$ may be due to technique, variation in body weight, different methods of calculation and inappropriate coefficient of metabolic body weight.

Accretion of fat is also dependent on synthesis and mobilization with increased accumulation of fat occurring when excess energy is available and mobilization of fat occurring during starvation (Anderson, 1972; Leat and Cox, 1980). Differing from protein, theoretical values for efficiency of fat deposition from ME are similar to reported values. Scheimann et al. (1961) reported that pigs utilize energy from dietary fat, carbohydrate and protein for fat synthesis with efficiences of .86, .76 and .66, respectively. Based on these efficiencies a cereal based diet would be expected to have an efficiency of .75 for fat accretion (ARC, 1981). In support of this ratio, Close and Fowler (1982) found the efficiency of .74 for fat deposition.

Table 3. ESTIMATES OF ENERGETIC EFFICIENCY OF PROTEIN (k_p) AND FAT (k_f) ACCRETION IN PIGS

Body Wt, kg	k_p	k_f	Source
2 to 7	.76	.78	Campell and Dukin, 1983
2 to 9	.76	.81	Kielanowski, 1965
5 to 25	.76	.78	Burlacu et al., 1973
9 to 58	.66	1.00	Burlacu et al., 1976
20 to 50	.71	.71	Close, 1978
20 to 40	.58	.70	Close et al., 1973
20	.52	.73	Fowler et al., 1973
24 to 45	.47	.69	Close and Mount, 1971
40 to 75	.57	.91	Berschauer et al., 1980
25 to 110	.52	.70	Oslage et al., 1970
30 to 110	.52	.70	Gadeken et al., 1974
20 to 90	.48	.77	Thorbek, 1975
20 to 90	.43	.77	Thorbek, 1970
20 to 90	.35	.73	Kotarbinska, 1969
75 to 110	.60	.82	Berschauer et al., 1980

Another method to express efficiency is the amount of ME required for retention as protein and fat. The kcal of ME required for protein accretion (kcal of ME/kcal of protein deposited),was found to be 2.25 kcal/kcal of protein in rats (Pullar and Webster, 1977). Kielanowski (1976) after a comprehensive review of past estimates suggested a value of 2.32 kcal ME/kcal protein deposition in pigs. The requirement for fat was reported to be 1.36 kcal ME/kcal fat deposited in rats (Pullar and Webster, 1977). This value agrees with the 1.4 kcal ME/kcal of fat deposited in growing pigs that had been fed a carbohydrate dietary energy source (Agricultural Research Council Committee: ARC/MRC, 1974).

The dietary ME required per gram of protein and fat accretion has been found to be greater for fat than protein. For 14.5 kg pigs Burlacu et al. (1973) found 7.43 kcal ME/g of protein deposition and 11.66 kcal ME/g of fat. In 23 to 33 kg pigs 12.09 kcal ME/g of protein and 13.69 kcal ME/g of fat deposited have been reported (Close and Mount, 1970). Edmunds et al. (1980) demonstrated a greater energy requirement for protein deposition in 25 kg gilts of 13.33 kcal ME/g protein than Burlacu et al. (1973) found for 14.5 kg pigs. For 90 kg pigs Close and Fowler (1982) estimated the energy required for protein deposition to be 10.49 kcal ME/g and 12.78 kcal ME/g of fat. Kotarbinska and Kielanowski (1967) reported similar values of 11.03 kcal ME/g of protein and 13.45 kcal ME/g of fat deposited in 90 kg pigs. In the same study (Kortarbinska and Kielanowski,

1967), 8.5 kg pigs only required 7.51 kcal ME /g of protein deposited and 11.65 kcal ME/g of fat. There appears to be a higher cost of protein and fat deposition in heavier weight pigs.

Energy Partitioning of Boars and Barrows. Comparisons of energy partitioning between boars and barrows are limited in the literature. Only one study has shown a direct comparison of partitioning of energy in boars and barrows (Holmes et al., 1982). Daily maintenance energy requirements of boars were 95 kcal/kg $BW^{\cdot 75}$ at 60 kg liveweight, i.e. at prepubertal age, and 60 kg barrows required 116 kcal/kg $BW^{\cdot 75}$ (Holmes et al., 1982). Efficiency of fat and protein deposition also tended to be greater in barrows (.76 and .48 kcal/kcal, respectively) than boars (.68 and .38 kcal/kcal, respectively; Holmes et al., 1982). Other comparisons that may be made are from two different citations and are on 60 kg boars and barrows, i.e., at a prepubertal age only. Two studies (Ludwigsen, 1980; Fuller et al., 1980) that allow comparison of nitrogen retention and heat production indicated that boars retained 4 to 31% more nitrogen/day and produced 6 to 11% more heat/day than barrows at 60 kg. Using indirect calorimetry (Close et al., 1983) reported that boars had a maintenance requirement of 118 to 136 kcal/kg $BW^{\cdot 75}$. Also studied by indirect calorimetry, similar weight barrows (Verstegen et al., 1973), were found to have a lower maintenance

requirement of 100 kcal/kg $BW^{\cdot 75}$. In a similar study barrows had maintenance requirements of 105 kcal/kg $BW^{\cdot 75}$ (Close et al., 1978). Two reports from Poland also have indicated that boars may have a higher maintenance requirement than barrows when the comparative slaughter method was used. Walach-Janiak et al. (1980) estimated that the requirement for 60 kg boars at 111 kcal/kg $BW^{\cdot 75}$, and Kortarbinska (1969) reported a maintenance requirement of 100 kcal/kg $BW^{\cdot 75}$ for similar weight barrows. Fuller (1980) also found maintenance requirement of 100 kcal/kg $BW^{\cdot 75}$ for barrows, using the comparative slaughter method. The greater maintenance requirements in boars than barrows from these comparisons may be questioned because statistical differences cannot be calculated. However, it is also necessary to emphasize that no report has provided data on postpubertal boars when maximum serum testosterone concentrations are present.

CHAPTER I

THE EFFECT OF AGE OF CASTRATION ON PERFORMANCE AND CARCASS COMPOSITION

Introduction

Castration of boars reduces the secretion and amounts of circulating androgens with subsequent alterations in behavior and growth (Allrich et al., 1982; Bonneau et al., 1982). Therefore, comparative studies on efficiency of gain and composition of intact versus castrated boars indicate the importance of steriod hormones on overall tissue growth (Wood and Esner, 1982; Wood and Riley, 1982; Knudson et al., 1985a,b). Subcutaneous implants delivering pubertal testosterone concentrations during prepubertal and postpubertal weight ranges have decreased total carcass fat and increased carcass muscle and bone weight of barrows (Mulvaney, 1984).

Androstenedione and testosterone are considered the predominant testicular androgens (Booth, 1975). Androstenendione has been found to be present in higher concentrations than testosterone early in life of cattle (Skinner et al., 1968; Bedair and Thibier, 1979) and swine (Martin et al., 1984). With advancing age however, the ratio of androstenedione to testosterone decreases and at puberty testosterone is the predominant androgen (Linder, 1969; Skinner et al., 1968; Bedair and Thibier, 1979; Martin et al., 1984). The effect of endogenous perinatal androgens on these carcass components has not been determined.

Early work with implanted or injected testosterone propionate (Woehling et al., 1951; Sleeth et al., 1953) did not result in altered carcass composition of barrows. This may have resulted from administration of too low a level of testosterone propinate. In rats the effects of testosterone on bone growth and composition have been demonstrated to be dose dependent (Kochakian and Endahl, 1959; Jansson et al., 1983).

Testosterone administered to castrated male guinea pigs increased RNA concentration and muscle weight (Kochakian et al., 1964). The depressed growth and muscle development after castrating male rats was restored to normal with testosterone administration (Kochakian, 1966). Gonadally intact male rabbits increased gain and efficiency of gain through testosterone administration (Grigsby et al., 1976). There also was an increase in semitendinosus muscle RNA, DNA

and myofibrillar protein content attributable to exogenous testosterone (Grigsby et al., 1976). Powell et al. (1980) injected barrows subcutaneously with a liquified mixture of testosterone and hydrogenated soybean oil that solidified at body temperature. Testosterone injected pigs had reduced feed intake, lower feed/gain and less average backfat thickness. Mulvaney (1984) demonstrated a decrease in carcass fat and an increase in carcass muscle and bone in barrows when testosterone was implanted to produce a serum concentration of 4 ng/ml. Oral administration of methyltestosterone has also been found to increase the weight of bone and lean, and decrease carcass fat of barrows (Beeson et al., 1956; Elliott and Fowler, 1974; Fowler et al., 1978).

Endogenous serum testosterone concentrations in boars varies with development (Colenbrander et al., 1978). Three phases of high serum testosterone concentration have been described: fetal, perinatal and the pubertal period. During each phase elevated testicular hydroxysteriod dehydrogenase activity has also been found (Moon and Raeside, 1972; Wrobel et al., 1973; Van Straaten and Wensing, 1978) as well as high testicular testosterone concentration (Booth, 1975). Of the three phases, circulating testosterone concentration was lowest during the fetal period (Colanbrander et al., 1978). Perinatal testosterone levels were found to be highest (1.3 ng/ml) at 2 to 3 wk after birth in one report (Colenbrander et al., 1978). In another study Martin et

al., (1984) found that peak concentrations of 1.6 to 1.8 ng/ml were not demonstrated until 5 to 7 wk of age. Thereafter, in both studies testosterone decreased to .47 to .57 ng/ml until 17 to 18 wk of age when the pubertal increase in testosterone occurred and persisted until the end of the study at 27 wk.

Thus, this study was designed to assess the effect of perinatal androgens on performance, gain and composition at 105 kg in intact and castrated male pigs.

Methods

Three littermate boars were selected at parturition from nine different litters resulting in a total of 27 boars (from Duroc or Hampshire sires and crossbred Yorkshire-Landrace dams). Within 6 h after birth boars were randomly allotted by litter to the following treatment groups: 1) intact boars, 2) boars castrated within 6 h of birth or 3) boars castrated at 6 wk of age. The pigs were left with their respective dams until weaned at 4 wk of age. From that age until 27 kg average pig weight per pen, all pigs were penned by treatment in a partially slotted floor, enviromentally controlled nursery . Nursery temperatures ranged from 21 to 29 C and floor space was .32 m^2/pig. At 27 kg live weight the pigs were relocated in an enviromentally controlled growing-finishing building on totally slatted floors. Approximately .56 m^2 of floor space

was provided until 57 kg average pig weight and thereafter, .78 m^2 was allowed until slaughter at 105 kg body weight. One of the boars castrated at 6 wk was taken out of the experiment at approximately 45 kg because of injury.

Three different diets were fed during this experiment (table I-1). An 18% crude protein corn-soybean meal diet (fortified to provide 1.12% lysine) with added antibiotic was fed ad libitum to boars and barrows from 4 wk of age until 27 kg live weight. Boars were fed the same diet without the added antibiotic from 27 kg until slaughter. This diet was equivalent to a 20% crude protein diet as recommended by Traverner et al. (1977) and Tyler et al. (1983) for maximum gain and percentage muscle for boars. To provide maximum gain and percentage muscle in barrows from 27 kg until slaughter a 15% crude protein corn-soybean meal diet was fed ad libitum (Williams et al., 1984; Christian et al., 1980). Individual weights were recorded biweekly on pigs from 4 wk until slaughter. At each weighing, feed consumption by pen was recorded. Average daily gain, feed intake and feed/gain data were calculated over 3 periods: 9 to 45 kg, 46 to 70 kg and 71 to 105 kg. These weight ranges represented perinatal, prepubertal and postpubertal periods (Colenbrander et al., 1978; Allrich et al., 1982).

Blood samples (10 ml) were collected from each pig weekly from birth to 6 wk of age; thereafter blood samples were collected every 2 wk. At collection time pigs were

Table I-1. DIETS FED TO BOARS AND BARROWS CASTRATED AT BIRTH OR SIX WEEKS OF AGE

		From 27 to 105 kg	
Ingredients, %	4 wk to 27 kg	Boars	Barrows castrated at Birth and 6wk
Corn (IFN 4-02-935)	68.5	69.0	78.25
Soybean meal - 44 (IFN 5-04-604)	27.4	27.4	18.4
Dicalcium phosphate (IFN 6-01-080)	1.4	1.4	1.25
Calcium carbonate (IFN 6-02-632)	1.0	1.0	1.1
MSU vit. - TMM[a]	.5	.25	.25
Salt (IFN 6-02-632)	.25	.25	.25
Se - vit. E premix[b]	.5	.5	.5
Lysine 78 %	.2	.2	---
Antibiotic[c]	.25	---	---
Calculated analysis			
Crude protein, %	18.0	18.0	15.0
Lysine, %	1.12[d]	1.12[d]	.73
Calcium, %	.76	.76	.73
Phosphorus, %	.66	.66	.60

[a] Supplying the following per kg of diet: Vitamin A, 3300 IU; Vitamin D_3, 660 IU; menadione sodium bisulfite, 2.2 mg; riboflavin, 3.3 mg; niacin, 17.6 mg; d -pantothenic acid, 13.2 mg; choline, 110mg; Vitamin B_{12}, 19.8 Mg; Zn, 75 mg; Fe, 60 mg; Mn, 37 mg; Cu, 10 mg and I, .5 mg.

[b] Supplying 22 IU Vitamin E and .1 mg Se per kg diet.

[c] Containing 4.4% chlortetracyline, 4.4% sulfamethazine and 2.2% penicillin.

[d] Equivalent to percentage lysine in 20% crude protein corn-soybean meal diet.

snared and blood collected by vena cava puncture. Concentration of testosterone in serum was quantified by radioimmunoassay using MSU antitestosterone serum number 74 raised against testosterone-3-oxime-human serum albumin (Appendix A.1). Assay validation was reported by Kiser et al. (1978). This assay has previously been used successfully for testosterone detection in boars (Kattesh et al., 1979; Mulvaney, 1984).

Longissimus muscle biopsy samples were removed from each pig at 45, 70 and 105 kg. Subsamples were excised between the 10th and 14th thoracic vertebrae 5 cm laterally from the dorsal median plane on the left side. Different locations within this span along the back were used for each subsequent subsample. The procedure involved clipping the hair from the sampling area and disinfecting the skin with 70% ethanol. At collection time Lidocaine was used for local block and an incision was made through the skin and backfat with a biopsy gun (Schied et al., 1970). A 10 g subsample of longissimus muscle was removed and the incision sutured. The subsample was placed in a Whirl-pak bag (Nasco, Fort Atkinson, WI) and frozen at -70 C in Dry Ice and alcohol. These samples were then stored in a -30 C freezer until analysis. Muscle fiber diameter was determined after subsamples were ground and powdered (Appendix A.2). The procedure used to determine fiber diameter (Appendix A.3) included 1.0% gluteraldhyde BSS

buffer (Appendix A.4) and .02 m guanidine-HCL buffer (Appendix B.5) as described by Mulvaney (1981).

When pigs weighed 105 kg they were slaughtered at the MSU Meat Laboratory. At slaughter, pigs were electrically stunned, exsanquinated, scalded and the remaining hair scraped from the carcass. Viscera, perirenal fat and head were removed from the carcass and not considered in further analysis. The carcasses were separated into right and left sides and weight recorded for each side.

The left side of each carcass was chilled at 2 C for 24 h and then measured for carcass length, longissimus muscle area (LMA) and 10th rib backfat thickness by standard procedures (National Swine Improvement Federation, 1981). The grid method (Hiller, 1970) was used to determine LMA.

The right side of each carcass was physically separated into skin, bone and soft tissues. Weight of each component was recorded. Soft tissues were ground in a Toledo Model number 5520 meat grinder through a 4-mm plate, mixed and reground through the 4-mm plate. During the course of the second grinding, 10 5- to 6-g subsamples were collected to obtain a 50- to 60-g sample that was placed in a Whirl-pak bag (Nasco, Fort Atkinson, WI), frozen and stored at -30 C until used for proximate analysis. Prior to proximate analysis, soft tissue samples were powdered (Appendix A.2) and then analyzed by standard AOAC (1980) methods of analysis for moisture (drying oven), ether extractable lipid (Goldfisch) and protein (Kjeldahl N x 6.25).

Right side fat weight was calculated from right side soft tissue weight and the adjusted percentage ether extract in right side soft tissue (adjusted to represent total adipose tissue calculated from the percentage ether extract in subcutaneous, intermuscular and intramuscular fat). Allen et al. (1976) reported that in 140- to 180- d old pigs, subcutaneous fat represented 75%, intermuscular fat 15% and intramuscular fat 10% of total carcass fat. The percentages of each depot were multiplied by their respective percentage ether extract (means were calculated per treatment group on 4 pigs) and summed. That summed percentage represented the weighted average ether extract in the three carcass fat depots. To calculate right side fat weight, percentage ether extract in right side soft tissues was divided by the average ether extract in carcass fat (means for treatment groups were calculated) and then multiplied by right side soft tissue weight. Right side fat-free muscle weights equaled right side weight minus right side fat, bone and skin weight. The percentage fat, bone, skin and fat-free muscle was calculated for the right side; these percentages were then multiplied by left side weight to determine fat, bone, skin and fat-free muscle weights of each left side. Right and left side weights of each component were summed to obtain total weight of each carcass component.

After the bones from the left side of the carcass were weighed at slaughter, the scapula, humerus and femur were individually weighed and measured for length. Weight was

also recorded on the fused tibia and fibula, and for the ulna and radius. However, length was measured only on the tibia and radius.

Prior to separation of the right carcass sides the teres minor, triceps brachii, brachialis, pectoralis profundus and semitendinosus muscles were isolated and measured for length while still attached to the carcass. Each muscle was then removed and weighed individually. The right carcass side longissimus muscle was also excised from each carcass at the the cranial edge of the tuber coxa to its cranial termination and then weighed. These muscles were selected because their anatomical location provided accessability. They also represented two higher growth rate muscles (longissimus and semitendinosus), two intermediate growth rate muscles (triceps and pectoralis) and two lower growth rate muscles (teres minor and brachialis) relative to the growth of total muscle (Richmond and Berg, 1982). Data were analyzed by one-way analysis of variance with unequal numbers.

Results and Discussion

Testosterone Concentration Data. The mean serum testosterone concentrations (MSTC) found in boars from 6 h to 19 wk of age are shown in figure I-1. When boars were 6 h old MSTC was .77 ng/ml and by 3 wk of age MSTC had increased to 1.65 ng/ml. Following 3 wk of age MSTC

decreased to a concentration of .59 ng/ml by 6 wk of age and no consistent increase occurred until after 15 wk of age when MSTC was 2.2 ng/ml. At 11 wk MSTC was 2.25 ng/ml, but by 13 wk of age only 1.14 ng/ml were found. The high MSTC recorded at 11 wk may have been due to episodic fluctuations in testosterone concentrations similar to that which Allrich et al. (1982) found in boars prior to puberty.

Maximum perinatal serum testosterone concentration was reported by Colenbrander et al. (1978) at 2 and 3 wk after birth (1.3ng/ml) and declined thereafter (Colenbrander et al., 1978). Martin et al. (1984) observed a higher testosterone concentration (1.6 to 1.8 ng/ml in the 5th and 7th wk after birth) i.e., at a later age than found by Colenbrander et al. (1978). These perinatal testosterone concentrations were found to decrease by 6 wk after birth to .47 ng/ml (Colenbrander et al., 1978) and by 9 wk to .31 to .56 ng/ml (Martin et al., 1984). Similar concentrations of .59 ng/ml were found at 6 wk in this study.

The low testosterone concentrations found by Colenbrander et al. (1978) in 6 wk old boars increased at 18 wk of age to 1.77 ng/ml. The testosterone concentrations observed by Martin et al. (1984) in boars remained at that

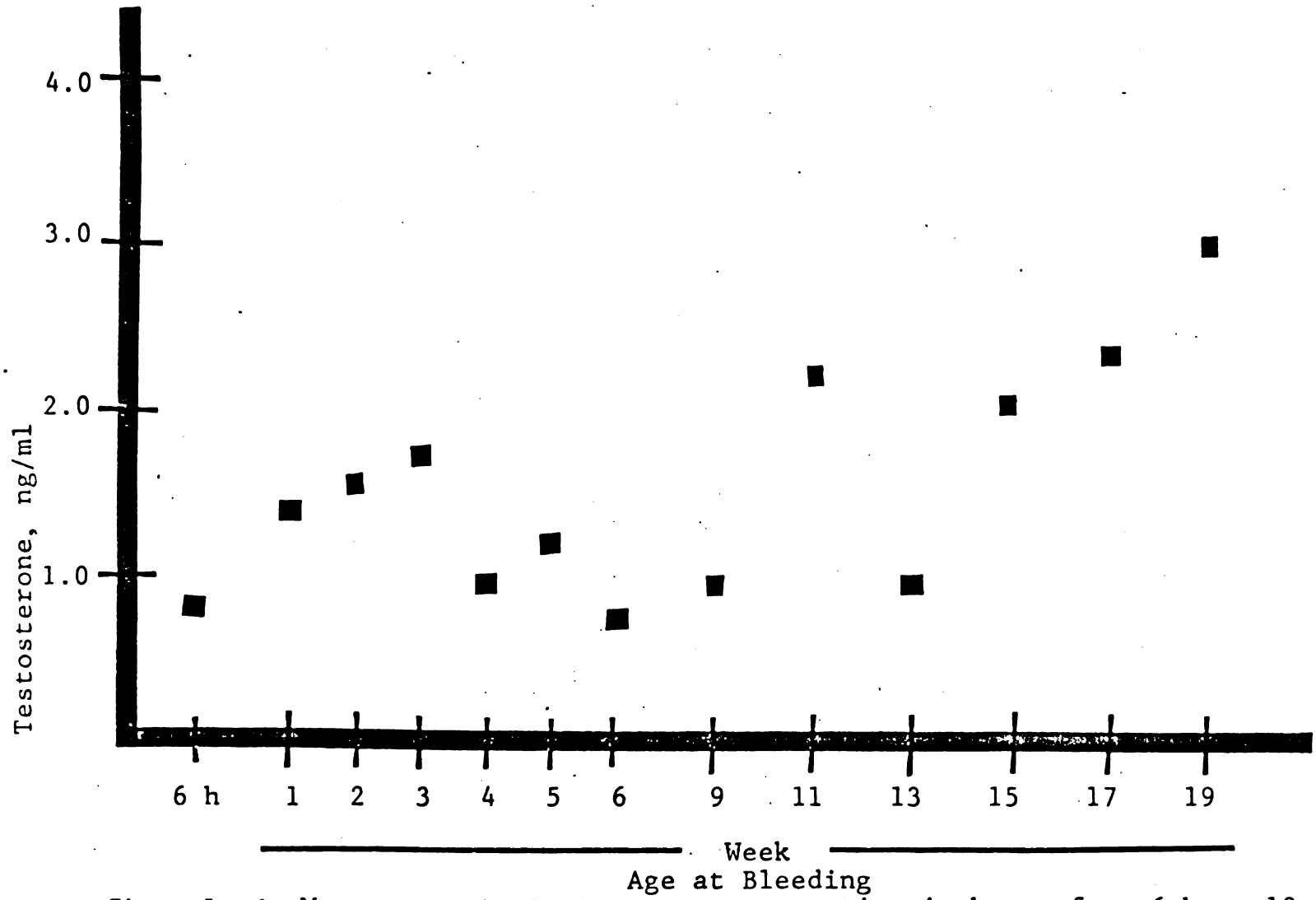


Figure I - 1. Mean serum testosterone concentration in boars from 6 h to 19 wk of age.

low concentration until 17 wk of age when testosterone concentration increased to 3.7 ng/ml by the 27th wk of age. Allrich et al. (1982) found baseline testosterone concentration of 2.28 ng/ml in boar serum at 14.3 wk of age and by 18.5 wk of age the concentration of testosterone had increased to 7.88 ng/ml. The approximate weight of 14.3 wk old boars was 45 kg and at 18.5 wk of age boars weighed 65 kg (Allrich et al., 1982).

The MSTC of 2.2 ng/ml found in 15 wk old boars in this study compares with the 2.28 ng/ml found by Allrich et al. (1982) in 14.3 wk old boars. However, boars weighed 70 kg at 15 wk in this study and only 45 kg at 14.3 wk in the study by Allrich et al. (1982).

The ratio of androstenedione to testosterone of 4.52 in 9 wk old boars demonstates that testosterone is not the only androgen found at a high concentration soon after birth. Androstenedione has been shown to have 22% of the anabolic activity on the rat levator ani muscle compared to testosterone (Liao and Fang, 1969). Even though androstenedione may have a lower anabolic activity than testosterone, the greater perinatal concentration of androstenedione (4.06 ng/ml at 5 wk of age) relative to testosterone (1.60 ng/ml at 5 wk of age; Martin et al., 1984) may provide a total activity of androstenedione that is comparable to testosterone. Therefore, the results found for time of castration and boars versus barrows will be

discussed relative to androgenic effect rather than due to only testosterone.

The boars that were castrated in this study had average serum testosterone concentrations of .43 ng/ml. Bonneau et al. (1982b) found that following castration of 175- d old boars there was a sharp decrease in testosterone to less than .4 ng/ml. This residual testosterone may be a product of adrenal synthesis that has been found in the equine castrated male (Silberzahn et al., 1984).

Gain and Feed Data. Average daily gain, feed intake and feed/gain data (table I-2) were compared for boars and barrows castrated at birth and 6 wk over 3 periods: 9 to 45 kg, 46 to 70 kg and 71 to 105 kg. No difference was found in average daily gain for time of castration or barrows versus boars. There was a trend for boars to have greater gain in the perinatal period than barrows. Numerous reports support the trend of boars growing faster than barrows (Blair and English, 1965; Burgess et al., 1966; Siers, 1975; Campell and King, 1982; Wood and Riley, 1982). However, other reports have shown no difference in growth rate (Kroeske, 1963; Prescott and Lamming, 1964; Hines, 1966; Omtvedt and Jesse, 1968; Hetzer and Miller, 1972; Newell and Bowland, 1972). When growth rate was greater in boars than barrows the difference was not demonstrated until after 50 kg (Blair and English, 1965; Witt and Schroder, 1969; Hansson, 1974).

Table I-2. AVERAGE DAILY GAIN (ADG), AVERAGE DAILY FEED INTAKE (ADFI) AND FEED/GAIN OF BOARS AND BARROWS CASTRATED AT BIRTH OR 6 WEEKS OF AGE[a]

	Group			
		Barrows		
Trait	Boars	Castrated at Birth	Castrated at 6 wk	EMS[b]
ADG, kg				
9 to 45 kg	.59	.55	.55	.01
46 to 70 kg	1.02	.94	.97	.01
71 to 105 kg	.94	1.00	.97	.01
ADFI, kg				
9 to 45 kg	1.2	1.2	1.2	
46 to 70 kg	2.7	2.6	2.8	
71 to 105 kg	2.8	3.2	3.4	
Feed/Gain				
9 to 45 kg	2.1	2.2	2.2	
46 to 70 kg	2.7	2.8	2.9	
71to 105 kg	3.0	3.4	3.3	

[a] None of the traits differed between groups within each weight range.

[b] Error mean square.

These differences were even more pronounced after 70 kg (Witt and Schroder, 1969; Knudson et al., 1985a).

Average daily feed intake and feed/gain ratio of barrows did not differ with time of castration. In the comparison of boars and barrows the largest numerical difference was found in the postpubertal period. During this period boars consumed 13.6% less feed per day and were 9.4% more efficient than barrows. Pay and Davis (1973) compared feed to gain for boars and barrows above and below 55 kg live weight, and reported no difference prior to 55 kg. From 55 to 90 kg however, boars were 11% more efficient. Campbell and King (1982) reported that feed intake of boars relative to barrows was not lower until after 45 kg. Pay and Davis (1973) also found a greater difference in feed intake between boars and barrows after they weighed 55 kg compared to before 55 kg, with boars consuming less than barrows.

Composition Data. Time of castration did not affect carcass measurements of barrows (table I-3). Therefore, boars were compared to the average carcass measurements of barrows castrated at birth and 6 wk. Boars had 23.6% less ($P<.05$) tenth rib backfat than barrows. This percentage is less than the 35% difference found at 88 kg (Mulvaney, 1984) or the 33.2% difference reported for 105 kg

Table I-3. CARCASS MEASUREMENTS AND CARCASS COMPOSITION OF BOARS AND BARROWS CASTRATED AT BIRTH OR 6 WEEKS OF AGE

	Group			
		Barrows		
Trait	Boars	Castrated at Birth	Castrated at 6 wk	EMS[a]
Longissimus area, cm^2	35.5	36.7	36.6	.336
Tenth rib backfat, cm	19.6[b]	26.4[c]	24.9[c]	.263
Length, cm	83.6	82.8	84.6	1.73
FFM[d], kg	39.2[e]	36.3[f]	35.6[f]	6.05
Fat, kg	18.5[e]	25.6[f b]	26.3[f c]	6.25
Bone, kg	8.7[e]	7.5[f]	8.1[f]	.55
Skin, kg	6.8[e]	5.5[f]	5.4[f]	.23

[a] Error mean square.

[b,c] Measurements within rows with different subscripts differ ($P<.05$).

[d] Fat free muscle.

[e,f] Measurements within rows with different subscripts differ ($P<.01$).

Table I-4. PERCENTAGE ETHER EXTRACT OF SUBCUTANEOUS, INTERMUSCULAR AND INTRAMUSCULAR FAT OF BOARS AND BARROWS CASTRATED AT BIRTH OR 6 WEEKS OF AGE[a]

	Group		
		Barrows	
Trait	Boars	Castrated at birth	Castrated at 6 wk
Subcutaneous EE, %	82.1	86.4	86.6
Intermuscular EE, %	79.9	81.1	77.9
Intramuscular EE, %	39.9	41.1	40.8
Average EE in Carcass Fat[b], %	77.5	81.1	80.7

[a] Mean of 4 pigs per group.

[b] Average percentage ether extract in carcass fat =(.75 x % Subcutaneous EE) + (.15 x % Intermuscular EE) + (.10 x % Intramuscular EE).

boars compared to barrows (Knudson et al., 1985b). The 23.6% difference in tenth rib backfat however, agrees with the 24% less backfat found for boars compared to barrows by Prescott and Lamming (1967). Carcass length and longissimus area did not differ between boars and barrows in this study.

Greater fat-free muscle ($P<.01$), bone ($P<.05$) and skin ($P<.01$) weights and less ($P<.01$) total fat weight was observed in boars relative to barrows (table I-3). No differences were found in these carcass components for barrows due to time of castration. Composition data for boars, and barrows castrated at birth and 6 wk of age are shown in figure I-2. The percentage of each component relative to total carcass weight is shown in the bars of figure I-2. Fat-free muscle weight in boars was 9% greater than in barrows. That difference was greater than the 3% difference shown in other studies (Wood and Enser, 1982; Wood and Riley, 1982) but less than the 15% difference reported by Prescott and Lamming (1967) and Mulvaney (1984). The 11% heavier bone weight in boars relative to barrows was similar to the 11% (Knudson et al.,1985b) and 12% (Prescott and Lamming, 1967) differences previously reported for boar versus barrow comparisons. The 25% greater skin weight of boars relative to barrows was greater than the 14% difference found in past work (Knudson et al., 1985b). This difference in skin weight of boars and barrows may have

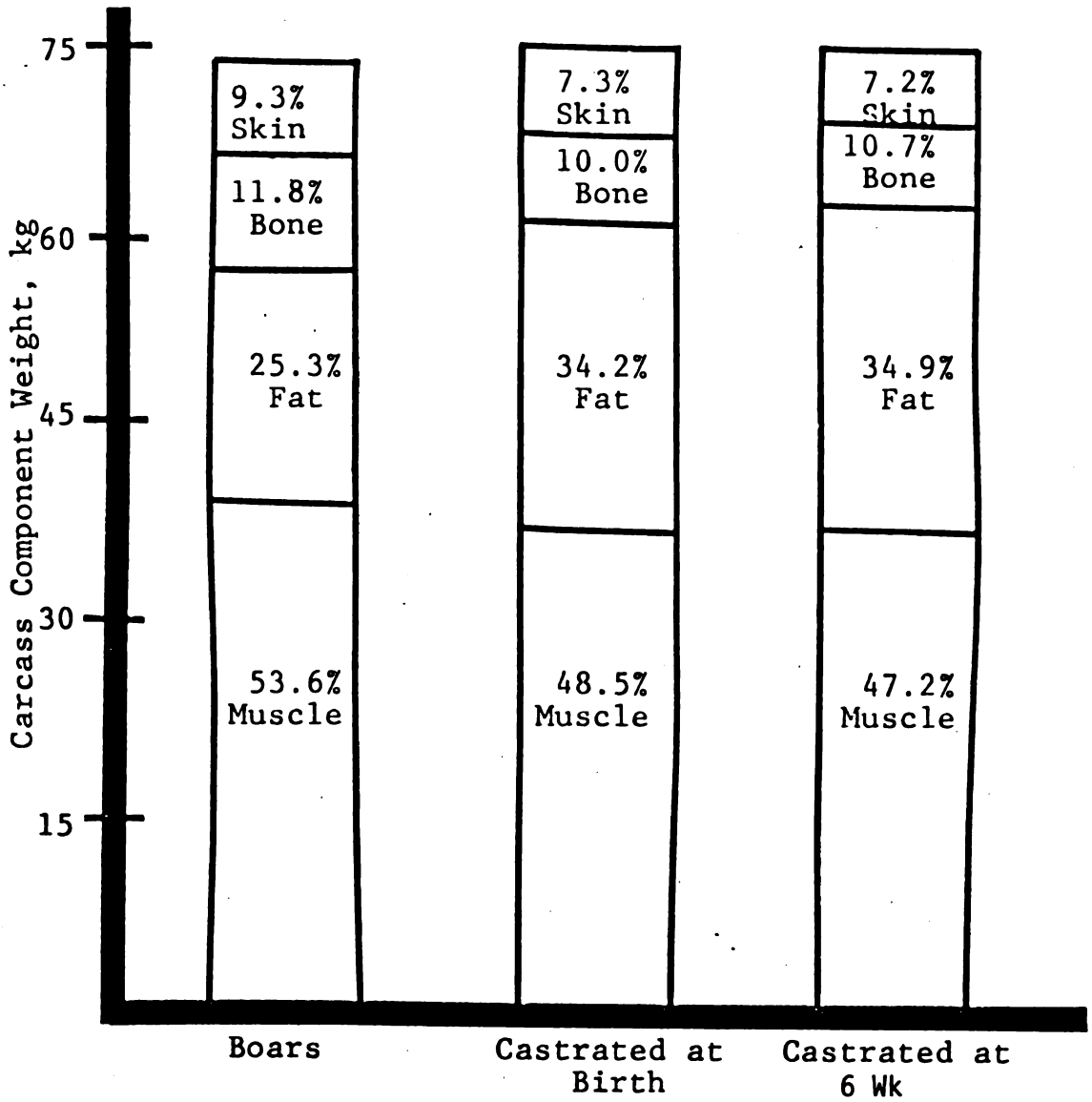


Figure I-2. Distribution by weight of carcass fat-free muscle, fat, bone and skin of boars and barrows castrated at birth or at 6 wk of age. Slaughter weight was 105 kg and the percentages that each carcass component constitutes of total carcass weight is shown in the respective tissue portion of the bars.

been due to a greater skin thickness found in boars compared to barrows by Wood and Riley (1982). In this study the 29% lower total carcass fat in boars relative to barrows was greater than the 23.6% difference found for tenth rib backfat. The 29% lower carcass fat in boars is in close agreement with the 33.2% difference found in an earlier study (Knudson et al., 1985b). However, the 29% difference in carcass fat was greater than the 20% difference reported by Mulvaney (1984) or the 24% difference found by Prescott and Lamming (1967).

Individual Muscle Data. No differences were found in individual muscle lengths due to time of castration (table I-5). Barrows castrated at birth had a 13.3% ($P<.01$) lower teres minor weight than those castrated at 6 wk. None of the other muscles or the composite weight of the selected muscles differed with time of castration. Boars had 11.6% longer ($P<.01$) triceps muscle, 11.8% longer ($P<.02$) semitendinosus muscle, and the combined length of the selected muscles was 7.1% greater ($P<.02$) than barrows. There was a trend for longer brachialis and pectoralis muscles in boars compared to barrows but the differences were not significant. The only difference in weight of selected muscles from boars and barrows was a 20% lower teres minor

Table I-5. INDIVIDUAL AND COMPOSITE WEIGHTS AND LENGTHS OF SELECTED MUSCLES OF BOARS AND BOARS CASTRATED AT BIRTH OR 6 WEEKS OF AGE

	Group			
		Barrows		
Traits	Boars	Castrated at Birth	Castrated at 6 wk	EMS[a]
Teres Minor: wt., g	37.4[b]	29.9[c]	34.5[b]	8.5
Length, cm	12.2	12.4	12.3	1.5
Triceps; wt., g	709.9	658.1	649.7	16413.9
Length, cm	16.3[b]	14.3[c]	14.9[c]	1.5
Brachialis; wt., g	105.7	97.8	98.9	70.4
Length, cm	15.4	14.8	14.4	0.7
Pectoralis: wt., g	90.2	85.9	85.2	46.5
Length, cm	13.1	12.5	12.3	2.8
Semitendinosus:wt., g	413.2	407.2	402.0	2242.2
Length, cm	21.8[d]	19.3[e]	19.7[e]	3.5
Composite[f]: wt., g	1353.6	1278.9	1266.1	25103.0
Length, cm	78.7[d]	73.3[e]	73.7[e]	17.8
Longissimus: wt., g	2069.4	2005.9	2070.2	22219.0

[a] Error mean square.
[b,c] Measurements within rows with different subscripts differ ($P<.01$).
[d,e] Measurements within rows with different subscripts differ ($P<.02$).
[f] Composite included weight and length of teres minor, triceps, brachialis, pectoralis and semitendinosus muscles.

weight in barrows castrated at birth compared to boars. No other muscle weights differed between boars and barrows even though there was a trend for all selected muscles to be heavier in boars than barrows. The composite muscle weight of the selected muscles tended to be 6.4% greater in boars when compared to barrows. The administration of testosterone to rabbits did not increase semitendinosus weights but did increase muscle RNA content (Grigsby et al., 1976). Testosterone administration has been found to selectively stimulate growth of specific skeletal muscles in guinea pigs (Kochakian and Tillotson, 1957). With the exception of the heavier teres minor weights in barrows castrated at 6 wk compared to barrows castrated at birth no other differences were found in any of the other muscle weights, including the brachialis that also was reported to be a slower growing muscle (Richmond and Berg, 1982).

Individual Bone Data. Bone weights did not differ for time of castration (table I-6). The 10.5% greater ($P<.01$) composite bone weight in boars compared to barrows was similar to the 11% greater total carcass bone weight in boars versus barrows. Greater weights of the humerus ($P<.02$), radius ($P<.01$) and femur ($P<.01$) were observed in boars than in barrows in this study. There also was a trend for greater scapula and tibia ($P<.08$) weights in boars.

Table I-6. INDIVIDUAL AND COMPOSITE BONE WEIGHTS AND LENGTHS OF BOARS AND BARROWS CASTRATED AT BIRTH OR 6 WEEKS OF AGE

	Group			
		Barrows		
Trait	Boars	Castrated at Birth	Castrated at 6 wk	EMS[a]
Scapula: wt, g	275.2	244.8	256.0	1177.4
Length, cm	19.7	19.8	20.1	0.5
Humerus: wt, g	337.5[b]	295.7[c]	307.1[c]	878.1
Length, cm	17.4	16.9	17.1	0.7
Radius: wt[d], g	254.2[e]	222.2[f]	238.2[f]	375.5
Length, cm	13.4	13.3	13.0	0.2
Femur: wt, g	374.8[e]	327.9[f]	330.4[f]	1046.5
Length, cm	20.7	20.2	20.3	0.3
Tibia: wt, g	259.2[h]	239.2[i]	243.5[i]	351.7
Length, cm	18.9	18.7	18.0	0.4
Composite[m]: wt, g	1501.0[e]	1340.8[f]	1375.1[f]	12606.1
Length, cm	89.9	88.4	88.5	4.9

[a] Error mean square.
Measurements within rows with different subscripts differ ($P<.02$)[b,c], ($P<.01$)[e,f], ($P<.08$)[h,i], ($P<.03$)[j,k].
[d] Weight of radius and ulna.
[g] Weight of tibia and fibula.
[m] Composite includes length, and weight of scapula, humerus, radius, femur and tibia.

Bone length did not differ between boars and barrows or for barrows castrated at different times. Mulvaney (1984) also reported no difference in length of the scapula, humerus, radius or tibia of boars and barrows, although, femurs in 88 kg boars were 4.8% longer than in castrates. In rats testosterone administration increased longitudinal bone growth in a dose-dependent relationship (Jansson et al., 1983). Even though testosterone may cause these effects at high concentrations, the physiological endogenous testosterone and other androgens in boars did not effect bone length in this study.

Longissimus Fiber Diameter Data. No difference was found in longissimus fiber diameter (LFD) in barrows relative to time of castration (table I-7). Boars also did not differ from barrows in LFD at 45 and 70 kg live weight. At 105 kg boars had 9.7% greater ($P<.03$) LFD than barrows castrated at 6 wk but did not differ from LFD of barrows castrated at birth. There was a trend for barrows to have greater LFD at 70 kg, but this numerical difference was not significant. LFD increased as live weight increased in boars to 105 kg. Barrows had maximum LFD at 70 kg..

Table I-7. LONGISSIMUS FIBER DIAMETER OF BOARS AND BOARS CASTRATED AT BIRTH OR 6 WEEKS OF AGE[a]

	Group			
		Barrows		
Live Weight	Boars	Castrated at Birth	Castrated at 6 wk	EMS[b]
45 kg	68.8	68.6	70.8	27.6
70 kg	73.2	75.2	75.6	31.2
105 kg	75.4[c]	72.8[cd]	68.6[d]	24.8

[a] Fiber diameter, um.

[b] Error mean square.

[c,d] Measurements within rows with different subscripts differ ($P<.03$).

Summary

Perinatal MSTC was highest (1.65 ng/ml) at 3 wk of age and decreased to .59 ng/ml by 6 wk of age in boars. Testosterone concentration did not increase consistently until after 15 wk of age (2.2 ng/ml). A MSTC of 2.25 ng/ml was found at 11 wk but at 13 wk of age that concentration had decreased to 1.14 ng/ml.

Average daily gain did not differ due to perinatal testosterone or for barrows compared to boars. The largest numerical differences in daily feed intake and feed/gain were found between 71 to 105 kg boars and barrows. These differences indicated that boars consumed less feed and were more efficient than barrows. Additional studies are necessary to determine if differences in daily feed intake and feed to gain between boars and barrows weighing 70 to 105 kg are statistically different. No differences were observed between the two barrow groups for intake or feed/gain ratio.

Perinatal testosterone did not alter carcass composition in barrows. Boars had less total carcass fat weight and greater carcass fat-free muscle, bone and skin weight than barrows. As a percentage of total carcass weight barrows had 9.25% more carcass fat than boars. Boars compensated for that difference in percentage of carcass weight with 5.75% more carcass fat-free muscle, 14.5%

greater bone and 20.5% more skin weight than barrows. Carcass length and longissimus area did not differ between boars and barrows, but backfat thickness was 23.6% less in boars than barrows.

The triceps, semitendinosus and combined length of selected muscles of boars were longer than those in barrows. The teres minor weight was greater in boars and barrows castrated at 6 wk relative to the barrows castrated at birth. No other selected muscles or the composite weight of the selected muscles differed between boars and barrows.

Composite bone weight of selected bones and the individual bone weights of the humerus, radius and femur were greater in boars than in barrows. In contrast to the greater composite length of selected muscles and individual selected muscles, none of the individual bone lengths or composite lengths differed between boars and barrows.

At 105 kg boars had greater longissimus fiber diameter (LFD) than barrows castrated at 6 wk. No other differences in LFD were found between boars and barrows.

In conclusion, perinatal testosterone did not alter performance, carcass composition or bone weights or lengths in barrows. The teres minor weight was greater in barrows that had increased perinatal testosterone concentrations.

Chapter II

Weight Gain, Performance and Carcass Composition of Boars, Barrows and Gilts

Introduction

Lower feed consumption and improved feed efficiency of boars relative to barrows have been established in many studies (Turton, 1969; Field, 1971; Kay and Houseman, 1975; Fuller, 1980; Seiderman et al., 1982). Feed consumption and conversion differences relative to specific weight ranges have not been as widely studied as overall performance to market weight (105 kg). Blair and English (1965) reported that efficiency of gain differed by 14.2% after 55 kg and Pay and Davis (1973) found that boars were 11% more efficient than barrows in conversion of feed to gain after 55 kg. Campbell and King (1982) also found no difference in gain prior to 45 kg but thereafter boars had an 8% greater growth rate than barrows. These reports indicate that differences between boars and barrows found at market weight may be the result of differences in performance after the onset of puberty.

In a previous study (Chapter I) the largest differences in average daily feed intake and feed/gain between boars and barrows were observed from 70 to 105 kg of body weight. That weight range also represents the postpubertal period of boars (period when serum testosterone concentration was greater than 2.0 ng/ml). No statistical analyses were performed on feed consumption and feed conversion data of boars and barrows in that study (Chapter I) because pens were not replicated.

The present study was designed to compare performance and carcass composition of boars, barrows and gilts fed dietary protein concentrations for optimum performance. Gain, feed intake and feed conversion were compared between boars, barrows and gilts over the three weight ranges described in Chapter I. Final carcass measurements of boars, barrows and gilts also were compared.

Methods

A littermate gilt and two boars were selected from sixteen litters at 3 wk of age resulting in a total of 48 pigs (from Duroc or Hampshire sires and crossbred Yorkshire-Landrace dams). At selection time one boar from each litter was castrated. When the pigs were 5 wk old, four pigs of the same sex (gilts, boars or barrows) were grouped per pen resulting in four pens per sex group. The trial was conducted in a naturally ventilated building with solid

concrete floors and 1.68 m^2 of floor space per pig. Individual pig weights and pen feed consumption were recorded at 2 wk intervals. The feeding trial was terminated when average pig weight per pen was 105 kg.

At the completion of the feeding trial two pigs from each pen that had body weight closest to the pen average were slaughtered and carcass measurements recorded. All carcasses were measured for backfat thickness and longissimus area (grid method; Hiller, 1970) at the 10th and 11th rib interface. Carcass length was measured from the anterior edge of the first rib to the anterior edge of the pubic symphysis.

Four different corn-soybean meal based diets were fed to pigs in the experiment (table II-1.). From 5 wk to 20 kg a 20% protein equivalent diet (18% crude protein and 1.12% lysine) with antibiotic was fed to all pigs. From 20 kg to 105 kg boars were fed a 20% protein equivalent diet (18% crude protein and 1.12% lysine), gilts were fed a 16% crude protein diet, and a 15% crude protein diet was fed to barrows. These diets were selected to meet or slightly exceed protein requirements for maximum gain and optimum composition of boars (Holmes et al., 1980; Tyler et al., 1983), gilts (Batterhan et al., 1985; Campbell et al., 1985) and barrows (Christian et al., 1980; Campell et al., 1984).

Average daily gain (ADG), average daily feed intake (DFI), total feed intake (TFI) and feed/gain were expressed for each of the three weight groups. The 70 to 105 kg

Table II-1. DIETS FED TO BOARS, BARROWS AND GILTS

Ingredient, %	5 wk to 20 kg	From 21 to 105 kg		
		Boars	Barrows	Gilts
Corn (IFN 4-02-935)	68.5	69.0	72.9	78.25
Soybean meal-44 (IFN 5-04-604)	27.4	27.4	23.5	18.4
Dicalcium phosphate (IFN 6-01-080)	1.4	1.4	1.5	1.25
Calcium carbonate (IFN 6-01-069)	1.0	1.0	1.1	1.1
MSU vit.-trace min. mix[a]	.5	.25	.25	.25
Salt (IFN 6-02-632)	.25	.25	.25	.25
Se-vitamin E premix[b]	.5	.5	.5	.5
Lysine 78%	.2	.2	--	--
Antibiotic[c]	.25	--	--	--
Calculated analysis				
Crude protein, %	18.0	18.0	16.0	15.0
Lysine, %	1.12[d]	1.12[d]	.84	.73
Calcium, %	.76	.76	.76	.75
Phosphorus, %	.66	.66	.64	.60

[a] Supplying the following per kg of diet: Vitamin A, 3,300 IU; Vitamin D_3, 660 IU; menadione sodium bisulfite, 2.2 mg; riboflavin, 3.3 mg; niacin, 17.6 mg; d-pantothetic acid, 13.2 mg; choline, 110 mg; Vitamin B_{12}, 19.8 Mg; Zn, 75 mg; Fe, 60 mg; Mn, 37 mg; Cu, 10 mg and I, .5 mg.

[b] Supplying 22 IU vitamin E and .1 mg Se per kg diet.

[c] Containing 4.4% chlortetracycline, 4.4% sulfamethazine and 2.2% penicillin.

[d] Equivalent to percentage lysine in 20% crude protein corn-soybean meal diet.

weight group corresponded to the postpubertal period of boars at 15 wk or approximately 70 kg (Chapter 1). That period of high serum testosterone concentration also was observed by Colenbrander et al. (1978), Allrich et al. (1982), and Martin et al. (1984). The test period prior to 70 kg was equally divided into a perinatal (11 to 40 kg) and prepubertal period (41 to 70 kg). Gilts were included in this trial to compare to boar and barrow performance.

Statistical analysis of data was by one-way analysis of variance.

Results and Discussion

Gain and Feed Data. ADG did not differ significantly for boars, barrows or gilts (table II-2). Boars did have a trend for a higher rate of gain, gilts tended to have lowest gains and barrows were intermediate over all periods. Other studies have shown that boars grew faster than barrows and gilts grew slower than barrows (Omtvedt and Jesse, 1971; Siers, 1975; Christain et al., 1980). These same relative differences in rate of gain were observed in the present study but they were not significant.

DFI was not different between boars, barrows and gilts in the two lighter weight groups (table II-2). From 70 to 105 kg, however, boars consumed 21% less feed than barrows and gilts differed from barrows in DFI by 14%. Boars feed

Table II-2. AVERAGE DAILY GAIN, AVERAGE DAILY FEED INTAKE, TOTAL FEED INTAKE, FEED/GAIN AND DAYS ON TEST OF BOARS, BARROWS AND GILTS AT THREE WEIGHT RANGES

Trait	Boars	Barrows	Gilts	EMS[a]
ADG,[b] kg				
11 to 40 kg	.56	.54	.49	.01
41 to 70 kg	.90	.90	.87	.01
71 to 105 kg	.96	.93	.86	.01
ADFI,[c] kg				
11 to 40 kg	1.1	1.1	1.0	.02
41 to 70 kg	2.1	2.3	2.2	.08
71 to 105 kg	2.6[b]	3.3[c]	2.8[b]	.07
DOT[d]				
11 to 40 kg	53	55	58	97
41 to 70 kg	33	35	36	17
71 to 105 kg	36	36	38	20
TFI,[e] kg				
11 to 40 kg	55.3	58.5	58.8	24.8
41 to 70 kg	67.6	75.7	73.6	37.4
71 to 105 kg	92.1[b]	120.7[cf]	111.8[cg]	100.7
Feed/Gain				
11 to 40 kg	1.9	2.0	2.0	.03
41 to 70 kg	2.3	2.6	2.5	.11
71 to 105 kg	2.7[b]	3.6[cd]	3.3[ce]	.05

[a] Error mean square.
[b] Average daily gain.
[c] Average daily feed intake.
[d] Days on test.
[e] Total feed intake.
Measurements within rows with different subscripts differ significantly: (P<.01)[b,c], (P<.07)[d,e], (P<.11)[f,g].

intake was numerically lower than gilts but not significantly different. In support of these observations, Blair and English (1965) found no difference in daily feed intake prior to 55 kg for boars, barrows and gilts. From 60 to 90 kg boars and gilts had similar daily feed consumption and both were less than barrows (Blair and English, 1960).

In the first two weight periods TFI per treatment group followed a similar pattern as the DFI data in the first two weight groups (table II-2). No differences were found in TFI from 11 to 40 kg or from 41 to 70 kg for boars, barrows and gilts. In contrast to the two lighter weight groups, from 71 to 105 kg, boars consumed 24% less ($P<.01$) feed than barrows and 21% less than gilts. There also was a trend for lower total feed consumption in gilts compared to barrows ($P<.11$).

Feed to gain results were similar to TFI and DFI in the final period. Efficiency of gain for boars was 23.7% greater than barrows ($P<.01$) and 17.6% more than gilts ($P<.01$) from 71 to 105 kg. There was a trend for a lower feed requirement for gain in gilts relative to barrows but that difference was not significant ($P<.07$). Boars have been reported to have a lower feed requirement for gain than barrows and gilts, while gilts do not differ from barrows (Omtvedt and Jesse, 1968, 1971; Siers, 1975). Blair and English (1965) reported that boars required the least amount of feed for gain, barrows the most and gilts were intermediate.

Days on test (DOT) did not differ between boars, barrows or gilts compared over any of the three weight ranges. Total DOT did tend to be greater for gilts (134 d) relative to boars (122 d) and barrows (126 d). Other reports have shown that gilts required more days on trial to reach the same final weight as boars and barrows (Omtvedt and Jesse, 1968, 1971: Froseth et al., 1973).

The ADFI data indicated that boars and gilts had a lower daily intake than barrows. However, total feed intake consumed from 11 to 105 kg final weight was similar for gilts and barrows and both were greater than boars. The lower daily feed intake in boars and gilts compared to barrows may be a result of indirect or direct action of gonadal hormones. Estrogen has been suggested to be the controlling factor in both sexes (Wade and Gray, 1979). In boars, endogenous estrogen (Claus and Hoffmann, 1980; Hay et al., 1981) may result from the conversion of testosterone or androstenedione to estrogen by aromatase, as has been observed in other species (Flores et al., 1973; Nimrod and Ryan, 1975). Serum estrogen concentrations in boars are reported to coincide with the pubertal increase in testosterone (Allrich et al., 1982). Estrogen was suggested to modulate food intake by altering the availability of oxidizable substrates (Wade and Gray, 1979) because food intake is recognized to be sensitive to changes in circulating metabolic fuels (Friedman and Stricker, 1976). Estradiol raises blood triglycerides in rats by reducing

adipose tissue lipoprotein lipase activity and stimulating hepatic triglyceride synthesis (Hamosh and Hamosh, 1975; Kim and Kalkhoff, 1975; Watkins et al., 1972). Testosterone administration to barrows also has been reported to decrease adipose tissue lipoprotein lipase activity (Mulvaney, 1984). This action was suggested to be due to estrogen action because barrows implanted with dihydrotestosterone (a non-aromatizable androgen) did not decrease lipoprotein lipase activity as did testosterone .

Carcass Data. In agreement with other studies (Zobrisky et al., 1959; Zobrisky et al., 1961; Charette, 1961; Omtvedt and Jesse, 1971; Blair and English, 1965; Hetzer and Miller, 1972; Froseth et al., 1973; Siers, 1975; Ellis, 1980) boars and gilts had a larger longissimus area, less tenth rib backfat, longer carcasses and greater percentage muscle than barrows (table II-3). No differences were found in carcass dressing percentage of boars, barrows or gilts.

Longissimus area was 12% greater in boars and 13% larger in gilts compared to barrows. These differences are lower than the 16% advantage for boars and 18% for gilts compared to barrows, reported by Siers (1975). But, the relationships are similar. The difference in backfat depth was even greater between the treatment groups. Boars had 28% less backfat than barrows, while gilts had 27% less backfat than barrows. These differences are greater than

Table II-3. CARCASS MEASUREMENTS OF BOARS, BARROWS AND GILTS AT 105 KG LIVE WEIGHT

Trait	Boars	Barrows	Gilts	EMS[a]
Longissimus area, cm^2	32.8[b]	29.2[c]	33.2[b]	10.1
10th rib backfat, cm	2.4[d]	3.4[e]	2.5[d]	.45
Length, cm	82.2[d]	79.8[e]	83.6[d]	4.8
Carcass muscle, %[f]	54.7[d]	50.4[e]	54.8[d]	7.7
Carcass dressing, %	72.6	74.7	75.2	6.7

[a] Error mean square.

[b,c] Measurements within rows with different subscripts differ ($P<.04$).

[d,e] Measurements within rows with different subscripts differ ($P<.01$).

[f] Calculated by the National Pork Producers Council (1983) formula.

the 17% and 11% leaner carcasses found for boars and gilts, respectively, compared to barrows reported by Cahill et al. (1960). The differences found for backfat between this study and others may be a reflection of subpopulation differences. Backfat differences of boars relative to barrows from the same research station (Michigan Swine Research Farm) were found to be 31% less in a previous study (Knudson et al., 1985a). The 3% and 5% longer boar and gilt carcasses than barrows, respectively, were similar to data reported in other studies (Cahill et al., 1960; Siers, 1975). Percentage carcass muscle was found to be greater in boars and gilts compared to barrows. These treatment differences in percentage muscle were in agreement with larger longissimus area and less 10th rib backfat found for boars and gilts relative to barrows. Boars had 8.5% and gilts 8.7% more carcass muscle than barrows.

Feed intake and efficiency advantages reported for boars over barrows (Kay and Houseman, 1975; Fuller, 1980; Seiderman et al., 1982) were not found until after 70 kg live weight. These differences correspond to the time of the pubertal increase in testosterone of boars, indicating that testosterone, either directly or indirectly, may be responsible for these differences. Daily feed consumption of gilts was similar to that of boars, but the amount of feed required for live weight gain was greater than boars and similar to that of barrows. The improved feed/gain of boars most likely is the result of testicular androgens not

present in barrows or gilts. Improved feed conversion in boars over barrows has been suggested to be due to a higher percentage carcass muscle in boars compared to barrows (Fuller, 1980). The advantage in feed conversion found for boars compared to gilts and barrows may not be explained entirely by an increase in muscle to fat deposition ratio. Boars and gilts had similar percentages of carcass muscle but boars were more efficient in conversion of feed to gain than gilts.

The improved efficiency of gain in boars over gilts may result from a synergism from the serum testosterone and estrogen concentrations that have been found in boars (Allrich et al., 1982). Rance and Max (1984) have investigated the effects of 17*B*-estradiol and testosterone administration to orchiectomized rats with respect to level of androgen receptors in rat skeletal muscle. Estrogen (17*B*-estradiol) was shown to cause induction of the cystolic androgen receptor in skeletal muscle of rats, alternatively, the rate of receptor degradation may be altered (Rance and Max, 1984). Both testosterone and estrogen also were reported to be required for normal sexual activity in rodents (Larsson et al., 1973) and boars (Parrott and Booth, 1984). Therefore, the action of serum estrogen and testosterone in boars may not only control sexual behavior but they may also act together to improve composition and efficiency of gain in boars over barrows. Further work in altering the ratio of testosterone to estrogen conversion

may provide even greater differences in composition and efficiency of gain than found between boars and barrows.

Summary

No differences were found in ADG between boars, barrows or gilts compared during any of the weight periods. DFI only differed between groups from 71 to 105 kg. Boars consumed 21%, and gilts 14% less feed per day than barrows. TFI also did not differ between groups prior to 71 kg. From 71 to 105 kg however, TFI of boars was less than both barrows and gilts by 24 and 21%, respectively. Feed to gain followed a similar pattern as found for TFI from 105 kg with boars requiring 25% and 18% less feed for gain than barrows and gilts, respectively. Boars and gilts did not differ in carcass measurements, although, differences were found when compared to barrows. Boars and gilts had 12 and 13% larger longissimus areas, 28 and 27% less tenth rib backfat, 3 and 5% longer carcasses and 8.5 and 8.7% more carcass muscle than barrows, respectively.

Chapter III

Metabolizable and Digestible Energy of the Same Diet Fed to Boars and Barrows at Several Intake Levels

Introduction

Growing-finishing trials have established that boars are more efficient than barrows in converting feed to live weight gain. Seideman et al. (1982) in a review, reported that utilizing the intact boar for meat production provided an advantage of 5.3% in feed conversion compared with barrows. Siers (1975) found that boars had 7.5% greater feed conversion to live weight gain than barrows and Wood and Riley (1982) demonstrated a difference of 19%. These investigations were conducted with pigs weighing approximately 20 to 105 kg. Feed conversion of boars and barrows were not observed to differ until after 70 kg live body weight in studies reported in Chapter II. The data reported in Chapter II indicated that boars required 24%

less feed than barrows for live weight gain from 70 to 105 kg. Prior to that weight range boars and barrows did not differ in feed efficiency.

The advantage in converting feed to gain in boars compared to barrows has been postulated to result from the differences in body composition (Fuller, 1980). Boars have a greater percentage of muscle and less fat than barrows (Newell and Bowland, 1972; Fuller, 1980; Wood and Riley, 1982; Castell and Strain, 1985). Burlacu et al. (1973) reported that the energy required to deposit a gram of fat was greater than protein. Overall efficiency of converting metabolizable energy (ME) to kcal of fat and protein favors the conversion to fat compared to protein (.56 for protein and .74 for fat, ARC, 1981). However, the greater energy density in fat (9.39 kcal/g; Brouwer, 1965) relative to protein (5.69 kcal/g; Brouwer, 1965) requires more total energy to deposit a gram of fat than a gram of protein (ARC, 1981).

Composition differences between boars and barrows may be the major factor for differences in conversion of feed to gain. However, another factor contributing to differences in feed conversion may be that boars and barrows differ in their ability to digest and absorb feedstuffs. Limited data have been published comparing the relationship of ME or digestible energy (DE) for boars and barrows compared from the same genetic pool and weighing 70 kg or more.

Level of feeding also has been suggested to affect dietary ME and DE. Haydon et al. (1984) observed a trend for a 4.8% increase in DE when feeding level was decreased from ad libitum (approximately 6%) to 3% of live weight for 25 kg pigs. Close et al. (1983) also found a trend for a 2 to 3% decrease in DE and ME with increased feed intake. This difference may not have been significant due to the fact that only four pigs were used per feeding level (Close et al., 1983). Metabolizable energy content also tends to increase with a decrease in feeding level (Hartog and Verstegen, 1984). Boars have lower daily feed consumption (Siederman et al., 1982; Castel and Strain, 1985) than barrows and this reduction in daily intake in boars may increase DE and/or ME compared to barrows. Therefore, this study was designed to compare DE and ME of the same corn-soybean meal based diet fed at several intake levels to boars and barrows weighing more than 70 kg.

Methods

A total of 48 boars (from Duroc or Hampshire sires and Yorkshire-Landrace cross dams) were selected at 3 wks of age, paired by litter and randomly allotted to: 1) intact or 2) castrated at 3 wk of age (barrows). From weaning (4 wk of age) until pigs were started on the balance experiment they were raised in an enviromentally controlled nursery and

growing-finishing building. The pigs weighed approximately 85 kg when they were started on the balance trial. This weight represented the projected mean weight of pigs fed in the experiment discussed in Chapter IV. The dietary ME determined in this experiment will be used to calculate dietary ME consumed by pigs in the experiment presented in Chapter IV.

At 85 kg six pairs of boars and barrows were randomly allotted to one of four feeding levels (FL) expressed as a percentage of live weight: 1) 2.5, 2)3.0, 3)3.5 or 4) 4.0%/d. The 2.5% of body weight FL was slightly above the estimated maintenance requirement (Headley et al., 1961) and the 4.0% FL was the estimated ad libitum intake (Headley et al., 1961). The other two FL were equally spaced between the low and high FL. The FL were calculated on an as-fed weight of diet.

At the start of the balance trial pigs were individually penned in metabolism cages and fed their daily allowance in two separate meals at 0700 and 1900 h each day. Saitoh and Takahashi (1985b) have indicated that frequency of feeding one, two or three meals per day for pigs did not affect digestibility of the diet, although, dietary nitrogen utilization was lower in boars when only one meal was fed compared to two and four meals per day (Partridge et al., 1985). Romsos et al. (1978) pair-fed pigs one and four meals per 48 h for 5.5 mo. Meal frequency did not influence

body weight gain, body composition, glucose tolerance or plasma glucose, cholesterol or triglyceride levels. Pigs fed one meal per day did have increased malic enzyme activity indicating greater lipogenic capacity. Zebrowska and Horszczaruk (1975) reported that feeding once or twice daily compared to ad libitum feeding influenced passage rate in the small intestine but did not affect the digestibilty of nitrogen or energy in the small intestine. Therefore, feeding two meals per day should not alter energy or nitrogen utilization compared to ad libitum feeding as used in commercial swine production.

Feces and urine were collected from each pig in the cages for 5 d following a 5 d adjustment period. At the completion of the 5 d trial, total collected feces per pig were oven dried at 100 C, weighed, ground and subsampled. The total urine collected for each pig was stirred and a subsample collected. Feces and urine subsamples were analyzed for nitrogen (Kjeldahl) by standard AOAC (1980) methods and total energy by bomb calorimeter-adiabiatic chamber.

The same diet was fed to all pigs from weaning to 85 kg before the balance trial began. All batches of feed were mixed from the same source of corn and soybean meal. The diet (table III-1) fed during the trial was a 20% crude protein equivalent (18% crude protein and 1.12%lysine) corn-soybean meal diet. All other nutrients met or

Table III-1. EXPERIMENTAL DIET[a] FED TO BOARS AND BARROWS

Ingredients	Percentage[a]
Corn (IFN 4-02-935)	68.65
Soybean meal-44 (IFN 5-04-604)	27.5
Dicalcium phosphate (IFN 6-01-080)	1.4
Calcium carbonate (IFN 6-01-069)	1.0
MSU Vitamin-trace mineral[b]	.5
Salt (IFN 6-02-632)	.25
Se-Vitamin E premix[c]	.5
L-Lysine HCl	.2[a]
Calculated Analysis	
Protein, %	18.0
Lysine, %	1.12[d]
Calcium, %	.76
Phosphorus, %	.66
Metabolizable energy, kcal/kg[a]	3343.0
Analysis	
Protein %	17.9
Gross energy, kcal/g	3935.0

[a] As-fed weight of ingredients.
[b] Supplying the following per kg of diet: Vitamin A, 3300 IU; Vitamin D, 660 IU; menadione sodium bisulfite, 2.2 mg; riboflavin, 3.3 mg; niacin, 17.6 mg; d-pantothetic acid, 13.2 mg; choline, 110 mg; Vitamin B_{12}, 19.8 Mg; Zn, 75 mg; Fe, 60 mg; Mn, 37 mg; Cu, 10 mg and I, .5mg.
[c] Supplying 22 IU Vitamin E and .1 mg Se per kg diet.
[d] Equivalent to percentage lysine in a 20% crude protein corn-soybean meal diet.

exceeded NRC (1979) requirements. The diet was calculated to meet or slightly exceed the protein requirements of boars (Tyler et al., 1983; Holmes et al., 1984). The 20% crude protein diet should not depress growth rate or alter composition of barrows (Holmes et al., 1980; Campbell et al., 1984).

The available energy from the excess protein fed to barrows may not be equal to the gross energy of protein because additional energy is required in the urea cycle for nitrogen excretion (Van Es, 1977). The additional energy required by the urea cycle for nitrogen excretion from the catabolism of the excess protein was calculated to be less than 1% of the total energy consumed (Nehring, 1967). Therefore, feeding the same diet to boars and barrows should not affect DE and ME.

Feed refusals during the balance trial were carefully collected at the end of the period, dried, weighed and analyzed for nitrogen and energy. To calculate actual intake per pig, that amount of nitrogen and energy was subtracted from the total amount fed.

Data were analyzed by 2 way analysis of variance (1 stage nested model with fixed effects of treatments, table III-2, Gill, 1978).

Table III-2. SOURCE OF VARIATION AND DEGREES OF FREEDOM

Source of variation	d.f.
Sex	1
Diets	3
Sex x Diet	3
Pairs/Diet	20
Error	20

Results and Discussion

Boar Barrow Balance Trial Data. DE of the diet was 2.4% greater ($P<.01$) for boars than for barrows (table III-3). This relationship also held true for ME content of the diet with a 2.2% advantage ($P<.01$) for boars relative to barrows. When ME was corrected for nitrogen balance, boars still had a 1.8% higher nitrogen corrected ME than barrows. The difference in the advantage of nitrogen corrected ME and ME of boars was a result of greater ($P<.01$) nitrogen retention compared to barrows. The 14% greater nitrogen retention by boars in this study compares with the 16% difference reported by Fuller et al. (1980). Nitrogen retention in boars relative to barrows has been found to be 18% greater in Pietrain pigs (Rerat, 1976) and as much as 28% higher in a another study (Piatowski and Jung, 1966).

The advantage in DE of boars versus barrows indicates that the ME difference was principally a digestive difference. Fecal energy loss per day was 12% greater ($P<.01$) in barrows compared to boars. That difference was supported by barrows excreting more dry matter resulting in 12.6% more ($P<.01$) dried fecal weight per day than boars. Barrows also had 9.8% greater ($P<.05$) energy loss per day in urine than boars. This difference suggests that boars and

Table III.3 BALANCE TRIAL RESULTS WITH BOARS AND BARROWS SUMMARIZED OVER ALL LEVELS OF INTAKE

Trait	Boars	Barrows	EMS[a]
Feed intake, kg/d	2.55	2.55	
Dietary digestible energy, kcal/g	3.540[b]	3.474[c]	.001
Dietary metabolizable energy, kcal/g	3.429[b]	3.355[c]	.001
Dietary metabolizable energy-nitrogen corrected, kcal/g	3.319[b]	3.259[c]	.001
Nitrogen-retention, g/d	41.2[b]	36.0[c]	34.2
Fecal energy loss, kcal/d	1188[b]	1358[c]	4854
Urine energy loss, kcal/d	266[d]	295[e]	1948
Dried fecal weight, g/d	271[b]	310[c]	320
Apparent biological value of protein, %	63.8[b]	54.6[c]	61.7
Apparent net protein utilization, %	57.8[b]	48.8[c]	50.8
Apparent nitrogen digestibility, %	90.4[b]	88.8[c]	.8

[a] Error mean square.
Measurenments within rows with different subscripts differ ($P<.01$)[b,c]; ($P<.05$)[d,e].

barrows not only differ in energy absorption, but also in the utilization of ME.

The pattern of differences found for energy also were demonstrated for protein and nitrogen. Boars had a 9.2% higher ($P<.01$) apparent biological value of protein (BV) and a consistent 9% greater ($P<.01$) apparent net protein utilization (NPU) than barrows. The values found for BV and NPU are lower than those reported in other studies with corn-soybean meal diets (Miller and Ku, 1979; Ilori et al., 1984). Those differences may be due to the higher dietary protein fed to boars and barrows during the finishing weight range in the present study. The barrows in the present study consumed more protein than their requirement (Holmes et al., 1980; Campbell et al., 1984), thereby increasing their urinary nitrogen excretion. High urinary nitrogen has a negative influence on apparent BV of protein and NPU which results in lower values (Cullison, 1982).

Balance Trial Feeding Level Data. The combined boars and barrows average DE, ME and nitrogen corrected ME were not found to differ at the four FL (table III-4). Parker and Clawson (1967) reported that level of dietary intake fed at approximately two, four and six times the maintenance

Table III-4. COMBINED BOAR AND BARROW BALANCE TRIAL RESULTS AT FOUR LEVELS OF DIETARY INTAKE

	Feeding Level, % Live weight				
Trait	2.5	3.0	3.5	4.0	EMS[a]
Feed intake per pig, kg/d	2.0	2.3	2.8	3.1	
Digestible energy, kcal/g	3.523	3.528	3.480	3.497	.001
Metabolizable energy, kcal/g	3.415	3.422	3.379	3.352	.001
NC[f] metabolizable energy, kcal/g	3.298	3.301	3.278	3.278	.001
Nitrogen-retention, g/d	34.3[b]	40.8[c]	42.9[c]	36.2[b]	34.2
Fecal energy loss, kcal/d[g]	952[b]	1085[c]	1526[d]	1527[d]	4854
Urine energy loss, kcal/d[g]	217[b]	245[c]	311[d]	349[e]	1948
Dried fecal weight, g/d	207[b]	234[c]	347[d]	377[e]	320
ABV[h] protein, %[g]	66.6[b]	65.9[b]	59.4[c]	44.9[d]	61.7
Apparent net protein utilization, %[g]	59.9[b]	62.1[b]	51.4[c]	39.8[d]	50.8
Apparent nitrogen digestibility, %	89.8[b]	94.2[c]	86.4[d]	87.9[e]	.8

[a] Error mean square.
[b c d e] Measurements within rows with different superscripts differ ($P<.01$).
[f] Nitrogen corrected.
[g] Diet by sex interaction ($P<.05$).
[h] Apparent biological value.

energy requirements of lactating sows did not alter DE. Most researchers have reported small but nonsignificant increases in DE or ME contents of the diet as feeding level decreased (Cunningham et al., 1962; Zivkovic and Bowland, 1963; Diggs et al., 1965; DeGoey and Ewan, 1975; Pearson et al., 1978). DE and ME also have tended to decrease with increasing dietary intake, but no significant differences were found (Haydon et al., 1984; Hartog and Verstegen, 1984). In contrast, Talley et al. (1976) reported that DE and ME increased with increased dietary energy intake in growing-finishing pigs. Others also have reported a similar trend (Beames, 1969; Peers et al., 1977).

DE, ME and nitrogen corrected ME tended to decrease with an increase in FL in the present study. Balance data are listed separately for boars and barrows in tables III-5 and III-6. The DE for boars did not decrease with increasing FL as was found for barrows (figure III-1). At the 2.5% FL boars only had a .9% higher DE than barrows but at the 4.0% FL there was a 2.6% difference. Comparison of ME followed a different pattern. It decreased as FL increased above the 3.0% FL in both boars and barrows maintaining a consistent 2.2% difference. Maximum ME was found at the 2.5 and 3.0% FL for boars and barrows,

Table III-5. BALANCE TRIAL RESULTS AT FOUR LEVELS OF INTAKE FOR BOARS

	Feeding Level, % Live weight				
Trait	2.5	3.0	3.5	4.0	EMS[a]
Feed intake per pig, kg/d	2.0	2.3	2.8	3.1	
Digestible energy, kcal/g	3.539	3.566	3.512	3.541	.001
Metabolizable energy, kcal/g	3.443	3.456	3.420	3.398	.001
Metabolizable energy-NC[b], kcal/g	3.315	3.339	3.305	3.316	.001
Nitrogen-retention, g/d	37.6	39.6	48.6	39.0	34.2
Fecal energy loss,[b] kcal/d	921	997	1414	1419	4854
Urine energy loss, kcal/d	193	256	269	346	1948
Dried fecal weight, g/d	201	214	321	351	320.5
ABV[c] of protein,%	72.5	63.8	68.2	50.6	61.7
Apparent net protein utilization, %	65.6	60.4	59.8	45.5	50.8
Apparent nitrogen digestibility, %	90.4	94.4	87.5	89.0	.8

[a] Error mean square.
[b] Nitrogen corrected.
[c] Apparent biological value.

Table III-6. BALANCE TRIAL RESULTS AT FOUR LEVELS OF INTAKE FOR BARROWS

	Feeding Level, % Live weight				
Trait	2.5	3.0	3.5	4.0	EMS[a]
Feed intake per pig, kg/d	2.0	2.3	2.8	3.1	
Digestible energy, kcal/g	3.507	3.489	3.448	3.452	.001
Metabolizable energy, kcal/g	3.387	3.387	3.339	3.306	.001
Metabolizable energy-NC[b], kcal/g	3.281	3.263	3.250	3.240	.001
Nitrogen-retention, g/d	31.1	42.1	37.3	33.4	34.2
Fecal energy loss, kcal/d	984	1174	1639	1635	4854
Urine energy loss, kcal/d	242	235	352	352	1948
Dried fecal weight, g/d	213	254	372	403	320
ABV[c] of protein, %	60.8	68.0	50.5	39.2	61.7
Apparent net protein utilization, %	54.2	63.9	43.1	34.0	50.8
Apparent nitrogen digestibility, %	89.2	94.0	85.4	86.7	.8

[a] Error ,ean square.
[b] Nitrogen corrected.
[c] Apparent biological value.

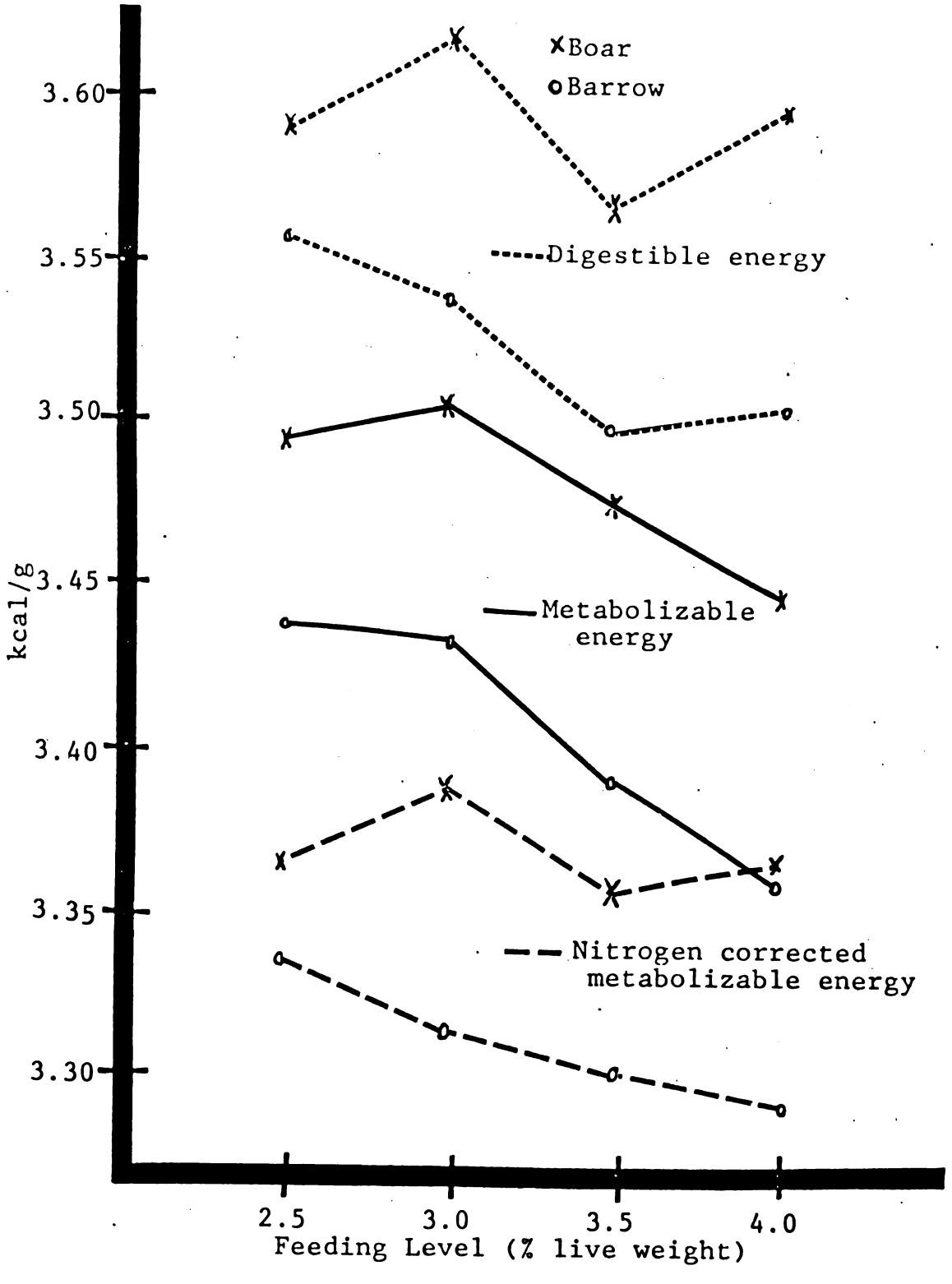


Figure III-1. Digestible, metabolizable and nitrogen corrected metabolizable energy of a similar diet fed at four levels of intake to boars and barrows.

respectively, and then decreased consistently to the 4.0% FL. Nitrogen corrected ME followed a similar trend as that found for DE with no real change for boars, but a decrease was found for barrows with increasing FL.

The combined boars and barrows average nitrogen retention was higher at 3.0 and 3.5% FL relative to the 2.5 and 4.0% FL (table III-4). These results were not consistent with published data. Nitrogen retention has generally been found to decrease with decreasing feeding level (Cunningham et al., 1962; DeGoey and Ewan, 1975; Haydon et al., 1984). The differences found in this study are difficult to explain. Nitrogen retention of boars compared at the four FL increased from the 2.5 to 3.5% FL and then decreased at the 4.0% FL. Nitrogen retention of barrows increased from the 2.5 to 3.0% FL and then decreased at the 3.0 and 4.0% FL.

Combined boars and barrows mean urinary and fecal energy loss per day and daily fecal dried weight increased with increased feeding level (figure III-2). A 61% increase in daily urine and fecal energy loss occurred at the 4.0% level compared to the 2.5% FL. Daily fecal dry matter increased even more and was 82% greater at the 4.0% level compared to the 2.5% intake level. A significant diet by sex interaction was found for fecal and urinary energy excretion. The increase in fecal energy excretion from the 2.5 to 3.0% FL was 131% greater in barrows compared to

boars. Urinary energy excretion continued to increase in boars from the 2.5 to 4.0% FL while barrows urinary energy excretion increased from the 2.5 to 3.5% FL with no differences found at the 3.5 and 4.0% FL.

Combined boars and barrows average protein utilization was highest at 2.5 and 3.0% FL and then decreased to the 4.0% FL. No difference in BV or NPU were found between the 2.5 and 3.0% FL (figure III-3). As level of intake increased, BV and NPU decreased and they were lowest at the 4.0% feeding level. BV and NPU at the 4.0% level were 32% and 35% lower than the mean of the 2.5 and 3.0% intake levels, respectively. Apparent nitrogen digestion (ND) coefficient was decreased 2.1% as feed intake was increased from 2.5 to 4.0%. A decrease in ND as feed intake increased also has been found in past work with pigs (Carr et al., 1977). A significant diet by sex interaction was found for BV and NPU. BV and NPU of barrows were found to decrease as FL increased above 3.0%. BV and NPU of boars were not found to decrease until FL increased above 3.5%.

Summary

Dietary DE (kcal/g), ME (kcal/g) and nitrogen corrected ME did not differ with the increase in feed intake. Daily fecal and urine energy loss and dried fecal

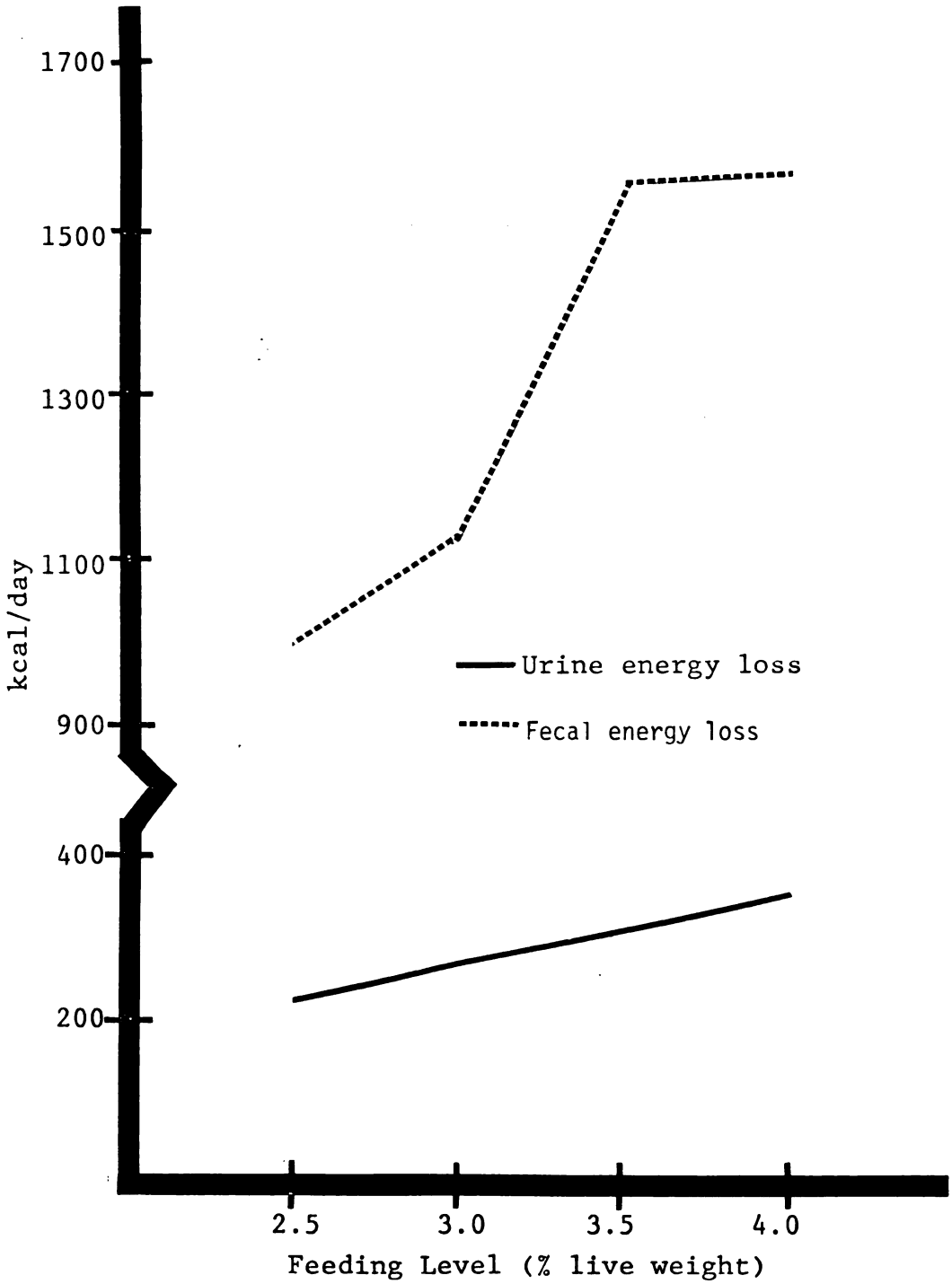


Figure III-2. Average of boars and barrows daily energy loss in feces and urine at four feeding levels.

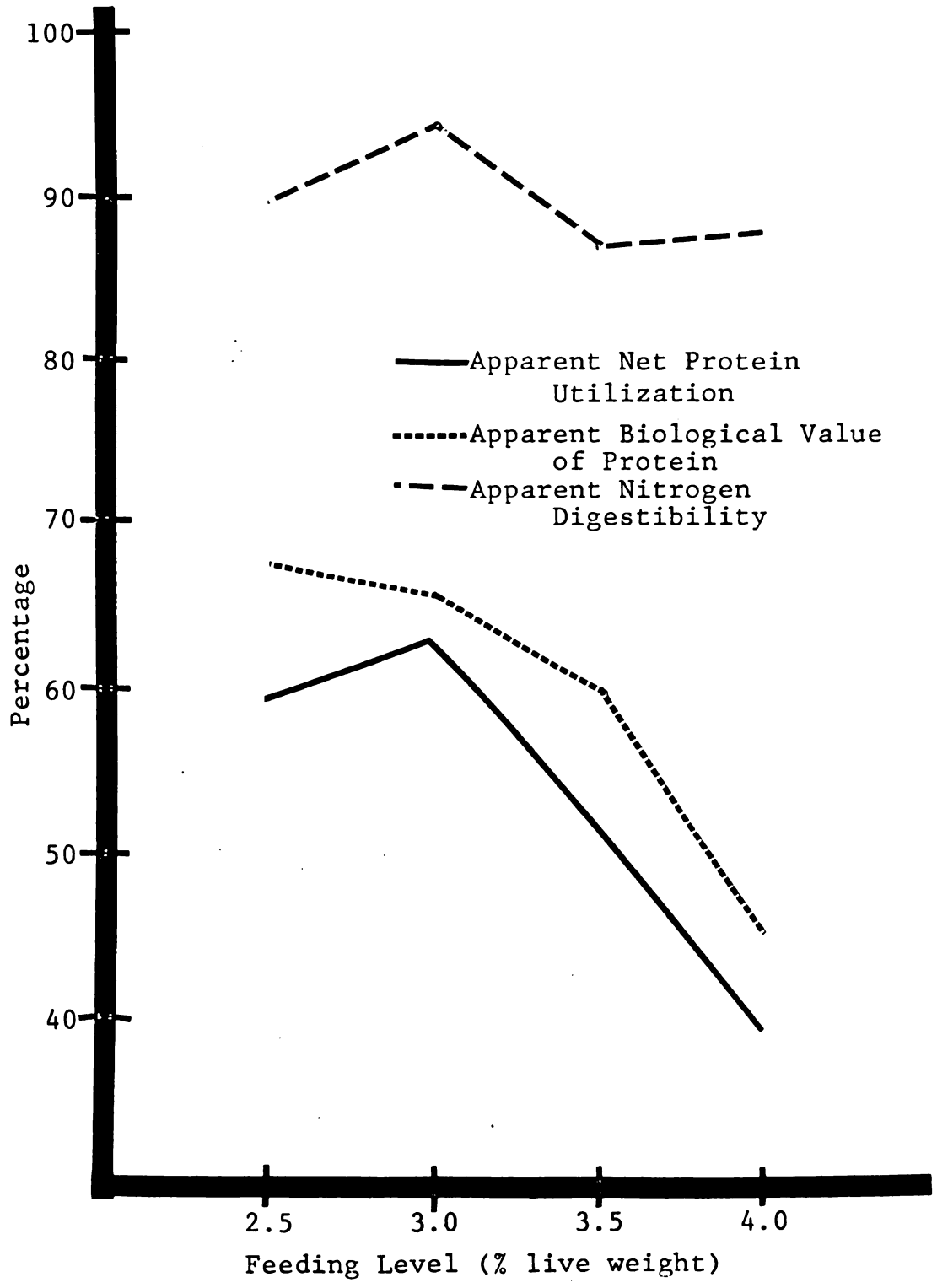


Figure III-3. Average of boars and barrows apparent nitrogen digestibility, apparent biological value of protein and net protein utilization at four feeding levels.

weight increased with the increase in feeding level. In contrast, BV, NPU and ND decreased with increased feed intake and concomitant nitrogen intake.

Comparing the results of boars and barrows, DE, ME and nitrogen corrected ME were all greater for boars. The higher ME in boars was primarily a result of improved energy digestibility compared to barrows. Fecal and urine energy excretion were greater in barrows while boars retained more nitrogen and had an increased utilization of protein.

The greater dietary DE content found for boars compared to barrows was significant although that difference was small, and less than 3%. Saitoh and Takahashi (1985c) found that nutrient digestibilities of pigs fed in cages were 1 to 2% greater than pigs fed in pens. External factors such as the confinement of boars in metabolism cages are stressful conditions that affect testicular steroidogenesis and have been found to lower androgen concentrations in peripheral serum (Liptrap and Raeside, 1968; Andresen, 1975; Andresen, 1976). The pigs in this trial were housed in individual cages. Whether the advantage found for boars in this study would also be found for pigs raised in pens requires further study. Another factor, is that if the DE differences found in this study were due to androgens, and if raising boars in crates lowers serum androgen concentrations, then the difference between DE of barrows and boars raised in pens

(with higher serum androgen concentrations than boars raised in crates) may be even greater.

Chapter IV

Comparison of Dietary Energy Partitioning in Boars and Barrows

Introduction

Dietary metabolizable energy in growing animals is required primarily for three major metabolic processes: protein and fat accretion, and maintenance (VanEs, 1977). The comparison of composition and energetic efficiency of gain of boars and barrows indicates that partitioning of energy between maintenance and protein and fat accretion may differ. Boars have greater energy partitioned to protein indicated through increased percentage carcass muscle and less fat compared to barrows (Fuller, 1980; Galbraith and Topps, 1981; Seideman et al., 1982: Knudson et al., 1985b).

Boars have a lower daily feed intake and an improved conversion of feed/gain than barrows (Omtvedt and Jesse, 1968; Wong et al., 1968; Texier, 1970; Wood and Riley, 1982; Campbell et al., 1985; Castel and Strain, 1985). A 9% advantage in feed/gain generally has been found for boars compared to barrows (Kay and Houseman, 1975) over a weight gain from soon after weaning (4 to 6 wk) to market weight (90 to 105 kg). However, in another study (Chapter II) as live weight increased from 71 to 105 kg, boars had a 24%

advantage in feed to gain ratio over barrows. Prior to that weight range feed/gain did not differ between boars and barrows.

Boars and barrows may also differ in the efficiency of dietary energy conversion to energy of protein and fat. The relative efficiency of energy conversion to energy in protein and fat is generally found to differ with fat deposition being more efficient (.74 for fat and .56 for protein, Agricultural Research Council, ARC, 1981). However, because of a greater energy density in fat (9.39 kcal/g, Brouwer, 1965) compared to protein (5.69 kcal/g, Brouwer, 1965) more energy is required for fat accretion (12.7 kcal/g) than for protein accretion (10.2 kcal/g, ARC, 1981). Therefore, a larger fat-free carcass portion (e.i., lean) in boars than in barrows may partially be responsible for the decrease in the amount of feed required for live weight gain in boars (Fuller,1980).

The total energy required for maintenance (ME_m) between boars and barrows may also differ. Holmes et al. (1982) reported that 60 kg barrows required 116 kcal/kg $BW^{.75}$ and boars 95 kcal/kg $BW^{.75}$ for ME_m. Comparisons made with pigs from two separate studies and of different genetic pools, one with barrows and the other with boars indicated that boars have a greater daily ME_m than barrows. When determined from indirect calorimetry, boars had a ME_m of 118 to 136 kcal/kg $BW^{.75}$ (Close et al., 1983) and barrows required 100 kcal/kg $BW^{.75}$ (Verstegen et al., 1973). Daily

ME_m requirements based on the comparative slaughter method were 111 kcal/kg $BW^{\cdot 75}$ for boars (Walach-Janiak et al., 1980) and 100 kcal/kg $BW^{\cdot 75}$ (Kortarbinska, 1969) for barrows. These latter comparisons indicate that boars have a greater requirement for ME_m than barrows and this does not agree with the higher ME_m requirements found for barrows compared to boars by Holmes et al. (1982). The contrasting results found in these few studies and the lack of comparisons on energy partitioning of boars and barrows at the weight range when efficiency of gain was found to differ (71 to 105 kg, Chapter II) indicates further work is needed to clarify these differences.

The expression of energy metabolism data for growing pigs also lacks agreement. Data are expressed on body weight (BW) as it was recognized that fasting heat production is proportional to BW. The expression of data for growing pigs has been found to differ from the traditional $BW^{\cdot 75}$ proposed by Brody (1945) and Klieber (1975). An exponent of BW for growing pigs lower than .75 in the order of .60 to .63 has provided a more favorable statistical fit than data expressed on $BW^{\cdot 75}$ (Fuller and Boyne, 1972; Holmes, 1974; Gadeken et al., 1974; Brown and Mount, 1982; Close and Fowler, 1982). The BW exponent of 2/3 originally suggested by Rubner (1800's; and cited by Klieber, 1961) may be more accurate for expressing data on a metabolic body weight basis for growing pigs than the traditional 3/4 exponent. This study was designed to

compare the partitioning of energy to maintenance and accretion of protein and fat in boars and barrows in the weight range from 70 to 105 kg with data expressed on $BW^{\cdot 66}$ and also on $BW^{\cdot 75}$ basis.

Methods

Twenty groups of 5 boars (from Duroc or Hampshire sires and Yorkshire-Landrace cross dams) were selected at 3 wk of age by litter and weight (a total of 100 boars). At that same age 10 of the groups were castrated (50 barrows) and the other 10 groups were left intact (50 boars). All pigs were raised by their respective dams until weaning (4 wk of age) and then moved to a nursery building. The building was enviromentally controlled and provided .32 m^2 of partially slotted floor space per pig. When pigs weighed 27 kg they were moved out of the nursery building and raised until 70 kg in a totally slotted floor, enviromentally controlled growing-finishing building that allowed .56 m^2 of floor space per pig.

When the pigs within each group averaged 70 kg they were assigned to one of 5 treatments. One pig per group was slaughtered initially and the other 4 were randomly assigned to one of four feeding levels: 1) 2.5%, 2) 3.0%, 3) 3.5% or 4) 4.0% of live weight/d. The lowest feeding level was slightly above the estimated maintenance requirement (Headley et al., 1961) and the highest feeding

Table VI-1. DIETS[a] FED TO BOARS AND BARROWS BEFORE AND DURING THE EXPERIMENT

Ingredients	Fed from 4 wk of age to 27 kg,%	Fed from 27kg to the end of experiemnt, %
Corn (IFN 4-02-935)	68.5	69.0
Soybean meal-44 (IFN 5-04-604)	27.4	27.4
Dicalcium phosphate (IFN 6-01-080)	1.4	1.4
Calcium carbonate (IFN 6-01-069)	1.0	1.0
MSU vitamin-trace mineral[b]	.5	.25
Salt (IFN 6-02-632)	.25	.25
Se-vitamin E premix[c]	.5	.5
Lysine 78%	.2[a]	.2[a]
Antibiotic[d]	.25	--
Calculated analysis		
Crude protein, %	18.0	18.0
Lysine, %	1.12[e]	1.12[e]
Calcium, %	.76	.76
Phosphorus, %	.66	.66
Metabolizable Energy, kcal/kg	3343.0	3343.0
Analysis		
Protein, %		18.0
Gross Energy, kcal/kg		3935.0

[a] As fed basis.

[b] Supplying the following per kg of diet: Vitamin A, 3300IU; Vitamin D_3, 660 IU; menadione sodium bisulfite, 2.2 mg; riboflavin, 3.3 mg; niacin, 17.6 mg; d-pantothenic acid, 13.2 mg; choline, 110 mg; Vitamin B_{12}, 19.8 Mg; Zn, 75 mg; Fe, 60 mg; Mn, 37 mg; Cu, 10 mg and I, .5mg.

[c] Supplying 22 IU of Vitamin E and .1 mg Se per diet.

[d] Containing 4.4% chlortetracycline, 4.4% sulfamethazine and 2.2% penicillin.

[e] Equivalent to percentage lysine in a 20% crude protein corn soybean meal diet from added lysine.

level was the estimated ad libitum intake (Headley et al., 1961). The other two feeding levels were equally spaced between the minimum and maximum feeding levels. Pigs were fed their respective dietary intake levels for 5 wk in individual feeding crates. Two meals per day were fed and water was available continuously from nipple waterers.

The diet fed to all pigs from 4 wk of age to 27 kg was a 20% crude protein equivalent (18% crude protein and 1.12% lysine) corn soybean meal diet with added antibiotic (table IV-1). From 27 to 70 kg and during the feeding trial all pigs were fed a 20% crude protein equivalent diet without added antibiotic (table IV-1) that was formulated to meet or slightly exceed the protein requirements of boars (Tyler et al., 1983; Holmes et al., 1984). That level of dietary protein exceeded barrow requirements but has been reported not to depress growth rate or alter composition of barrows (Holmes et al., 1980; Campbell et al., 1984). This diet was fed in a previous experiment (Chapter III) and dietary nitrogen corrected metabolizable energy (ME) was determined for boars and barrows at the four levels of dietary intake (Chapter III). The diet in the previous experiment (Chapter III) and in this experiment were mixed from the same batch of soybean-meal and corn source.

Dietary ME was found to differ ($P<.01$) between boars and barrows but was not significantly different for the four levels of intake (Chapter III). However, the actual ME found for boars and barrows at the four levels of intake

(table IV-2) represented the best estimates of dietary ME at each intake level and were used in this experiment to calculate total energy intake (Personal communication, Magee, 1985)

At the end of the feeding trial, pigs were slaughtered. Twenty-four h prior to slaughter, feed was withheld from pigs to be slaughtered. At slaughter, pigs were electrically stunned and exsanguinated. Total blood from each carcass was collected, weighed and subsampled. The dorsal and ventral midline of each carcass was marked to distinguish between right and left side skin. The entire skin was then manually removed, weighed and separated into right and left sides. The right side skin was weighed and saved for grinding. In addition, the fore and hind feet from the right and left sides were removed, weighed and the right side feet saved for grinding. After skinning, the head was removed at the atlas-axis joint and the carcass eviscerated. The tongue was removed from each head and placed in a plastic bag along with the viscera. The tongue and viscera were weighed, and stomach and intestines were flushed of contents later the same day and then ground. The head was weighed and split medially into right and left halves. The right side was weighed and saved for grinding. Total hot carcass weight, and right and left side carcass weights were recorded for each carcass. After weight was recorded the right side of each carcass was sawed into

Table IV-2 NITROGEN CORRECTED METABOLIZABLE ENERGY OF A COMMON DIET FED TO BOARS AND BARROWS AT FOUR LEVELS OF INTAKE

	Intake, % Live Weight			
Sex	2.5	3.0	3.5	4.0
Boars, kcal/g	3.315	3.339	3.305	3.316
Barrows, kcal/g	3.281	3.263	3.250	3.240

From Chapter III, table III-5 and III-6.

approximately 10 pieces and placed in a plastic bag along with the right side of the head, right side feet and skin to assemble all right side components. These right side components were frozen and stored at -30 C until ground.

The entire viscera (stomach, gall bladder, small and large intestine) and urinary bladder from each carcass were flushed of all contents with water. Excess water was stripped from the viscera by it passing between the fingers. The viscera was then weighed to record an empty viscera weight. The empty viscera was ground in a Toledo Model number 5520 meat grinder through a 4-mm plate, mixed and reground through the 4-mm plate. During the course of the second grinding, 10 5- to 6-g subsamples were collected to obtain a 50- to 60-g sample that was placed in a Whirl-pak bag (Nasco, Fort Atkinson, WI) and stored at -30 C until later analysis.

The frozen (-30 C) mass of right side components were cut into approximately 1000 g chunks by a hydraulic cutter and then ground in a 20 cm Autio grinder (Autio Co., Astoria, OH) through a 1.27-cm plate, mixed and reground through the 1.27-cm plate. During the course of the second grinding, 10 150- to 200-g subsamples were collected to obtain a 1500- to 2000-g sample that was placed in a plastic bag. That 1500 to 2000 g sample was chilled at 2 C for 6 h and then ground in a Hobart Food Cutter (model T215 6A, Hobart Co., Troy, OH) through a 4-mm plate, mixed and reground through the 4-mm plate. During the course of the

second grinding, 10 5- to 6-g subsamples were collected to obtain a 50- to 60-g sample that was placed in a Whirl-pak bag (Nasco, Fort Atkinson, WI) and stored at -30 C until later analysis.

The subsamples of blood, viscera and right side components were individually cryogenically powdered (Appendix A.2) and analyzed by standard AOAC (1980) methods of analysis for moisture (drying oven), ether extract (Goldfisch) and protein (Kjeldahl N x 6.25). Each blood, viscera and right side component subsample and ether extractable lipid from each subsample were measured for total gross energy by bomb calorimeter-adiabiatic chamber (Parr Instruments).

Total empty body gross energy, total ether extractable lipid (fat), total protein and total gross energy of fat and protein were calculated for each carcass. The following equations were used to calculate those values:

1) Total components (TC) weight, g = total skin weight + total head weight + total feet weight + total carcass weight.

2) Right side components (RSC) weight, g = right side skin weight + right side head weight + right side feet weight + right side carcass weight.

3) Percentage of right side components of total components (PRSCTC) = RSC weight / TC weight.

4) Viscera calculations:
   Total viscera energy (TVE), kcal = viscera empty weight (VEW) x viscera energy.
   Total viscera (TV) ether extractable lipid (EEL), g = VEW x viscera % EEL.
   TV protein (TVP), g = VEW x viscera % protein.
   TV EEL energy, kcal = TV EEL x energy of viscera EEL.
   TV energy (TVPE), kcal = TVE - TV EEL energy.

5) Blood calculations:
   Total blood energy(TBE), kcal = blood weight(BW) x blood energy
   Total blood (TB) EEL, g = BW x blood % EEL.
   Total blood protein (TBP), g = BW x blood % protein.
   Total blood EEL energy, kcal = TB EEL x 9.39.
   Total blood protein energy (TBPE), kcal = TBE - TB EEL energy.

6) Carcass calculations:
   RSC energy, kcal = RSC weight x RSC energy.
   RSC EEL, g = RSC weight x RSC % EEL.
   RSC protein, g = RSC weight x RSC % protein.
   RSC EEL energy, kcal = RSC EEL x energy of RSC EEL.
   RSC protein energy, kcal = RSC energy - RSC EEL energy.
   TC energy (TCE), kcal = RSC energy / PRSCTC.
   TC EEL, g = RSC EEL / PRSCTC.
   TC protein (TCP), g = RSC protein / PRSCTC.
   TC EEL energy, kcal = RSC EEL energy / PRSCTC.
   TC protein energy (TCPE), kcal = RSC protein energy / PRSCTC.

7) Empty body weight (EB) calculations:
   EB energy, kcal = TCE + TBE + TVE.
   EB EEL, g = TC EEL + TB EEL + TV EEL.
   EB protein, g = TCP + TBP + TVP.
   EB EEL energy, kcal = TC EEL energy + TB EEL energy + TV EELenergy.
   EB protein energy, kcal = TCPE + TBPE + TVPE.

Variation in EB protein energy and EB EEL (fat) energy between pigs calculated by the described method were too great to calculate a multiple regression on metabolizable energy intake (MEI; MEI = ME_m + k_p EB protein energy + k_f EB EEL energy). The energy of viscera and EB ranged from 8.9 to 9.6 kcal/g. The method of calculating total fat energy from energy of EEL multiplied by total EEL and then subtracting this total fat energy from total energy to arrive at protein energy magnified the variation in EEL energy four times for each carcass. Therefore, the amount of energy retained in EB protein and fat were calculated from EB protein g/d multiplied by 5.69 kcal/g (Brouwer,

1965) and EB fat g/d multiplied by 9.39 kcal/g (Brouwer, 1965). Total EB energy was calculated by two methods. The first method was as first described above (analyzed EB energy) and the second method was by the sum of EB protein and EB fat multiplied by the standard energy concentrations (calculated EB energy) reported by Brouwer (1965).

Data were expressed on body weight (BW) using both the exponents .66 and .75 as estimates of metabolic body weight. The exponent .66 has been shown to estimate metabolic BW with a higher correlation than .75 in past energy metabolism data for growing pigs (Brown and Mount, 1982; Close and Fowler, 1982). However, the original exponent of approximately .75 proposed by Brody (1945) and Klieber (1975) has been used more widely and allows a wider comparison with other data.

To calculate retained EB energy and EB protein and fat the initial slaughter pig from each group provided a baseline composition. Retention was calculated as the difference between the retained energy, protein and fat of the initial slaughter pigs and that of the pigs fed the different levels of dietary intake. The MEI for each pig was calculated by multiplying the total weight of feed consumed during the 5 wk feeding trial by the respective dietary ME determined (Chapter III) for that treatment group (sex and feeding level).

Maintenance requirements of boars and barrows were calculated by inverse linear regression (Gill, 1978) with

data expressed per d on $BW^{.66}$ and $BW^{.75}$ basis. The two methods used to determine EB energy retention, i.e., analyzed EB energy, (ARE) and calculated EB energy, (CRE) were separately regressed on MEI to determine maintenance energy requirements. Daily retained energy (RE) was regressed on MEI as the independent variable and retained energy as the dependent variable (RE = b + a MEI). At zero RE ME_m requirements were calculated from inverse linear regression equation $ME_m = - b/a$.

The factorial method (Kielanowski, 1966) was used to calculate the energy requirement of maintenance for boars and barrows, in addition to the efficiency and the amount of energy required for protein and fat energy accretion. The multiple linear regression equation used was as follows: $MEI = ME_M + k_p P + k_f F$. MEI is the metabolizable energy intake (kcal/d), ME_M is the energy required for maintenance (kcal/d), P is the energy retained as protein (kcal/d) and F is the energy retained in fat (kcal/d). The coefficients k_p and k_f are the kcal of energy expended for a kcal of protein and fat deposition, respectively. The calculated ratios $1/k_p$ and $1/k_f$ are the efficiencies of dietary energy converted to energy in protein and fat, respectively (Kielanowski, 1966).

Six boars and six barrows were removed from the analysis. These pigs proved to be outliers in either calculated empty body energy, analyzed empty body energy or calculated protein energy and were greater than three

standard deviations from the mean. The factors used to explain these pigs as outliers were excessive pneumonia and/or atrophic rhinitis in pigs at slaughter time or low final slaughter weight. The multiple linear regression and linear regression calculated from the entire data set are listed in appendix C-1 and C-2. Data were analyzed by linear regression, multiple linear regression and two-way (sex by feeding level) analysis of variance using SAS statistical software (Goodnight et al., 1982).

RESULTS

Feed Intake Data. The mean daily feed intake was calculated for boars and barrows, and expressed on empty body weight (BW)$\cdot^{66}$ and BW$\cdot^{75}$ (table IV-3). No differences were found for feed intake between boars and barrows at BW$\cdot^{66}$ or BW$\cdot^{75}$. Feeding level (FL) increased ($P<.01$) linearly from the calculated 2.5 to 4.0% FL for boars (table IV-4) and for barrows (table IV-5). The percentage increase in feed intake from the 2.5 to 4.0% FL was 40% for boars and 38% for barrows. These increases were consistent at BW$\cdot^{66}$ and BW$\cdot^{75}$.

Empty Body Weight Data. Mean BW was calculated for boars and for barrows and did not differ when adjusted to BW$\cdot^{66}$ or BW$\cdot^{75}$ (table IV-3). The actual mean BW for boars was 92.7 kg and 91.7 kg for barrows. The designated feed intake for boars (table IV-4) from 2.5 to 4.0% FL increased linearly ($P<.02$) with the increase in BW$\cdot^{66}$ and BW$\cdot^{75}$. The

Table IV-3. MEAN DAILY FEED INTAKE AND EMPTY BODY WEIGHT OF BOARS AND BARROWS EXPRESSED ON EMPTY BODY WEIGHT$^{\cdot 75}$ AND EMPTY BODY WEIGHT$^{\cdot 66}$

Traits[a]	Boars	Barrows	EMS[b]
Empty body weight(BW), kg:			
$BW^{\cdot 66}$	19.9	19.7	3.9
$BW^{\cdot 75}$	29.9	29.6	11.3
Feed intake, kcal/d/kg:			
$BW^{\cdot 66}$	403.4	403.2	966.6
$BW^{\cdot 75}$	268.3	268.8	441.1

[a] No significant differences between boars and barrows.
[b] Error mean square.

Table IV-4. DAILY FEED INTAKE AND EMPTY BODY WEIGHT OF BOARS AT THE DIFFERENT FEEDING LEVELS EXPRESSED ON EMPTY BODY WEIGHT$^{.66}$ AND EMPTY BODY WEIGHT$^{.75}$

Trait	Feeding Level,% live weight 2.5	3.0	3.5	4.0	EMS[a]
Empty body weight(BW), kg:					
$BW^{.66}$[b]	19.4	19.2	19.9	21.1	2.25
$BW^{.75}$[b]	29.1	28.8	29.9	31.9	6.56
Feed intake, kcal/d/kg:					
$BW^{.66}$[c]	333	386	423	470	858
$BW^{.75}$[c]	223	258	282	311	402

[a] Error mean square.
[b] Linear response for measurements within rows ($P<.02$).
[c] Linear response for measurements within rows ($P<.01$).

Table IV-5. DAILY FEED INTAKE AND EMPTY BODY WEIGHT OF BARROWS AT THE DIFFERENT FEEDING LEVELS EXPRESSED ON EMPTY BODY WEIGHT$^{.75}$ AND EMPTY BODY WEIGHT$^{.66}$

	Feeding Level, % live weight				
Trait	2.5	3.0	3.5	4.0	EMS[a]
Empty body weight(BW), kg:					
$BW^{.66}$	18.8	19.6	19.7	20.6	5.55
$BW^{.75}$	28.1	29.4	29.5	31.1	16.0
Feed intake, kcal/d/kg:					
$BW^{.66}$[b]	333	394	424	462	1074
$BW^{.75}$[b]	223	263	283	306	480

[a] Error mean square.
[b] Linear response for measurements within rows ($P<.01$).

percentage increase in BW of boars from the 2.5 to 4.0% FL was 10%. Barrows also had a 10% increase in BW as FL increased from 2.5 to 4.0%, however the linear increase was not significant ($P<.15$, table IV-5).

Empty Body Retention Data. The average retention of each EB trait was adjusted on $BW^{\cdot 66}$ and $BW^{\cdot 75}$ basis and calculated over all FL and at each individual FL for boars and barrows. The following discussion will compare the overall averages and the average found at 2.5 and 4.0% FL between boars and barrows. These comparisons were consistent on $BW^{\cdot 66}$ and $BW^{\cdot 75}$. The relationship of empty body (EB) retained protein and fat energy between boars and barrows were the same as that found for retained protein and fat because retained protein and fat energy were calculated from retained protein and fat using standard energy concentrations (Brouwer, 1965). Therefore, to avoid repetition the comparison of retained protein and fat energy between boars and barrows will not be presented.

Mean daily EB protein retention of boars calculated over all feed intakes was 19% greater than barrows when data were expressed on $BW^{\cdot 66}$ (table IV-6) and $BW^{\cdot 75}$ (table IV-7). The linear increase ($P<.01$) in daily protein retention with increased FL from 2.5 to 4.0% was 60% in boars (tables IV-8 and IV-10) and only 43% in barrows (tables IV-9 and IV-11). The greater daily EB protein retention in boars compared to barrows resulted in an absolute difference between boars and

Table IV-6. MEAN DAILY EMPTY BODY (EB) AND VISCERA (VC) RETENTION IN BOARS AND BARROWS EXPRESSED ON EMPTY BODY WEIGHT·[66]

Trait	Boars	Barrows	EMS[a]
Number of pigs	34	34	
EB protein, g/d[b]	6.23	5.20	1.67
EB fat, g/d[b]	8.88	14.37	5.87
EB protein energy, kcal/d[b]	35.4	29.6	54.2
EB fat energy, kcal/d[b]	83.4	135.0	517.2
EB calculated energy, kcal/d[b]	118.9	164.6	608.1
EB analyzed energy, kcal/d[b]	123.1	165.2	521.5
VC protein, g/d[b]	.40	.27	.01
VC fat, g/d[b]	.50	.89	.07
VC protein energy, kcal/d	2.32	2.16	1.75
VC fat energy, kcal/d[b]	4.81	7.72	5.62
VC energy, kcal/d[b]	6.98	9.80	9.38

[a] Error mean square.
[b] Measurements within rows differed ($P<.01$).

Table IV-7. MEAN DAILY EMPTY BODY (EB) AND VISCERA (VC) RETENTION IN BOARS AND BARROWS EXPRESSED ON EMPTY BODY WEIGHT·⁷⁵

Trait	Boars	Barrows	EMS[a]
Number of pigs	34	34	
EB protein, g/d[b]	4.14	3.47	.74
EB fat, g/d[b]	5.90	9.57	2.54
EB protein energy, kcal/d[b]	23.6	19.7	24.0
EB fat energy, kcal/d[b]	55.4	89.9	224.1
EB calculated energy, kcal/d[b]	79.0	109.6	264.4
EB analyzed energy, kcal/d[b]	81.8	110.2	247.2
VC protein, g/d	.26	.18	.01
VC fat, g/d[b]	.33	.59	.03
VC protein energy, kcal/d[b]	1.54	1.44	.80
VC fat energy, kcal/d[b]	3.20	5.14	2.45
VC energy, kcal/d[b]	4.64	6.53	4.13

[a] Error mean square.
[b] Measurements within rows differed (P<.01).

Table IV-8. MEAN DAILY EMPTY BODY (EB) AND VISCERA (VC) RETENTION IN BOARS AT DIFFERENT FEEDING LEVELS EXPRESSED ON EMPTY BODY WEIGHT.[66]

	Feeding Levels, %				
Trait	2.5	3.0	3.5	4.0	EMS[a]
Number of pigs	7	10	9	8	
EB protein, g/d[b]	4.71	5.52	7.15	7.53	1.37
EB fat, g/d[b]	5.45	7.81	9.51	12.86	4.18
EB protein energy, kcal/d[b]	26.8	31.4	40.7	42.9	44.5
EB fat energy, kcal/d[b]	51.2	73.4	89.3	119.9	368.5
EB calculated energy, kcal/d[b]	78.0	104.8	130.0	162.7	452.7
EB analyzed energy, kcal/d[b]	86.3	107.6	132.2	166.4	374.1
VC protein, g/d[c]	.36	.31	.43	.49	.02
VC fat, g/d	.41	.45	.54	.62	.03
VC protein energy, kcal/d[b]	1.73	1.86	2.69	2.98	1.08
VC fat energy, kcal/d[b]	3.88	4.26	5.25	5.87	2.04
VC energy, kcal/d[b]	5.73	5.92	7.67	8.58	4.27

[a] Error mean square.
[b] Linear response for measurements within rows ($P<.01$).
[c] Linear response for measurements within rows ($P<.02$).

Table IV-9. MEAN DAILY EMPTY BODY (EB) AND VISCERA (VC) RETENTION IN BARROWS AT DIFFERENT FEEDING LEVELS EXPRESSED ON EMPTY BODY WEIGHT·[66]

	Feeding Levels, %				
Trait	2.5	3.0	3.5	4.0	EMS[a]
Number of pigs	10	10	7	7	
EB protein, g/d[b]	4.16	5.22	5.48	5.95	1.97
EB fat, g/d[c]	10.1	13.8	15.6	17.9	7.56
EB protein energy, kcal/d[b]	23.7	29.7	31.2	33.8	63.9
EB fat energy, kcal/d[c]	94.6	129.9	147.0	168.4	666.6
EB calculated energy, kcal/d[c]	118.3	159.6	178.2	202.3	763.5
EB analyzed energy, kcal/d[c]	112.3	154.0	183.8	210.8	669.0
VC protein, g/d[c]	.20	.21	.25	.42	.01
VC fat, g/d[c]	.51	.79	.95	1.31	.12
VC protein energy, kcal/d	1.63	1.80	2.40	2.79	2.42
VC fat energy, kcal/d[c]	4.59	7.39	8.06	10.86	9.20
VC energy, kcal/d[c]	6.07	8.89	10.59	13.67	14.30

[a] Error mean square.
[b] Linear response for measurements within rows ($P<.02$).
[c] Linear response for measurements within rows ($P<.01$).

Table IV-10. MEAN DAILY EMPTY BODY (EB) AND VISCERA (VC) RETENTION IN BOARS AT DIFFERENT FEEDING LEVELS EXPRESSED ON EMPTY BODY WEIGHT·$^{.75}$

	Feeding Levels, %				
Trait	2.5	3.0	3.5	4.0	EMS[a]
Number of pigs	7	10	9	8	
EB protein, g/d[b]	3.14	3.69	4.76	4.97	.59
EB fat, g/d[b]	3.63	5.22	6.33	8.43	1.87
EB protein energy, kcal/d[b]	17.8	21.0	27.1	28.3	19.2
EB fat energy, kcal/d[b]	34.1	49.0	59.4	79.1	165.1
EB calculated energy, kcal/d[b]	52.0	70.0	86.5	107.4	201.0
EB analyzed energy, kcal/d[b]	57.6	71.9	88.0	109.9	170.1
VC protein, g/d[c]	.24	.21	.28	.32	.01
VC fat, g/d[b]	.27	.30	.36	.41	.01
VC protein energy, kcal/d[b]	1.15	1.25	1.80	1.97	.48
VC fat energy, kcal/d[b]	2.59	2.85	3.50	3.88	.91
VC energy, kcal/d[b]	3.83	3.96	5.11	5.67	1.92

[a] Error mean square.
[b] Linear response for measurements within rows ($P<.01$).
[c] Linear response for measurements within rows ($P<.03$).

Table IV-11. MEAN DAILY EMPTY BODY (EB) AND VISCERA (VC) RETENTION IN BARROWS AT DIFFERENT FEEDING LEVELS EXPRESSED ON EMPTY BODY WEIGHT·$^{.75}$

	Feeding Levels, %				
Trait	2.5	3.0	3.5	4.0	EMS[a]
Number of pigs	10	10	7	7	
EB protein, g/d[b]	2.79	3.48	3.66	3.94	.89
EB fat, g/d[c]	6.76	9.21	10.44	11.89	3.21
EB protein energy, kcal/d[b]	15.9	19.8	20.8	22.4	28.8
EB fat energy, kcal/d[c]	63.4	86.5	98.0	111.6	283.1
EB calculated energy, kcal/d[c]	79.3	106.3	118.8	134.0	327.8
EB analyzed energy, kcal/d[c]	75.4	102.8	122.6	139.8	324.3
VC protein, g/d[c]	.13	.14	.17	.28	.01
VC fat, g/d[c]	.34	.53	.63	.87	.05
VC protein energy, kcal/d	1.10	1.21	1.61	1.85	1.11
VC fat energy, kcal/d[c]	3.08	4.91	5.38	7.18	3.99
VC energy, kcal/d[c]	4.08	5.92	7.07	9.04	6.35

[a] Error mean square.
[b] Linear response for measurements within rows ($P<.02$).
[c] Linear response for measurements within rows ($P<.01$).

barrows of .55 g/d/BW$^{.66}$ (.35 g/d/BW$^{.75}$) at 2.5% FL and 1.58 g/d/BW$^{.66}$ (1.03 g/d/BW$^{.75}$) at the 4.0% FL. A 187% increase in the difference between EB protein retention of boars and barrows was observed at the 4.0% FL relative to the 2.5% FL. These comparisons indicate that as FL increased from 2.5 to 4.0% FL, boars increase protein retention at a greater rate than barrows.

Daily fat retention was greater in barrows than boars. Barrows mean daily EB fat retention over all feeding levels was 62% greater than boars (tables IV-6 and IV-7). The comparison of absolute differences in daily EB fat retention between boars and barrows was 4.65 g/d/BW$^{.66}$ (3.13 g/d/BW$^{.75}$) at the 2.5% FL and 5.04 g/d/BW$^{.66}$ (3.46 g/d/BW$^{.75}$) at the 4.0% FL, with barrows being greater than boars (tables IV-8 to IV-11). These differences resulted in an 8% greater daily EB fat retention for barrows than boars at the 4.0% FL relative to the 2.5% FL. Calculating the percentage increase in daily EB fat retention at 4.0% FL compared to 2.5% FL resulted in a 136% increase for boars and a 77% increase for barrows. The greater percentage change for boars is relative to the lower retention at the 2.5% FL. However the important EB fat retention comparison is the 8% increase in this difference between boars and barrows found at the 4.0% FL relative to the difference at the 2.5% FL. These results indicate that as FL increased from 2.5 to 4.0%, barrows increased the energy partitioned to daily EB fat retention by 8% compared to boars while

overall FL mean retention of fat for barrows was 62% greater than boars.

Total daily EB energy retention followed the pattern found for daily EB fat retention and was greater in barrows than for boars. The mean daily EB energy retention in barrows calculated over all FL was 34 (ARE) to 38% (CRE) greater than boars (tables IV-6 and IV-7). The absolute difference in ARE between boars and barrows increased from 26 kcal/d/$BW^{.66}$ (18 kcal/d/$BW^{.75}$) at the 2.5% FL to 44 kcal/d/$BW^{.66}$ (30 kcal/d/$BW^{.75}$) at the 4.0% FL. However, the difference in CRE was 40 kcal/d/$BW^{.66}$ (27 kcal/d/$BW^{.75}$) between barrows and boars at both the 2.5 and 4.0% FL (tables IV-8 to IV-11). These contrasting results in the difference between boars and barrows in the total amount of daily EB energy retention calculated from ARE and CRE at the two FL are difficult to explain.

Viscera Data. Certain viscera trait data between boars and barrows were not consistently different when expressed on $BW^{.66}$ compared to $BW^{.75}$. The mean daily viscera protein retention (VPR) calculated over all FL did not differ significantly between boars and barrows expressed on $BW^{.75}$ (table IV-7). However, on $BW^{.66}$ boars mean VPR was 48% greater ($P<.01$) than barrows (table IV-6). The average VPR calculated for each individual FL resulted in a linear increase ($P<.01$) from 2.5 to 4.0% FL for boars and barrows expressed on $BW^{.66}$ (tables IV-7 and IV-10) and $BW^{.75}$ (tables

IV-9 and IV-10). Boars had greater VPR at the 2.5% FL which was .16 g/d/$BW^{.66}$ greater ($P<.01$) than barrows. Boars also had greater VPR at the 4.0% FL with a greater ($P<.01$) retention rate of .07 g/d/$BW^{.66}$ than barrows. The difference between VPR of boars and barrows at the 4.0% compared to the 2.5% FL was decreased 56%.

The daily viscera protein energy retention (VPE) difference between boars and barrows was not consistent with VPR. When mean VPE was calculated over all FL and expressed on $BW^{.75}$ (tables IV-7 and IV-8) boars had 7% more VPE than barrows. However, overall mean VPE was not significantly different between boars and barrows when expressed on $BW^{.66}$ (tables IV-7 and IV-8). VPE increased linearly ($P<.01$) as FL increased from 2.5 to 4.0% in boars and barrows. The difference between boars and barrows VPE at 4.0% FL was twice as great as the difference found at the 2.5% FL, with boars being greater than barrows.

Mean daily viscera fat retention (VFR) over all FL was 78% greater in barrows than boars. This difference was consistent when data were expressed on $BW^{.66}$ (table IV-5) and $BW^{.75}$ (table IV-6). The average VFR for each FL increased linearly ($P<.01$) from 2.5 to 4.0% FL for barrows expressed on $BW^{.66}$ (table IV-8) and $BW^{.75}$ (table IV-10) and for boars expressed on $BW^{.75}$ basis (table IV-9). At the 2.5% FL barrows had greater VFR of .07 g/d on $BW^{.75}$ and .10 g/d on $BW^{.66}$ basis than boars. At the 4.0% FL barrows had greater VFR of .46 g/d on $BW^{.75}$ and .69 g/d on $BW^{.66}$ basis

than boars. These VFR differences between boars and barrows, compared at the 4.0% FL relative to the 2.5% FL increased 557 ($BW^{\cdot 66}$) to 620% ($BW^{\cdot 75}$).

The difference in daily viscera fat energy retention (VFE) between boars and barrows were consistent with VFR. Overall VFE was 61% greater in barrows than boars on $BW^{\cdot 66}$ and $BW^{\cdot 75}$ basis. Both boars and barrows increased VFE with increasing FL and the rate of increase was greater in barrows.

Daily viscera energy retention (VER) differences between boars and barrows followed a similar pattern found for VFE. The average VER calculated from all FL was 41% greater in barrows than boars (tables IV-5 and IV-6). The mean VER for each FL increased linearly ($P<.01$) as intake increased from 2.5 to 4.0% for boars and barrows expressed on $BW^{\cdot 66}$ (tables IV-7 and IV-8) and $BW^{\cdot 75}$ basis (tables IV-9 and IV-10). The difference in VER between boars and barrows at the 4.0% FL increased 14-fold from the difference found at the 2.5% FL, and was greater for barrows than for boars.

Linear Regression Data. The regression of MEI (independent variable) on retained energy (dependent variable) was calculated for boars and for barrows and expressed on $BW^{\cdot 66}$ and $BW^{\cdot 75}$ basis. Retained energy was determined by the two methods, as described in the methods sections. The first method used to calculate retained energy was the calculated EB retained energy (CRE) and the

second method was analyzed EB retained energy (ARE). No statistically significant differences were found for the linear regression model (LRM) variables calculated from CRE (table IV-12) or ARE (table IV-13) between boars and barrows. However, consistent numerical differences in CRE and ARE LRM variables were found between boars and barrows.

The slope of the LRM, considered as the efficiency of energy retained was consistent whether CRE data were expressed on $BW^{\cdot 66}$ or $BW^{\cdot 75}$ for boars and for barrows. Boars mean efficiency (expressed on $BW^{\cdot 66}$ and $BW^{\cdot 75}$) of CRE was 53% and for barrows 60.5%, indicating a 14% greater efficiency in the retention of energy for barrows compared to boars.

The positive intercept has been used as an indication of heat production and was 19% greater in boars than barrows when data were expressed on $BW^{\cdot 66}$ and $BW^{\cdot 75}$. When intercepts from data expressed on $BW^{\cdot 66}$ were compared to data expressed on $BW^{\cdot 75}$ heat production was 53% greater.

Maintenance energy requirements (MEm) are calculated by inverse linear regression and at zero retained energy the calculation is simply the negative of the intercept divided by the slope. Boars calculated MEm was 36% greater than barrows when expressed on $BW^{\cdot 66}$ and $BW^{\cdot 75}$. As was found for the intercept, the calculated MEm from data expressed on $BW^{\cdot 66}$ were 52% greater than data expressed on $BW^{\cdot 75}$.

Table IV-12. CALCULATED LINEAR REGRESION FOR DAILY DIETARY METABOLIZABLE INTAKE ON CALCULATED DAILY EMPTY BODY RETAINED ENERGY FOR BOARS AND BARROWS

Groups	ME_m[a]	Intercept	SE[b]	Slope[c]	SE[b]	R^2
Boars[d]:						
.66[e]	179	-94.8	27.8	.53	.06	.65
.75[f]	118	-62.3	19.1	.53	.05	.63
Barrows[d]:						
.66[e]	131	-80.0	23.0	.61	.07	.72
.75[f]	87	-52.2	18.3	.60	.07	.71

[a] Calculated metabolizable energy of maintenance, kcal/d (-intercept / slope).
[b] Standard error.
[c] Efficiency of energy retained.
[d] Number of pigs was 34 with 32 degrees of freedom in error for each group.
[e] Expressed on body weight$^{.66}$.
[f] Expressed on body weight$^{.75}$.

Table IV-13. CALCULATED LINEAR REGRESION FOR DAILY DIETARY METABOLIZABLE INTAKE ON ANALYZED DAILY EMPTY BODY RETAINED ENERGY FOR BOARS AND BARROWS

Groups	ME_m[a]	Intercept	SE[b]	Slope	SE[b]	R^2
Boars[c]:						
.66[d]	171	-89.0	23.0	.52	.06	.72
.75[e]	114	-59.3	16.0	.52	.06	.71
Barrows[c]:						
.66[d]	121	-70.0	26.6	.58	.09	.65
.75[e]	85	-50.0	14.9	.59	.09	.66

[a] Calculated metabolizable energy of maintenance, kcal/d (-intercept / slope).
[b] Standard error.
[c] Number of pigs was 34 with 32 degrees of freedom in error for each group: no measurement between boars and barrows differed.
[d] Expressed on body weight$^{.66}$.
[e] Expressed on body weight$^{.75}$.

The comparison of LRM calculated for boars and barrows from ARE had a similar relationship to the comparison of LRM of boars versus barrows calculated from CRE. The mean efficiencies of energy retention calculated from ARE were 2% lower for boars and 3% less for barrows compared to efficiencies calculated from CRE. Intercepts and MEm determined from the ARE all tended to be 7% lower than those calculated from CRE. The relationships of greater intercepts and MEm for boars compared to barrows and for data expressed on $BW^{\cdot 66}$ relative to $BW^{\cdot 75}$ from ARE were also found for CRE.

Multiple Regression Data. The retained protein and fat energy were calculated from protein and fat retention (independent variable) and regressed on MEI (dependent variable). All data were expressed on $BW^{\cdot 66}$ and $BW^{\cdot 75}$ basis (table IV-14). The coefficients of protein (k_p) and fat (k_f) retention were considered as the energy required to deposit a kcal of energy in protein and fat, respectively (Kielanowski, 1965). No significant differences were found for k_p or k_f between boars and barrows. The energy required for fat deposition in boars tended to be 5% and 8% greater than barrows when data were expressed on $BW^{\cdot 66}$ or $BW^{\cdot 75}$, respectively. The efficiency of fat energy accretion ($1/k_f$) for boars was 85% when data were calculated

Table IV-14. CALCULATED MULTIPLE LINEAR REGGRESION FOR DAILY EMPTY BODY RETAINED PROTEIN AND FAT ENERGY ON DAILY DIETARY METABOLIZABLE INTAKE FOR BOARS AND BARROWS

Groups	Intercept[a]	SE[b]	K_P[c]	SE[b]	K_F[d]	SE[b]	R^2
Boars[e]:							
.66[f]	252.7[h]	23.9	1.52	.80	1.17	.24	.65
.75[g]	171.5[j]	16.3	1.38	.82	1.17	.24	.63
Barrows[e]:							
.66[f]	198.5[i]	23.0	1.78	.68	1.12	.15	.73
.75[g]	133.3[k]	15.5	1.93	.67	1.07	.16	.72

[a] Calculated metabolizable energy of maintenance, kcal/d.
[b] Standard error.
[c] Metabolizable energy (kcal) required to deposit a kcal of protein.
[d] Metabolizable energy (kcal) required to deposit a kcal of fat.
[e] Number of pigs was 34 with 31 degrees of freedom for each group.
[f] Expressed on body weight$^{.66}$.
[g] Expressed on body weight$^{.75}$.
[h i] Measurements within columns with different superscripts differed ($P<.11$).
[j k] Measurements within columns with different superscripts differed ($P<.09$).

on $BW^{\cdot 66}$ and $BW^{\cdot 75}$. Barrows had a higher efficiency of fat energy accretion on $BW^{\cdot 75}$ of 93% compared to 89% found on $BW^{\cdot 66}$. Mean efficiencies of fat energy retention calculated on $BW^{\cdot 66}$ and $BW^{\cdot 75}$ for boars and barrows were 7% greater in barrows compared to boars. For protein deposition the relationship was reversed with boars requiring less energy for a kcal of protein accretion than barrows. The efficiencies of protein energy accretion ($1/k_p$) were 66 ($BW^{\cdot 66}$) to 72% ($BW^{\cdot 75}$) for boars and 52 ($BW^{\cdot 75}$) to 56% ($BW^{\cdot 66}$) for barrows. The mean protein energy retention efficiencies (on $BW^{\cdot 66}$ and $BW^{\cdot 75}$) for boars was 28% greater than for barrows.

The intercept of the multiple regression equation has been considered as the ME_m (Kielanowski, 1965). The comparison between boars and barrows approached significance ($P<.09$ and $P<.11$) being greater in boars on both the $BW^{\cdot 66}$ and $BW^{\cdot 75}$ basis. On a $BW^{\cdot 66}$ basis ME_m for boars was 27% greater and on $BW^{\cdot 75}$ basis 29% higher than ME_m of barrows. The ME_m calculated from the data expressed on $BW^{\cdot 66}$ compared to data expressed on $BW^{\cdot 75}$ were consistently 48% greater ($P<.01$) for both boars and barrows.

Discussion

The energy retention in protein and fat found for boars and barrows at the 2.5% FL indicates that this FL was above maintenance energy requirements for boars and barrows. At

the 4.0% FL barrows consumed all feed provided shortly after feeding but boars demonstrated a less aggresive eating habit and did not consume all of the daily feed allowed, indicating that the 4.0% FL slightly exceeded ad libitum intake for boars. Daily feed consumption has been reported to be 21% lower for boars than barrows over the weight range studied (Chapter II). Therefore, the maximum FL may have been near ad libitum intake in boars but was below the ad libitum intake of barrows by as much as 21%. Hence, the greater energy intake associated with ad libitum intake in barrows may have increased fattening in barrows even more.

The lack of differences found in the final EB weight agrees with past studies that have shown no difference in growth rate or final weight of boars and barrows (Campbell et al., 1985; Castel and Strain, 1985).

The greater daily protein and lower fat retention in EB and viscera of boars compared to barrows were consistent with other studies that have shown greater carcass muscle and less total carcass fat in boars than in barrows (Wood and Riley, 1982; Campbell et al., 1985; Castel and Strain, 1985; Knudson et al., 1985b). The percentage difference in the retention of protein and fat in boars and barrows were found to be greater for visceral comparisons than for EB. EB protein retention was 19% greater while viscera protein retention was 48% higher in boars compared to barrows. The difference in viscera fat retention between barrows and boars was also greater than EB fat retention. Barrows had

78% higher viscera fat retention and 62% more EB fat retention than boars. The difference in total energy retention of boars and barrows followed the relationship found for retained fat rather than protein, with barrows retaining 61% more viscera energy and only 34 to 38% more EB energy than boars.

These comparisons indicate that fat and protein retention differences between boars and barrows are greater in viscera than EB. The viscera protein retention in boars was 48% greater than in barrows. The EB protein retention was 19% higher in boars relative to barrows. The difference in these two percentages was greater than similar comparisons found in this study between viscera and EB fat or energy retention in boars and barrows. Even though the largest percentage difference between boars and barrows was in fat retention (in both viscera and empty body) the largest retention difference in viscera and EB between boars and barrows was protein retention (tables IV-6 and IV-7).

The greater viscera and EB protein retention in boars compared to barrows may be a factor in the trend for greater heat production for boars compared to barrows. In this study the fasting heat production determined from the intercept in the linear regression model tended to be greater in boars than in barrows. Comparison of heat production of boars and barrows from two previous studies have shown 60 kg boars produced 6 to 11% more heat/day than barrows. Higher heat production in boars compared to

barrows may be associated with the greater overall protein retention found for boars in the present study and the increased protein synthesis suggested in skeletal muscle of boars compared to barrows from in vitro studies (Mulvaney, 1984). Garlick et al. (1976) estimated that protein turnover accounted for a major portion (17%) of overall metabolic rate and Reeds (1980) suggested that protein synthesis contributes a constant proportion (15%) of the total body energy expenditure to heat production. Fasting heat production has been found to be more highly correlated with lean tissue weight than total body weight by Tess et al. (1984a). The increased viscera protein retention in boars may contribute significantly to the greater heat production in boars relative to barrows. Reeds (1980) reported that fractional protein synthesis was higher in visceral tissues than skeletal muscle resulting in a greater visceral protein turnover than in skeletal muscle (Schimke, 1977). Tess et al. (1984a) found that viscera protein weight also was highly correlated with fasting heat production. Although fasting heat production tended to be 18% to 27% greater in boars than barrows the relative differences in fasting heat production were not significantly different between boars and barrows. Another factor to consider is that efficiency of energy retention has been shown to be less than the efficiency of energy used for maintenance (ARC, 1980; Garrett, 1980). The linear

regression method assumes a constant efficiency for both processes and therefore may overestimate heat production.

The comparison of ME_n between boars and barrows resulted in a trend for greater ME_n for boars than barrows. This difference was consistent for all methods of calculation, and approached significance when calculated from the MLR method. The ME_n for boars tended to be 27 to 41% greater than for barrows. The results of the present study are supported by other comparisons of ME_n in boars and barrows. ME_n reported by Close et al. (1983) for boars were higher than ME_n found for barrows by Verstegen et al. (1973). ME_n determined by Walach-Janiak et al. (1980) for boars was higher than ME_n reported by Kortarbinska (1969) for barrows. The differences found in these studies indicate an 11 to 27% higher ME_n in boars compared to barrows. These percentages are lower than the 27 to 41% comparison in the present study. The higher percentages may be a factor of BW, because in the present study boars and barrows were approximately 90 kg and they were only 60 kg in the other studies. The higher ME_n indicated for boars relative to barrows also may be related to efficiency of protein retention. Additional discussion on ME_n in relation to efficiencies of protein and fat deposition follows.

The efficiency of total EB energy retention in barrows and boars were compared and tended to be 12 to 14% greater in barrows than boars. This greater overall efficiency of energy retention in barrows is likely to be due to the

significantly greater fat retention in barrows, as fat energy retention is more efficient than retention of protein energy (ARC, 1981).

The retention efficiencies of protein energy compared to fat energy (from boars and barrows) resulted in a trend for greater efficiency of fat energy retention than protein energy retention. These results agree with past studies that have shown that retention of fat energy was more efficient than retention of protein energy (Thorbek, 1970, 1975; Kortarbinska, 1969; Berschauer et al., 1980).

The comparison of efficiencies of protein and fat energy retention between boars and barrows resulted in boars tending to be more efficient in protein energy retention while barrows tended to be more efficient in fat energy retention. Holmes et al. (1982) reported a different relationship for efficiency of protein and fat energy retention between boars and barrows than found in the present study. Barrows tended to have greater efficiency of both protein and fat energy retention than boars (Holmes et al., 1982). However, neither in the study by Holmes et al. (1982) nor in the present study were the efficiency differences significantly different and no other reports have shown a comparison of protein and fat energy retention efficiencies between boars and barrows.

The explanation for the trend for greater efficiencies of protein energy retention in boars relative to barrows is not readily apparent. The average efficiencies of protein

energy retention found in boars (69%) and barrows (54%) in the present study can be related to overall protein turnover. Van Es (1977) has theorized that from stochiometric calculations that 4 to 5 molecules of ATP are needed for each peptide bond in protein synthesis. As an average 1 mol of amino acids in a peptide chain weighs about 100 g thus it can be stated that 4 to 5 mol of ATP are needed to link the amino acids of 100 g of protein that contain approximately 569 kcal (100 g x 5.69 kcal/g of protein; Brouwer, 1965). This amount of ATP can be produced by oxidation of (4 to 5) x 18 kcal/ATP = 90 kcal ME, so that the expected energetic efficiency for protein synthesis is close to 569/(569 + 90) = 86% (van Es, 1977). With two turnovers of protein the efficiency decreases to 569/(569 + 90 + 90 +90) = 68% which is similar to the efficiency of protein retention found for boars in this study. At four turnovers of protein the efficiency decreases to 569/(569 + 90 + 90 +90 + 90 + 90) = 56%, similar to the efficiency found for barrows. Mulvaney (1984) found higher in vitro rates of protein synthesis and degradation in boars compared to barrows. These differences found by Mulvaney (1984) indicate a greater protein turnover in boars than barrows which disagrees with no difference found in protein accretion between boars and barrows in the present study. If boars do have a greater protein turnover than barrows, the relative energy required for protein accretion in boars should be somewhat greater. However, ME_m and fasting heat

production tended to be greater in boars than barrows. The higher ME_m in boars relative to barrows may be the energy associated with increased protein turnover in boars. Therefore, the efficiency of protein accretion appears to be greater in boars because the energy of protein turnover is calculated in ME_m.

Another area of discussion is related to the comparison of overall efficiency of energy deposition and energy required for increased weight gain. The daily protein (PE) and fat (FE) energy retention at the 4.0% FL expressed on $BW^{.66}$ and the corresponding ME daily feed intake (FI) and efficiencies of protein (EPR) and fat (EFR) retention from MLR for boars and barrows were considered in the following calculations.

Efficiency of energy retention in boars = (42.9 PE/.66 EPR + 119.9 FE/.85 EFR)/470 FI = .44

Efficiency of energy retention in barrrows = (33.8 PE/.56 EPR + 168.4 FE/.89 EFR)/462 FI = .54

These calculations indicate that barrows (.54) are more efficient than boars (.44) in retention of ME energy.

On a weight basis the accretion of protein is associated with water at a protein/water ratio of .25 (Van Es, 1977). Consideration of the addition of water with protein allows the following calculations to be made with the grams of retained protein (RP) x 5 (1 g of protein associated with 4 g of water), grams of retained fat (RF), and the same FI as used in the previous calculations.

Daily grams of weight retention in boars per kcal of ME

FI = ((7.53 RP x 5) + 12.86 RF)/470 FI = .11

Daily grams of weight retention in barrows per kcal of

ME FI = ((5.95 RP x 5) + 17.9 RF)/462 FI = .10

These calculations indicate a 10% greater weight retention per kcal of ME intake in boars compared to barrows when water is included in the calculation. When water is not considered, the respective weight retentions per kcal of ME intake are .052 g/d for barrows and .043 g/d for boars.

The final area of discussion is related to the limitations of the methods used in this experiment. The accuracy of the linear regression method for predicting maintenance energy requirements and efficiency of energy retention is dependent on providing varying feed intake levels over the widest possible range and yet still have greater than zero retained energy. The 2.5% FL provided that retained energy was higher than zero however, a FL lower lower than 2.5 % may have resulted in a wider range in FL. Even though the 4.0% FL was similar to the ad libitum intake for boars a greater maximum FL was needed for barrows.

The number of replicates in the present study were calculated from the variation of compositional differences between boars and barrows. The number of replications based on compositional differences were not enough to provide statistical differences in maintenance energy requirements and efficiency of protein, fat and energy retention between

boars and barrows. In energy future studies the number of replications should be based on the variation of the parameters of primary importance.

Summary

Retention of protein was greater in boars relative to baprows while retention of fat was greater in barrows compared to boars in viscera and EB. These relationships were found in retention of protein and fat energy in viscera and empty body between boars and barrows.

The comparison of LRM variables between boars and barrows resulted in no significant differences, although consistent trends were found for increased ME_n and fasting heat production in boars while overall efficiency of energy retention tended to be greater in barrows. Calculated from the MLR, greater ME_n in boars compared to barrows approached significance while no difference was found in the efficiencies of protein and fat between boars and barrows.

In conclusion boars tended to have a greater ME_n than barrows while barrows tended to have greater efficiency of energy retention, supported by a greater daily fat retention in barrows relative to boars.

Final Summary

Mean serum testosterone concentration (MSTC) in boars increased after birth to 1.65 ng/ml at 3 wk of age and then decreased to .59 ng/ml by 6 wk of age. MSTC were not found to increase consistently again until after 15 wk af age (70 kg live weight) when MSTC was 2.2 ng/ml. Compared to castration at 6 wk of age pigs castrated at birth had lower weights of teres minor muscles. With the exception of that difference, perinatal androgens were not found to alter performance or development of muscles, fat or bone in 105 kg barrows.

In the comparison of boars, barrows and gilts fed optimum dietary protein no differences in performance were found prior to 70 kg live weight. From 71 to 105 kg, daily feed intake of boars was 21% less and gilts 14 % less than barrows. Efficiency of gain also, differed only in the final period with boars having 23.7% greater efficiency than barrows and 17.6% higher than gilts.

Digestible energy (DE), metabolizable energy (ME) and nitrogen corrected metabolizable (ME_N) of a similar diet were greater in boars compared to barrows by 2.4%, 2.2% and 1.8%, respectively. When feeding level was increased from 2.5% to 4.0% of live weight no difference was found in DE, ME or ME_N for either boars or barrows.

Daily protein retention was greater in boars relative to barrows and daily retention of fat and total energy were higher in barrows compared to boars. Total energy retention determined by linear regression tended to be greater in barrows than boars. However, metabolizable energy of maintenance (ME_m) and fasting heat production calculated by this method tended to be greater in boars compared to barrows. ME_m determined from multiple linear regression also tended to be greater in boars relative to barrows. The comparison of efficiencies of protein and fat energy retention determined from multiple linear regression resulted in a trend for higher efficiency of protein retention in boars and for greater fat energy retention in barrows. Although, the efficiency of total energy retention tended to be greater in barrows than boars the lower feed required for gain in boars relative to barrows appears to be due to the greater protein retention and the water associated with that greater retained protein in boars.

APPENDICES

Appendix A.1

Testosterone Assay

PREPARATION

1. Set up assay sheet (160 tube maximum - including standards, standard serum,samples).

2. Number extraction tubes (16 x 100 mm) for Tracers (TR), standard serum (SS) and blanks.

3. Number assay tubes (12 x 75 mm) for standards, zeros, SS and samples.

EXTRACTION EFFICIENCY

1. Add 10 ul ^{3}H testosterone (refrigerator 3 - no. 3072) to each of 3 scintillation vials and 3 extraction tubes (TR). Dry with nitrgen. (Use Hamilton syringe - clean with MeOH before and after).

2. To the scintillation vials add 5.0 ml ACS cocktail, cap and label "TTC" (tracer total counts). Set aside.

3. To tubes add appropriate amount of serum (200ul) from random samples to be assayed or a standard serum, allow to equilibrate 30 min and proceed with extractions.

SAMPLING AND EXTRACTION

1. Sampling - add 200 ul serum to extraction tubes according to the assay sheet.
   a) Standard serum - low (200 ul) and high (50 ul) in triplicate.

   b) Unknowns - 200 ul in duplicate.

2. Extraction - add 10 volumes (2 ml) Benzene: Hexane (1:2) to each tube.
   a) Vortex all tubes for 30 s.

   b) Freeze in the tubes with a MeOH: dry ice bath.

   c) Decant the supernatant:
      1) TR decant into scintillation vials, add 5.0 ml ACS, cap, label "TR" and set aside.
      2) Decant samples and standard serum into 12 x 75 mm tubes.
      3) Evaporate the solvent in vacuum oven in the hood.

Page 2 Appendix A.1

STANDARD CURVES

1. With Hamilton syringe, add appropriate amounts to tubes. Do in triplicate: 0, 5, 10, 15, 20, 25, 30, 40, 60, 80, 100 ul. These are taken from stock testosterone solution (10 ng/ml).

2. Allow to dry in vacuum drying oven.

ASSAY PROCEDURE

1. Add 200 ul antibody (antibody has cross reactivity with dihydrotestosterone of approximately 60% and 1.7% with androstendione) to all tubes (not background), vortex 2 s.

2. Allow to equilibrate 30 min at room temperature.

3. Add 200 ul ^{3}H testosterone to all tubes and to 3 scintillation vials, vortex tubes. To scintillation vials add 5.0 ml ASC, cap and label "100%" or "TC". Set aside.

4. Incubate tubes 12 to 18 h at 1 to 5 C cooler.

SEPARATION OF BOND VS. FREE HORMONE
(.5% charcoal, 1% dextran)

1. Put stock charcoal solution on magnetic stirrer for about 10 min.

2. Put assay tubes on ice bath for 10 to 15 min.

3. Aliquot enough charcoal for assay into small beaker with a stir bar and place in ice bath on stir plate.

4. Add .5 ml charcoal to all tubes with a Cornwall syringe.

5. Vortex and spin 15 min at 3000 rpm.

6. Put carriers into ice bath.

7. Decant the supernatants into scintillation vials and mix with 5.0 ml ACS.

(These steps must be done quickly and without interruption)

COUNTING

1. Load counter according to the computer protocol.

2. Count tubes for 4 min and record on magnetic tape.

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COMPUTER PROTOCOL:

Back ground
"O"
Std curves
TTC
TR
Samples - (blanks, high serum, low serum and samples)
100% or TC

APPENDIX A.2

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 of cylinder with a metal plate welded to one end. A solid piston in the cylinder was placed on top of the sample and the samples were crushed into approximately 2.0 cm diameter fragments using a sledge hammer. The sample was then placed in a IKA Universalmuhle model M20 high speed impact mill (Tekmar Co., Cincinnati, OH) with equal amounts of crushed Dry-Ice for 45 to 60 s. 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.

APPENDIX A.3

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 4 C for 1 h.
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 h.
6. Pipett off .02 M guanidine-HCl buffer and discard.
7. Add 2 ml of BSS buffer (Appendix B.1 and B.2) plus 2 drops of methylene blue.
8. Gently shake at 4 C for at least 2 d.
9. Remove beaker from shaker and homogenize for 30 s using a Virtis 45 model Super 30 homogenizer (Gardiner, NY).
10. Put one to two drops of mixture on microscope slide- add cover slip.
11. Measure diameter of 50 fibers at a total magnification of 400. Use a micrmeter scale in the eye piece that is calibrated with a stage micrometer to measure fiber diameter. Express fiber diameters in um.

APPENDIX A.4

Gluteraldehyde - BSS Buffer

- 1% gluteraldehyde in BSS Buffer.
- BSS Buffer:
  - Mix the following compounds with deionized 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 A.5

Guanidine - HCL Buffer

Make a : 1) .02 M guandine - HCl solution.

2) .05 M boric acid - KOH buffer.

Mix to a pH 9.5.

APPENDIX B.1

Guanadine - HCL in Borate Buffer

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

APPENDIX B.2

.05 M Borate Buffer pH 8.5

1. Mix 31.0 g Boric acid in 1000 ml deionized H_2O.
2. Mix 47.6 g Borax in 1000 ml deionized H_2O.
3. Add 50 ml of solution 1 to 14 ml of solution 2 and dilute with deionized H_2O to a total of 200 ml.

APPENDIX C-1

Linear Regression on 40 Boars and 40 Barrows

Groups	Intercept	SE[a]	Slope	SE[a]	R^2
Boars:					
.66[b]	-80	28	.49	.07	.55
.75[c]	-53	19	.48	.07	.53
Barrows:					
.66[b]	-100	30	.63	.07	.45
.75[c]	-65	24	.61	.07	.42

[a] Standard error.
[b] Data expressed to body weight$^{.66}$.
[c] Data expressed to body weight$^{.75}$.

APPENDIX C-2

Multiple Linear Regression on 40 Boars and 40 Barrows

Groups	Intercept[a]	SE[b]	k_p[c]	SE[b]	k_f[d]	SE[a]	R^2
Boars:							
.66[e]	281	21	.09	.60	1.38	.20	.58
.75[f]	192	14	-.07	.60	1.37	.20	.56
Barrows:							
.66[e]	256	24	.30	.73	1.10	.13	.45
.75[f]	168	17	.47	.76	1.09	.14	.42

[a] Calculated metabolizable energy of maintenance.
[b] Standard error.
[c] Metabolizable energy (kcal) required to deposite a kcal of protein.
[d] Metabolizable energy (kcal) required to deposite a kcal of fat.
[e] Data expressed to body weight$^{.66}$.
[f] Data expressed to body weight$^{.75}$.

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