VISUAL APPRAISAL OF BOVINE CANNON BONE SIZE AS RELATED TO PERFORMANCE AND CARCASS TRAITS AND METACARPAL MEASUREMENTS

by

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B. S., Kansas State University, 1971

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1973

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ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation and gratitude to Dr. Michael E. Dikeman for his guidance and encouragement during the research study and preparation of the manuscript. Appreciation is also extended to Dr. Dell M. Allen and Dr. Gary L. Allee for reviewing the thesis. Special appreciation is expressed to Dr. Arthur Dayton for his advice and assistance with the statistical analysis.

Appreciation is extended to the staff of U.S. Meat Animal Research Center, Clay Center, Nebraska, who initiated and designed the cattle germ plasm evaluation program and to the Livestock Division, Consumer and Marketing Service, U.S.D.A. for their assistance in the collection of carcass data. Appreciation is also extended to the Sunflower Packing co., York, Nebraska, and Housing and Food Service, Kansas State University for their excellent cooperation in the slaughtering and processing of the animals.

In addition, the author wishes to thank his parents for their understanding and encouragement and above all, a special thanks to Mary Howell.

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INTRODUCTION

The term "ruggedness of bone" is used in live animal appraisal and selection of breeding and market animals. In judging live animals, ruggedness is often related to muscling, growth potential, and hardiness of the breeding or market animal.

Ruggedness of bone as evaluated in this study deals with the size or circumference of the cannon bone in relation to body size. There is some controversy among livestock people concerning the accuracy and usefulness of appraising bone size. Some contend that apparent differences in bone size are actually differences in hide thickness, hair length, and tendon size. Furthermore, there is the question of whether ruggedness of bone is actually related to growth rate, muscling, and cutability.

Literature relating live animal visual appraisal of cannon bone size with actual bone circumference, growth rate, carcass composition, or other economic traits is limited. Considerable research has been published dealing with live cannon circumference measurements and metacarpal measurements, but the results are inconsistent and few studies include all economic traits.

A large variability of type is represented by 14 different breed crosses in this study. Hereford, Angus, Jersey, South Devon, Limousin, Simmental, and Charolais sires were mated to Angus and Hereford dams and evaluated for economic traits relating to growth rate and carcass cutability. These animals were from the same cowherd, similar in age, fed the same ration, and raised under the same environmental conditions.

The objectives of this study were: 1) compare feeder and slaughter visual appraisal of bone size to live cannon and metacarpal measurements, 2) relate feeder and slaughter visual bone appraisal to growth rate and carcass composition, 3) compare live cannon measurements to growth rate and carcass muscling, and 4) correlate live cannon measurements to metacarpal and metacarpal cross-section measurements.

This research project combines live animal bone appraisal scores, live cannon measurements, actual metacarpal measurements, growth rate and carcass composition data. The author therefore contends this is one of the most thorough studies conducted to date in regard to ruggedness of bone.

REVIEW OF LITERATURE

Early Research

The relationship between cannon bone size and carcass muscling and weight of bone in the carcass has long been reported to exist. Lush (1926) stated, "the whole problem of size of bone in its relation to meat value, to the desirability of cattle as feeder cattle, and to the desirability of cattle for range-beef production is a large one." He found the most practical indication of percentage bone in the carcass to be the weight of the four legs below the knees and hocks. In his study with 43 steers, he found a correlation of (0.90) between the percentage of bone in the carcass and the percentage which the legs are of the live animal.

Hammond (1932) and Palsson (1939) found in sheep that during growth a bone develops in length, then later rapidly develops in thickness. Hammond states, "As the different bones of the limbs are in different stages of development at birth, the cannon, with its earlier development, has little more length growth to make but much thickness." Working out the ratio of total bone weight to the weight of one cannon, he found the ratio varied most when different ages were concerned. He explains this by the fact that the cannon bone develops early in life as compared with most other bones in the body.

Palsson found the weights of the four cannons to be highly correlated with skeletal weight in lambs. The relationship between the left forecannon and the total weight of bone in the carcass was similar to all four cannons. He states, "The best single measure we have found for estimating the weight of total bone in the carcass is therefore the weight of one forecannon."

McMeekan (1956), in research work in Europe and New Zealand, completely dissected thousands of meat animals, weighing and measuring every individual muscle and every individual bone in the body. He found a strong positive correlation between the weight of bone in each meat animal and the weight of muscle tissue. McMeekan explained, "It is not possible to get a carcass with a really great wealth of fleshing without having associated with that flesh a heavy weight of bone." He concludes, "So strong is this relationship that the weight of muscle can be determined within 1% if the weights of the cannon bones are known."

This early work has been the basis of much of the research conducted in regard to muscle to bone ratio and cannon bone measurements. Little research, however, has been conducted in regard to the live animal visual appraisal of cannon bone size, growth potential and carcass composition.

Visual Appraisal

Most of the research dealing with cannon bone appraisal has been with the slaughter animal. Varying results have been reported in regard to the relationship between visual cannon size and growth characters, carcass muscling and actual bone measurements. Weseli (1957) using 153 steers representing the Angus, Hereford and Shorthorn breeds visually appraised cannon bone size along with body and carcass measurements. These animals were exhibited at the International Livestock Exposition and carcass contest and ranged from 12 to 18 months of age and 364 to 591 kg in weight and were from many locations. The circumference of the left cannon was measured midway between the knee and pastern joint with additional frontal width and lateral depth measurements being taken. A committee of three appraisers visually estimated bone size and grade on the live animal. The average score of the committee was used in the analysis. Visual bone size was scored from 2 to 14 with 2 representing very heavy boned steers. At the time of slaughter the left metacarpal was removed and cleaned of all excess tissue. Circumference, lateral width, and frontal depth measurements were taken on the clean metacarpus in a similar fashion as the live cannon measurements.

Bone scores were highly significantly correlated with live weight (-.36) but were not related to live cannon circumference measurements (simple correlation -.04, and partial correlation 0.16). Simple correlations between bone score and dressing percent and fat thickness were not significant. However, the partial correlations (holding live weight constant) between bone score and dressing percentage (0.27) and fat thickness (0.22) were significant. This indicates that among similar weight steers, those appraised as having large bones tended to have lower dressing percents and tended to have less fat. Although the simple correlation between bone score and loin eye area (-.20) was significant, the partial correlation was not significant (-.10), indicating that for steers of similar weight bone score is not related to loin eye area.

Weseli also indicated rugged bone scores were associated with large metacarpal measurements. Visual bone scores were significantly correlated with metacarpal frontal width measurements (-.51 simple and -.43 partial), lateral depth measurements (-.20 and -.13) and circumference (-.49 and -.33). Holding weight constant decreased the correlation coefficients in every instance.

Boughton (1958) visually estimated bone size and took linear measurements on the live animal including cannon circumference on 30 Hereford steers and 53 Hereford heifers. A committee of six individuals independently assigned bone scores from 1 to 7, with 1 being very fine and 7 very rugged.

Bone appraisal was not well correlated with carcass characteristics for either heifers of steers. Loin eye area, fat thickness, marbling score, and the percentage of wholesale cuts were not significantly related to bone scores. Among heifers of similar weights, bone appraisal was highly correlated ($P<.01$) with percentage of commercial round (0.46), percentage of total wholesale cuts (0.44), and correlated ($P<.05$) with percentage loin (-.27).

Boughton's results also indicated that large cannon circumference was associated with the appraiser's estimation of large bone in heifers (0.61 simple and 0.51 partial). Bone appraisal was highly correlated (0.57 simple and 0.60 partial) for muscle appraisal in steers but not with live grade or live weight.

Adams, Carroll and Albaugh (1971) visually appraised cannon bone size in a different manner. In their study they collected the portion of the right front leg distal to the carpus from 124 Hereford and Hereford-Red Angus cross steers of approximately 15 months of age, which were fed the same high-concentrate ration from weaning, and had a mean live weight of 442 kg. The visual appraisal of the limbs was made by placing them front side up on the laboratory floor. Three livestock judges scored the bone size from 1 to 9 with 1 being small minus and 9 large plus. The judges, after independently scoring the shanks, re-evaluated the shanks and jointly made a combined subjective score.

Growth characteristics were found to be related to live bone size appraisal. Weight per day of age to weaning, weaning grade, final weight, feedlot average daily gain, weight per day of age to slaughter, cold carcass weight per day of age, and estimated pounds of retail cuts per day of age were significantly correlated (P<.01) to the combined visual bone score with correlation coefficients ranging from 0.29 to 0.51. Weaning weight was not significantly correlated to the visual bone appraisal.

Rib eye area was the only carcass trait studied that was highly positively correlated (0.31) to the combined estimate of bone size. No significant relationships were found between bone appraisal and fat thickness, percentage of kidney and pelvic fat, or quality grade.

Individual estimates of bone size generally had highly significant correlations with metacarpal measurements. In every instance, the correlation coefficients were higher using the combined score than for any individual's score. Highly significant correlations were found between bone score and metacarpal weight (0.50), diameter (0.65), thickness (0.49), circumference (0.67), and bone cross-sectional area (0.48). The judges' estimates of bone size were not significantly related to metacarpal specific gravity, length, weight, wall thickness, or specific gravity of the metacarpal cross-section. Adams concluded that subjective estimates of bone size have value in determining merit in cattle.

Long (personal communication) presented an opposing theory to that of Adams and coworkers. He states that the circumference of the leg of live animals between the knee and ankle is not a measure of bone but of hair, hide, connective tissue, tendon and bone. Thus, he states, "you cannot simply measure the size of bone visually in live animals; therefore it is not a trait to consider in selection or evaluation programs."

Live Cannon Measurements

Growth and Performance Characteristics

Several studies have been conducted with the live animal measurement of cannon bone circumference. Lush (1932) measured cannon circumference along with twenty other measurements on the live steer when studying the relationship of body shape of feeder steers to rate of gain, dressing percent, and value of the carcass. Correlations of (0.31, 0.37, 0.81, 0.37, and 0.32) were found between cannon bone circumference and rate of gain, dressing percent, meat value per steer, meat value per live weight, and estimated fatness. Lush concluded that the regression coefficients indicate that steers which were fatter and more heavily muscled but smaller boned than other steers of the same size had the highest dressing percent and the most desirable meat at the end of the feeding period.

Cannon circumference along with several other live measurements were collected by Hankins, Knapp and Phillips (1943). In beef Shorthorns and dual purpose cattle cannon circumference was not significantly correlated to the muscle-bone ratio (-.26 and -.04, respectively). Correlations of efficiency of gain and age of steer at slaughter with muscle-bone ratio were also very low (-.04 and -.08). Hankins concluded, "No relationship was found between live animal measurements and the muscle-bone ratio, indicating that selections could not be made on the basis of conformation as evaluated by such measurements."

Yao, Dawson and Cook (1953) collected 19 live animal measurements of 101 beef Shorthorn and 62 milking Shorthorn steers. Cannon circumference was positively correlated ($P<.05$) with birth weight (0.16), and showed a negative, nonsignificant correlation with days to weaning, feed efficiency, daily gain, slaughter grade, carcass grade, and dressing percent. Cannon bone circumference was generally not significantly correlated to any of the body measurements.

One study has been conducted dealing with the cannon bone measurement in the new-born calf. Flock, Carter and Priode (1962) collected several linear measurements along with birth weight and birth conformation scores on 473 Angus, 514 Hereford and 438 Shorthorn calves over a 5-year period. Two traits observed at weaning time were average daily gain from birth to weaning and a weaning type score. Cannon bone circumference was correlated ($P<.01$) with birth weight (0.54) and birth type (0.33). However, preweaning average daily gain had a highly significant negative regression on circumference of cannon bone in Herefords. The negative relationship between cannon circumference and subsequent gain was indicated in the other two breeds.

Scarth (1966) estimated the heritabilities, and the genetic and phenotypic correlations among front cannon circumference, rear cannon length and performance characteristics from the progeny of beef sires selected as outstanding Polled Hereford individuals on the basis of show ring performance. Cannon circumference was measured at a point midway between the knee and ankle on the live animal along with other linear measurements the day before slaughter.

Cannon circumference was significantly different between sexes and among sires. The heritability estimate for cannon circumference was calculated as (0.83) with a standard deviation of (0.73 in.). This is somewhat higher than the heritability estimate of (0.34) Dawson, Yao and Cook (1955) reported. From the heritability estimates calculated, Scarth stated that a very rapid rate of breeding progress could be expected with selection for circumference of front cannon.

Scarth found that shallower-bodied cattle were longer-rumped, had larger front cannon circumference, longer rear cannons and had faster gains up to 205 days of age. The phenotypic correlations for 205-day adjusted weight with circumference of front cannon and length of rear cannon were 0.35 and 0.44, respectively. Forecannon circumference was also highly significantly correlated to seven month grade (0.37), live weight per day of age (0.37), and age at slaughter (-.41). The genetic correlations for cannon circumference with adjusted 205-day weight and live weight per day of age at slaughter were 0.42 and 0.19, respectively.

Stout (1970) also studied the genetic and phenotypic correlations between live measurements and growth characteristics of progeny sired by selected Polled Hereford bulls which had placed high in show ring performance. Forecannon circumference, the minimum circumference of the metacarpus, and rear cannon length were measured the day before slaughter along with several other body measurements on the live animal.

Growth characteristics were found to have a high relationship with cannon circumference. High phenotypic correlations ($P<.01$) were found between cannon circumference and 205-day adjusted weight (0.24), 305-day weight (0.27), 305-day grade (0.20), rear cannon length (0.18) and slaughter age (-.29).

Carcass Traits

Breed differences in the relationship between cannon bone circumference and carcass characteristics were reported by Weseli (1957). Among Hereford steers of similar weight, those with larger cannon circumference tended to have lower dressing percents and were trimmer. The simple correlations were not significant for the Hereford breed, although when partial correlations were calculated, dressing percentage (-.37) and fat thickness (-.36) were significantly related to cannon circumference. Partial correlations within Angus and Shorthorn breeds showed no relationship between live cannon circumference and dressing percent or fat thickness.

Live cannon circumference was significantly correlated with live weight (0.47) and with loin eye area (0.30). However, the partial correlations were nonsignificant. Weseli also found the simple correlations of cannon circumference with dressing percent and fat thickness were nonsignificant.

Boughton (1958) found a significant partial correlation (carcass weight held constant) between live cannon circumference and percentage of round, loin, rib, and chuck in heifers. However, he did not find any significant correlations between live cannon circumference and any carcass traits in steers.

Orme et al. (1959_b) collected data from 31 yearling steers of Angus and Hereford breeding. Circumference measurements were recorded on the fore and hind legs along with other live and carcass measurements. The joint effects of live weight and fore and hind cannon circumference were associated with 27 to 43% of the variation existing in rib eye area. Fore and hind cannon circumference showed negative correlations with rib eye area (-.23 and -.46). Fore and hind cannon circumferences were also significantly correlated to percentage of primal cuts (round, loin and rib on a live weight basis) with values of 0.35 and 0.41, respectively.

Cattle with larger cannon circumference were shown to have larger loin eyes, less fat at the twelfth rib and lower dressing percents in a study by Good et al. (1961). They collected data from 674 steers shown in the on-foot carcass show at the 1956-57-58 International Livestock Expositions. These steers represented the Angus, Hereford and Shorthorn breeds ranging from 364 to approximately 591 kg live weight and from 12 to 18 months in age. Linear measurements along with cannon circumference at the midpoints were obtained.

Circumference of cannon bone was negatively correlated ($P<.05$) over pooled data for dressing percent, marbling score, and fat cover (-.32, -.32 and -.34, respectively). Rib eye area, (holding live weight constant) was lowly correlated with cannon circumference with a value of 0.13. Good concluded that heavy-boned cattle with large rounds are desirable since these animals tend to have less fat and more lean. These results agree with McMeekan (1956) whose studies indicated fine-boned animals of the various classes of livestock yield a smaller percent of lean meat and a larger proportion of fat than heavier-boned animals of the same weight.

Scarth (1966) indicated a high positive association between circumference of front cannon and estimates of carcass cutability. He reported significant correlations when pooled within sex and sires between forecannon circumference and loin eye area (0.29), carcass grade (-.29), marbling score (-.26), and percent trimmed loin (0.30). Highly significant correlations were found between cannon circumference and hide weight (0.56), dressing percent (-.41), weight of trimmed loin plus round per day of age (0.48), and percent trimmed round (0.56). From correlations in this study, Scarth concluded that selection for cattle with longer rumps, thicker rounds, larger circumference of front cannon, and longer rear cannon would be desirable because faster gaining cattle and cattle with higher carcass cutability would be obtained from this selection. However, this selection would also result in genetically lower grading carcasses and carcasses with less tender loin eye steaks.

Busch, Dinkel and Minyard (1969) collected data from 745 grade Hereford steers raised on 25 private ranches over a period of 7 years. Eighteen linear and circumference measurements were taken shortly before the steers were slaughtered. Various subjective scores were also placed on the animals at the beginning and end of the feeding trial. Cannon circumference (measured at the smallest portion) was shown to have a high positive significant correlation to edible portion with values ranging from 0.40 to 0.46 on the three groups studied. Busch concluded, though, that body measurements were of little value in predicting edible portion, as slaughter weight and measurements combined accounted for only 2 to 4% more variation in edible portion than slaughter weight alone.

Forecannon circumference, rear cannon length and the estimates of cutability and fat thickness were favorably correlated phenotypically with carcass meatiness in a study conducted by Stout (1970). A high, significant phenotypic correlation was shown between cannon circumference and dressing percent (-.34), carcass weight per day of age (0.28), fat thickness (-.29), trimmed round percentage (0.29), percentage of trimmed loin and round (0.24), and percentage of cutability (0.27). Significant, but low, negative phenotypic correlations were reported for carcass grade (-.11) and marbling score (-.17), while loin eye area and percent trimmed loin were not significantly related to cannon bone circumference.

The relationship between cannon bone size and amount of trimmed retail cuts was studied by Skelley, Durfos and Bonnette (1972) using 140 Angus and 26 Polled Hereford steers which were approximately the same age and were fed for 150 days on the same ration to a final weight of 375 to 400 kg. The circumference of the fore and hind cannons with hide intact was measured midway between the joints. The total weight of both the forefeet and hindfeet was recorded. Longissimus muscle area, fat thickness, and the percentage of trimmed retail cuts were not significantly related to the circumference or weight of the fore and hind cannon bones. Forecannon circumference showed a negative relationship ($P>.05$) to the percentage of total fat trim on either a carcass or live weight basis. Forecannon weight and hind cannon weight and circumference were generally related with fat trim as a percentage of live or carcass weight.

Orts, King and Butler (1969) made a simulated live cannon bone measurement during slaughter on 63 half sibling Hereford steers. Using needle fitted calipers they measured the width and depth of the third metacarpal at its midpoint. These needles penetrated the hide, tendons and adipose tissue to the bone. Loin eye area was significantly correlated to live width as was chilled carcass weight. Live cannon depth showed a significant correlation with percent loin (0.34) and fat trim (-.25).

In a study of bovine topography and its relationship to composition, Kauffman, Smith and Long (1970) studied extremes in body type. Twelve steers were used in the study. The angular-shaped cattle were called "ectomorphs" and the bulging-quartered, convex-shaped cattle were called "mesomorphs." They chose these extremes as they felt that a distinct tendency existed for angular-shaped bodies (ectomorphs) to posess relatively smaller bones. However, plans to select for "light" and "heavy" boned structures in both extremes were discarded because of "a lack of preciseness in subjective appraisal."

Loin eye area, fat thickness, marbling and quality grade were higher for the mesomorphs and cutability score was higher for the ectomorphs. Mesomorphs were found to have a significantly ($P<.01$) greater fat-free muscle percentage and muscle-bone ratio. Percent bone was significantly higher for the ectomorphs and percent fat was not significantly different.

Live metacarpal width and length were significantly different for the two types with the ectomorphs having the larger values. The percentage of shank plus foot, live cannon circumference, percent ash, and bone wall area were not significantly different between types. Kauffman concluded, "It is apparent that bone mass at the center of the metacarpal was similar, even though live width was different. Perhaps this difference is related to thickness of hide. The bone data suggest that heavy and light, large and small, and dense and porous bone exist in both groups."

Relationship with Metacarpal Measurements

Little research has been done in regard to the comparison of live cannon measurements to metacarpal measurements. Weseli (1957) found live cannon circumference highly significantly related to metacarpal circumference (0.43 simple and 0.31 partial), and live cannon frontal width and lateral depth measurements were highly correlated with their respective carcass measurements, revealing that larger-boned animals tended to have larger actual bone measurements.

Long (personal communication) (1972) has presented the theory that the circumference of the leg of live animals between the knee and ankle or hock and ankle is not a measure of bone but of hair, hide, connective tissue, tendon, and bone, and any exterior measurement would give no idea of the thickness of the wall of the bone or of its strength or density. Among steers of similar weight and wide differences in muscling, the bone may be heavy or light, large or small, and dense or porous throughout the group with no particular association with amount of muscling. He also feels that bone varies little in percentage of carcass or body weight and there is practically no variation in shape of bones from one animal to another. "Therefore, we do a great deal of talking about differences in bone, but, in reality, the differences are quite small when compared with differences in fat and muscle."

Metacarpal Measurements

Growth and Performance Characteristics

Wilson *et al.* (1971) measured both fore and hind cannons on 65 steers and 68 heifers sired by Angus and Hereford sires to study the relationship of metacarpal bone dimensions, as measured in the carcass, with growth and meatiness. The correlations indicated that animals with greater metacarpal dimensions tend to have heavier 205-day weights and reach slaughter weight at younger ages. Metacarpal circumference was significantly correlated to 205-day weight (0.36) and slaughter age (-.41). Bone length most accurately predicted the growth and carcass characteristics, with metacarpal length slightly more accurate in predicting growth and carcass desirability than was metatarsal length.

There was no consistent or significant differences between right and left metacarpals of the animal or between metacarpals and metatarsals, indicating that measurements on only one of the bones were needed.

Metacarpal bone circumference in a study by Coble *et al.* (1971b) were found to be highly related to adjusted 205-day weight (0.36), slaughter age (-.41), and carcass weight per day of age (0.41). Like metacarpal circumference, metatarsal circumference and metacarpal cross-sectional area measurements were highly related to growth characteristics while density was nonsignificant. There was no consistent tendency for measurements on either the metacarpal or metatarsal to be more highly correlated with growth characters, agreeing with Wilson et al. (1971). These results indicate that animals with greater bone dimensions grew more rapidly.

Coble et al. (1971_a) studied the sire, sex and laterality effects on bovine metacarpal and metatarsal characteristics. Midpoint circumferences were significantly affected by sires. Generally significant sire effects were observed for metacarpal and metatarsal area measurements. Age of slaughter significantly affected most of the bone characteristics except bone density. There was no significant side effect for any of the metacarpal and metatarsal characteristics. These data therefore indicated a high degree of bilateral symmetry in limb bone dimensions.

Carcass Traits

Weseli (1957) found carcass bone measurements highly correlated to live weight (0.24 to 0.38). Metacarpus circumference was significantly correlated with dressing percent (-.34) but holding weight constant the correlation was highly significant (-.57). Among cattle of similar weights, loin eye area was not significantly correlated with metacarpal circumference (-0.11). However, when differences in weight were not considered, the simple correlation between loin eye area and metacarpal circumference (0.22) was highly significant. The simple correlation between fat thickness and metacarpal circumference was nonsignificant while the partial correlation (-.27) was highly significant.

Wythe (1958) computed a number of simple correlation coefficients using carcass and bone data from 28 Hereford and Brahman crossbred steers. The correlations reported between weight and length of bones indicate that bones develop proportionately both in length and weight. A strong positive relationship was found between bone thickness (weight:length ratio) and muscling characteristics. The metacarpal and metatarsal weight, length, and weight:length ratio were highly significantly correlated to area of rib eye muscle and trimmed wholesale cut weights with values from (0.48 to 0.71).

Orts (1959) reported highly significant simple correlations for metacarpus and metatarsus measurements with wholesale cut weights and longissimus muscle area. However, when chilled carcass weight was held constant nearly all significance was lost. One hundred thirty-two steers representing Hereford, Angus, Brahman, Sussex and Charolais breed crosses were used in this study ranging from 150 to 600 days of age. Rib eye area was shown to have a high simple correlation with metacarpal weight (0.47), area (0.86), weight:length ratio (0.59), and specific gravity (0.57). Partial correlation coefficients (holding age constant) between trimmed bone weight, weight:length ratio, various wholesale cuts, and rib eye area were highly significant. With age constant, rib eye area was highly significantly correlated to metacarpal weight (0.31), area (0.26), weight:length ratio (0.28) and specific gravity

(0.32). Orts concluded that bones develop proportionally with age.

Research by Orme et al. (1959a) indicates larger metacarpal measurements are related to increased body size. A direct relationship existed between chilled carcass weight and most of the metacarpal measurements with the exception of metacarpal circumference. Holding weight constant, regression coefficients indicated that for the same weight, steers with a greater amount of bone tend to have the highest percentage of primal cuts. The weight and width of either the metacarpus or metatarsus along with thickness, length or circumference of the metatarsus were associated with 30 to 40% of the variation which existed in live animal weight.

Weight and length relationships between certain long bones of cattle and the association between bone thickness and muscling of 28 yearling Hereford steers were studied by Wythe, Orts and King (1961). Metacarpal weight was found to have a high correlation with rib eye area (0.49) (holding weight constant). Weight:length ratio, which Wythe uses as an indicator of bone thickness, was positively correlated to the weights of the wholesale cuts and rib eye area with partial correlations ranging from 0.46 to 0.65. Wythe concluded bones of an animal develop proportionately in length and weight and that a real association existed between bone thickness and muscling of cattle.

Wilson et al. (1971) reported that animals with greater metacarpal dimensions were leaner at slaughter and yielded more pounds of trimmed round and loin per day of age and had lean which was slightly more tender. Circumference of the metacarpus was shown to have a correlation ($P<.01$) with fat thickness (-.25), weight of loin and round per day (0.36), and marbling score (-.28). Tenderness as evaluated by Warner-Bratzler shear force was significantly correlated with metacarpal circumference while loin eye area approached significance with correlations of -.21 and 0.16, respectively.

Coble et al. (1971_b) extensively measured the metacarpus and metatarsus bones from 65 steers and 68 heifers representing 11 sires. Longissimus area and cutability were generally correlated ($P>.05$) with bone measurements. Metacarpal circumference was significantly correlated with fat thickness (-.25), weight of loin and round per day (0.43), marbling score (-.28), and Warner-Bratzler shear force (-.21). Bone density was not related to any of the carcass characteristics. The correlations reported suggest that animals with greater metacarpal or metatarsal circumference and cross-sectional area measurements tend to have less fat cover, deposit more muscle per day of age, and have lower marbling scores.

Metacarpal measurements in a study by Skelley et al. (1972) were found to have a significant relationship to carcass meatiness. Weight, length, circumference at the midpoint and specific gravity were measured on the right metacarpus of 166 beef carcasses. Longissimus muscle area and fat thickness were not significantly correlated with any of the metacarpal measurements. Trimmed retail cuts, as percentages of the carcass and live weight, were correlated (P<.01) with metacarpal circumference (0.22 carcass and 0.23 live), weight (0.31 and 0.35) and specific gravity (-.23 and -.28), while length showed no relationship to percent retail cuts. Percent total fat trim was negatively correlated (P<.05) with metacarpal circumference, weight and length. Skelley concludes that beef carcasses with larger bones tend to have a greater amount of lean meat when measured by the percent closely trimmed retail cuts.

MATERIALS AND METHODS

A total of 484 steers from the cattle germ plasm evaluation program conducted jointly by the U.S. Meat Animal Research Center, Clay Center, Nebraska, and Kansas State University are included in this study. One hundred fifty of these steers were born in 1970 and the remaining 334 were born in 1971. Twenty-four Hereford, 25 Angus, 26 Jersey, 28 South Devon, 18 Limousin, 19 Simmental and 18 Charolais bulls were artificially mated to Hereford and Angus cows 2, 3, 4, 5 and 6 years old. The Hereford and Angus bulls had been selected on individual performance as a basis of acceptance for progeny testing by an artificial insemination organization. The Charolais breed included domestic and French bulls. The Simmental bulls were those available commercially, and some that the Canada Department of Agriculture had imported for research. The Limousin bulls were those available commercially. The South Devon bulls were sampled from a commercial importation, and the Jersey bulls were selected at random from two artificial insemination organizations.

The two calf crops used in this study were born in late March, April and early May of 1970 and 1971. They were creep fed a ration of whole oats beginning in mid-July until weaning in October or November at approximately 200 days of age. Birth weight, average daily gain to weaning and 200-day weight were recorded.

<u>Growth Data</u>

At weaning, steer calves with adjusted weaning weights more than three standard deviations below the mean for their breeding groups were removed from the study. The remaining steers were placed in the feedlot by breed of sire groups (replicated with two lots per sire breed) to obtain growth rate and feed efficiency data. Feedlot rations were similar for the two years consisting of 60% corn silage, 35% concentrate (ground shell corn, ground sorghum grain and ground wheat) and a 38% crude protein supplement. Postweaning average daily gains were based on actual weaning weights and final weights at slaughter. Final weights at slaughter were the average of two weights (on feed and water) taken on different days to reduce errors due to differences in fill.

Approximately one-third of the steers in each breed of sire by breed of dam group was slaughtered at each of three slaughter dates, which were 215, 243, and 271 days on feed after weaning for the 1970 calf-crop and 200, 242, and 283 days on feed after weaning for the 1971 calf-crop. Table I shows the number of steers slaughtered by breed groups and slaughter groups for the 1970 and 1971 calf-crops. Slaughter groups 1, 2 and 3 represent the slaughter periods for the 1971 calf-crop, while only the last slaughter period steers for the 1970 calf-crop are used in this analysis and are represented as slaughter group 4. The steers slaughtered from each breed group at each of the three times were identified at random

TABLE I.

Animal Numbers
by Breed Crosses and Slaughter Groups
for 1970 and 1971 Calf Crops

	Slaughter Group				
	1971			1970	
Breed*	1	2	3	4	Total
HxH	9	9	9	7	34
AxA	8	9	9	13	39
HxA	10	10	11	16	47
AxH	12	13	12	10	47
CxH	9	9	9	10	37
CxA	5	7	7	14	33
JxH	8	7	8	8	31
JxA	7	7	8	14	36
SDxH	5	7	6	3	21
SDxA	6	5	6	7	24
SxH	9	9	8	10	36
SxA	9	9	9	14	41
LxH	5	5	5	11	26
LxA	7	6	6	13	32
	109	112	113	150	484

*Breed Codes

Hereford--H
Angus--A
Charolais--C
Jersey--J
South Devon--SD
Simmental--S
Limousin--L

across all birth dates. Thus, the steers slaughtered at each of the three times had approximately the same average birth date, resulting in an average age difference between slaughter groups of 28 days for the 1970 calf-crop and 42 days for the 1971 calf-crop.

Slaughter and Carcass Data

The steers were transported to a commercial slaughter plant approximately 12 hours prior to slaughter. After slaughter, the carcasses were allowed to chill 24 hours before carcass data was obtained. U.S.D.A. Yield and Quality grades were determined by representatives of the Livestock Division, Consumer and Marketing Service, U.S.D.A. and Kansas State University. Loin eye area and fat thickness measurements were also obtained.

The right side of each carcass was transported to Kansas State University approximately 56 hours after slaughter to obtain detailed cut-out data. Dressing percent and right side chilled weight were recorded. Each side was separated into wholesale cuts, which were then processed into closely trimmed boneless cuts (rib bones in ribs, vertebrae in loin) with no more than 0.30 in. of fat on any surface. Roasts from the trimmed round, loin, rib and chuck, and fat trim, lean trim, and bone were determined as percentages of carcass weight. Lean trim was adjusted to 25% fat to obtain total retail product and percentage of cutability.

Bone Scores and Measurements

Visual bone size was scored on the steers once after weaning (feeder bone score) and just prior to slaughter. The steers were scored for ruggedness of bone by three judges on a basis of 1 to 10 (1 = extremely large and 10 = extremely small) relative to the animals' structural size. In addition to bone size, growth potential was scored at weaning with 1 extremely good and 10 extremely poor.

Hide weights were obtained at slaughter and the fore and hind shanks were removed and weighed (weight of the four cannons) with hoof and hide intact. Circumference was measured on the right cannon at its midpoint with the hide, hair, and tendons intact and then transported to Kansas State University where additional measurements were obtained.

The right metacarpus was cleaned of all extraneous material (hide, hair, tendons and connective tissue), and weights in air and water were recorded to determine bone specific gravity, with water temperature maintained at 20°C as specified by Kraybill, Bitter and Hankins (1952). Metacarpal length was measured from the articular surface of the lateral portion of the proximal end to the fourth condyle on the distal end as shown in figure 1. Bone circumference was measured with a steel tape at one-half the length, where a cross-section was removed and traced on acetate paper. Total area and marrow cavity area were then measured with a planimeter with bone wall area calculated by difference. Four bone wall thickness

THIS BOOK CONTAINS NUMEROUS PICTURES THAT ARE ATTACHED TO DOCUMENTS CROOKED.

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Figure 1. Metacarpal length measurement.

measurements using four separate locations (illustrated in figure 2) were made from the cross-section tracing. A ratio of total cross-sectional area:marrow cavity area and ratio of metacarpus circumference:total cross-sectional area were computed.

Statistical Analysis

A two-way analysis of variance was used with breed group and slaughter group in the model. The bone scores and cannon and metacarpal measurements were analyzed by the least squares method with breed differences computed by least significant difference (LSD). Simple and partial correlations among the traits studied were pooled over all breed groups and within breed groupings as outlined by Snedecor and Cochran (1967).

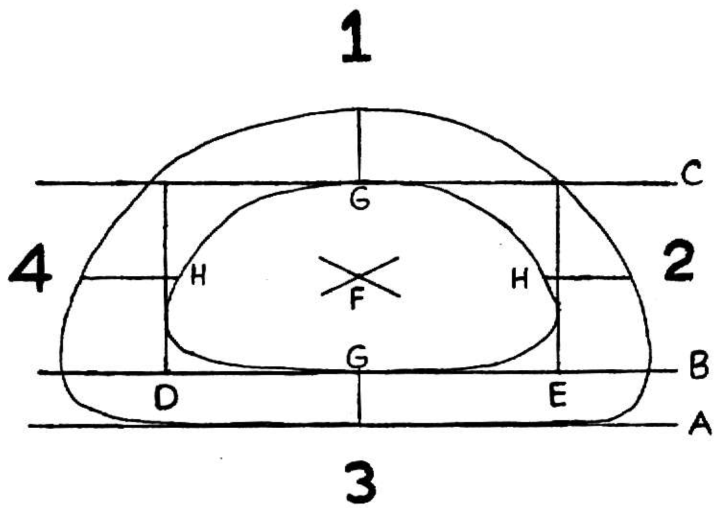

Figure 2. Metacarpal Bone Wall Thickness Measurements

An average of four bone wall measurements were taken to determine bone wall thickness. Parallel lines (A, B, and C) were drawn on the flat or posterior edge, and anterior and posterior edges of the marrow cavity of the metacarpal cross-section tracing. Perpendicular lines (D and E) were then drawn at the medial and lateral edges of the cavity. The mid-point (F) was determined by connecting opposite corners. Bone measurements 1 and 3 were then determined by drawing a line (G) through the midpoint perpendicular to the posterior edge and 2 and 4 were obtained by drawing a line (H) parallel to the posterior edge of the bone through the midpoint.

RESULTS AND DISCUSSION

Breed Cross and Slaughter Group Affects on Bone Scores and Cannon Bone Measurements

The least square means from the analysis of variance for bone scores and cannon measurements of the 484 steers studied are presented in table II by breed cross and slaughter group. Significant ($P<.05$) breed differences were observed for bone scores, cannon weights, and cannon circumferences. The Simmental x Hereford (SxH) and Charolais x Hereford (CxH) breed crosses were significantly larger boned as evaluated by both feeder and slaughter bone scores. These breed crosses also had the heaviest cannon weights and largest forecannon circumferences. On the other end of the spectrum, the Jersey crosses were scored as being the lightest boned and had the lightest cannon weights and smallest forecannon circumferences.

The Charolais x Angus (CxA), Simmental x Angus (SxA) and Hereford x Hereford (HxH) breed crosses were similar in feeder and slaughter bone scores and forecannon circumferences but were significantly different from each other in cannon weights. There was some overlapping among the other breed crosses between bone scores, cannon weight, and cannon circumference, but, generally, the animals scored as rugged boned feeder animals were also scored as rugged boned slaughter animals. This ranking of breed crosses was generally evident throughout all the least square means.

TABLE II.

Least Square Means of Bone Scores and Cannon Measurements by Breed and Slaughter Groups[1]

Breed	Feeder Bone Score[2]	Slaughter Bone Score[2]	Total Cannon Weight (kg)	Right Cannon Circ. (cm)
SxH	3.49^{a}	3.19^{a}	10.06^{a}	21.84^{a}
CxH	3.50^{a}	3.42^{a}	9.64^{b}	21.64^{a}
CxA	4.15^{b}	4.27^{b}	8.79^{d}	20.50^{cd}
HxH	4.27^{bc}	4.51^{b}	8.16^{efg}	20.57^{bc}
SxA	4.32^{bc}	4.24^{b}	9.26^{c}	20.96^{b}
HxA	4.54^{c}	5.14^{c}	8.05^{fg}	20.17^{de}
AxH	4.83^{d}	5.21^{c}	8.10^{fg}	20.24^{cde}
LxH	5.27^{e}	5.19^{c}	8.51^{de}	20.30^{cde}
LxA	5.69^{f}	5.62^{d}	8.15^{efg}	20.02^{e}
AxA	5.75^{f}	5.68^{d}	7.45^{hi}	19.46^{g}
SDxH	5.77^{f}	5.19^{c}	8.39^{def}	20.02^{ef}
SDxA	6.07^{f}	5.82^{d}	7.85^{gh}	19.53^{fg}
JxA	6.79^{g}	7.41^{f}	7.09^{j}	18.24^{h}
JxH	6.98^{g}	7.09^{e}	7.35^{ih}	18.67^{h}
Slaughter Group				
1	5.07^{a}	4.87^{a}	7.87^{a}	19.99^{a}
2	5.06^{a}	5.29^{b}	8.15^{b}	19.99^{a}
3	5.14^{a}	5.12^{c}	8.79^{c}	20.65^{b}
4	5.14^{a}	5.29^{b}	8.57^{d}	19.99^{a}

[1]Means in the same column having different superscripts are significantly ($P<.05$) different.

[2]Bone Score: 1 = extremely large; 10 = extremely small.

Figures 3 to 7 are photographs of steers that were used in this study. A rugged boned feeder steer with a bone score of 2.3 is shown in figure 3, while the steer in figure 4 has a bone score of 4.7 which is typical for an average boned steer. A light boned slaughter steer with a score of 8.3 is shown in figure 5, while the average boned slaughter steer in figure 6 had a bone score of 4.7. A bone score of 3.3 was assigned to the rugged boned slaughter steer in figure 7. These figures illustrate the large amount of variation in visual bone size.

Significant differences were found for slaughter bone scores, cannon weights, and cannon circumferences among slaughter groups while feeder bone scores did not vary significantly among slaughter groups. While slaughter bone scores and cannon circumference varied significantly, there was no tendency to increase or decrease as slaughter weight increased. Cannon weight did increase from slaughter period 1 through 3.

Breed Cross and Slaughter Group Affects on Metacarpal Measurements and Percentage of Carcass Bone

Significant differences were observed between breed crosses for the metacarpal measurements listed in table III. Breeds with the heaviest cannon weights and largest cannon circumferences (table II) were also found to have the heaviest metacarpal weights and largest circumference measurements. Likewise, the Jersey crosses, which had the lightest cannons and smallest circumferences, were also found to have the

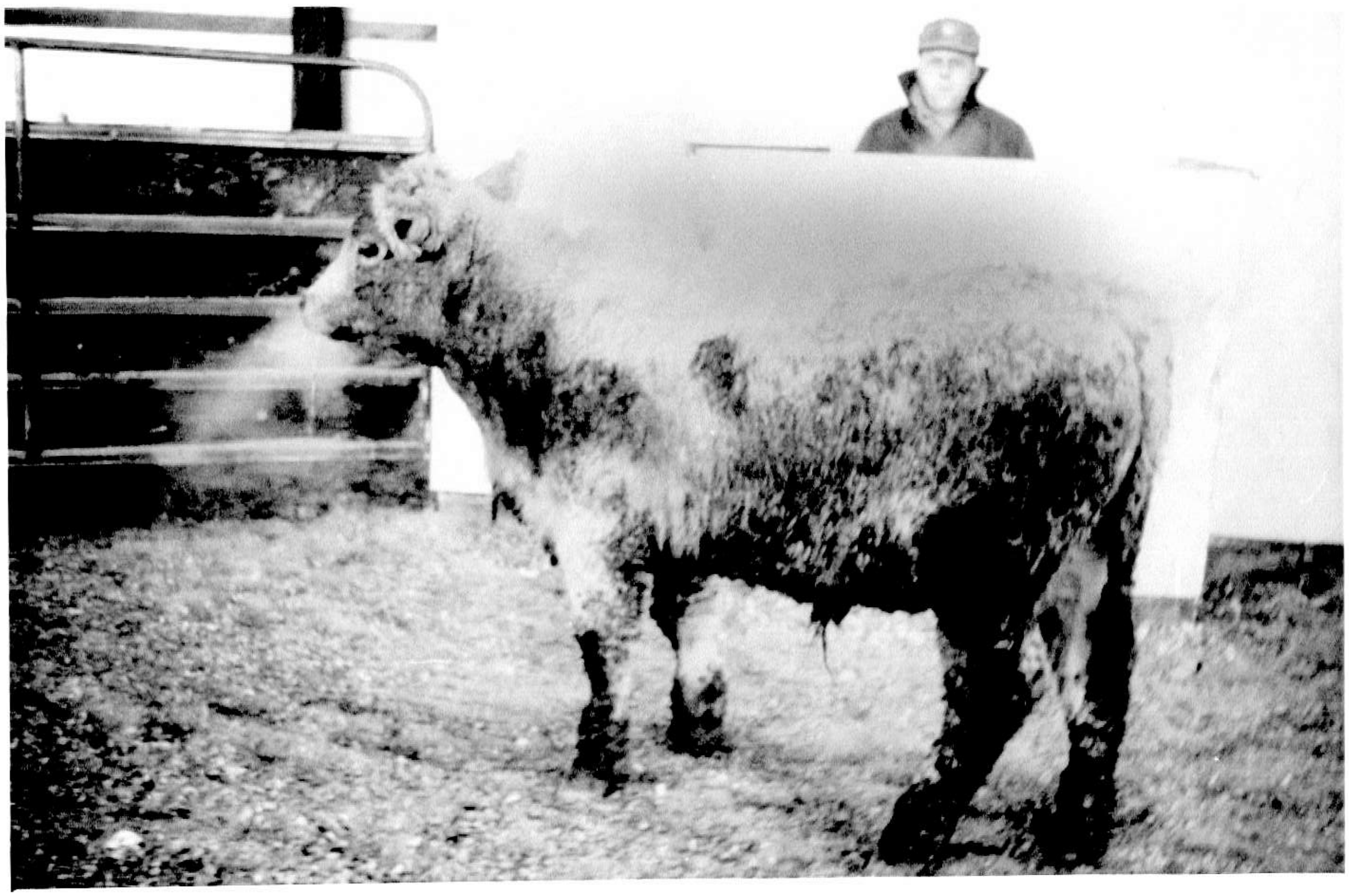

Figure 3. Rugged boned feeder steer with a bone score of 2.3.

Figure 4. Average boned feeder steer with a bone score of 4.7.

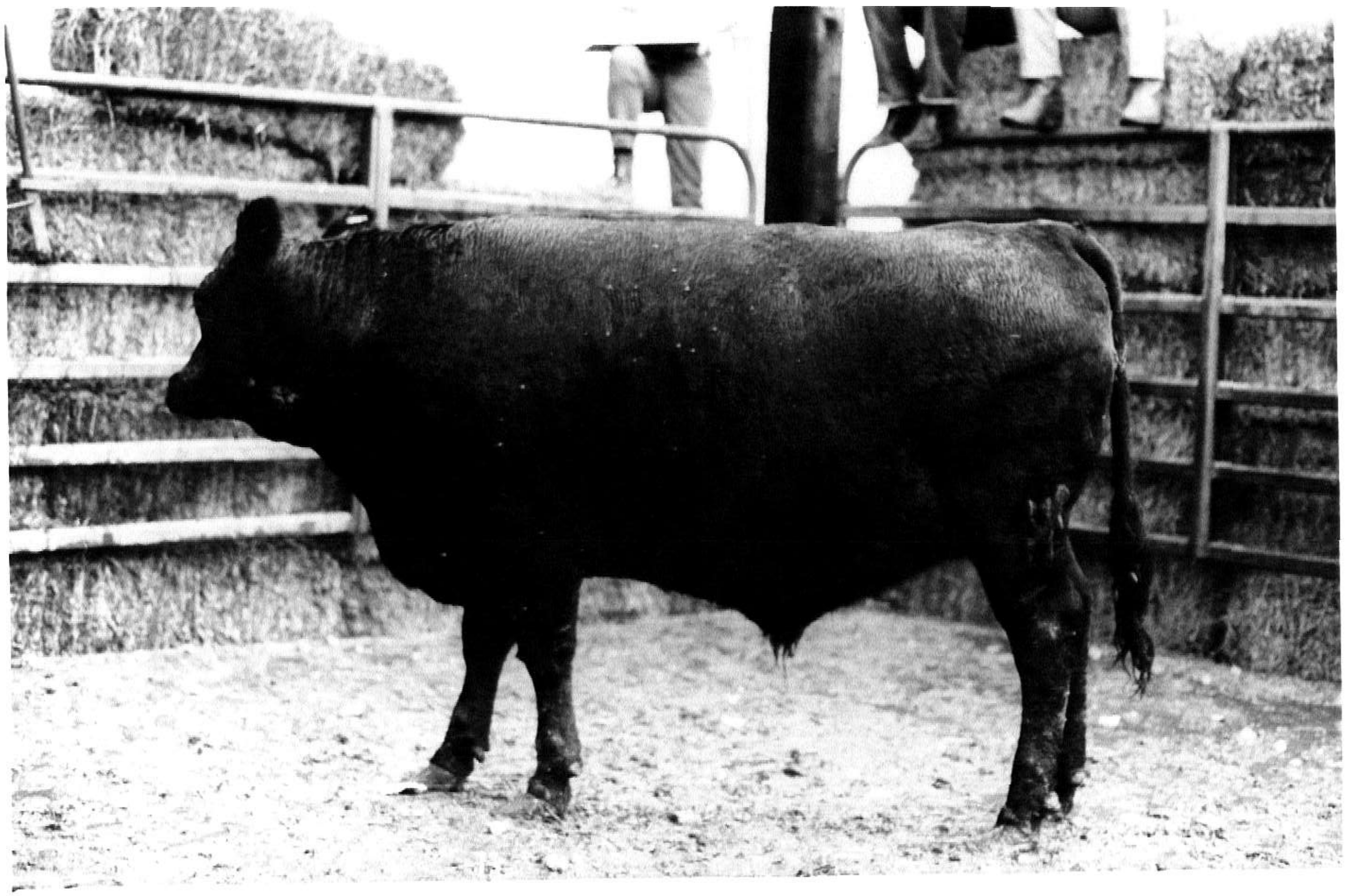

Figure 5. Light boned slaughter steer (bone score of 8.3).

Figure 6. Average boned slaughter steer (bone score of 4.7).

Figure 7. Rugged boned slaughter steer (bone score of 3.3).

TABLE III.

Least Square Means of
Metacarpal Measurements and Percent Carcass Bone
by Breed and Slaughter Groups[1]

Breed	M.C. Weight (gm)	M.C. Length (cm)	M.C. Circ. (cm)	M.C. Specific Gravity	Percent Carcass Bone
SxH	526.22[a]	20.24[a]	12.57[a]	.3383[b]	13.26[a]
CxH	510.53[ab]	20.07[ab]	12.29[b]	.3301[cd]	13.02[a]
CxA	477.49[cd]	19.66[cd]	11.89[c]	.3351[bc]	11.98[cde]
HxH	417.34[fg]	18.62[f]	11.46[d]	.3353[bc]	12.34[bc]
SxA	492.67[bc]	20.07[ab]	11.99[c]	.3313[cd]	12.42[b]
HxA	404.25[gh]	18.57[f]	11.33[d]	.3378[b]	11.19[f]
AxH	407.57[g]	18.57[f]	11.48[d]	.3384[b]	11.68[e]
LxH	453.89[de]	19.91[abc]	11.43[d]	.3405[b]	12.45[b]
LxA	442.34[e]	19.76[bcd]	11.35[d]	.3399[b]	11.97[cde]
AxA	373.48[i]	18.24[g]	11.10[e]	.3383[b]	11.11[f]
SDxH	454.96[de]	20.02[abc]	11.51[d]	.3350[bcd]	12.18[bcd]
SDxA	432.93[ef]	19.51[de]	11.43[d]	.3365[bc]	11.63[e]
JxA	385.40[hi]	19.20[e]	10.82[f]	.3515[a]	11.90[de]
JxH	398.15[gh]	19.25[e]	10.90[ef]	.3491[a]	12.51[b]
Slaughter Group					
1	424.79[a]	19.41[a]	11.38[a]	.3323[a]	12.58[a]
2	432.94[a]	19.48[a]	11.51[ab]	.3420[b]	11.76[b]
3	450.99[b]	19.43[a]	11.66[bc]	.3464[c]	11.56[b]
4	456.20[b]	19.30[a]	11.58[c]	.3298[a]	12.57[a]

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[1]Means in the same column having different superscripts are significantly (P<.05) different.

lightest metacarpals and smallest metacarpal circumference measurements. Figure 8 shows the large variation in size between large and small metacarpal bones. The breed crosses with the heaviest metacarpal weights also tended to have the longest metacarpals, but these differences were not consistent.

Significant differences were found between breed groups for metacarpal specific gravity. The Jersey crosses, with the smallest metacarpal measurements, had the highest specific gravity values. Differences in specific gravity between the other breed crosses were inconsistent with the other metacarpal measurements. Metacarpal specific gravity tended to increase with slaughter groups, which may be partly due to age differences or physiological maturity. Since during physiological maturity bone becomes more calcified with a greater density, specific gravity might be expected to increase.

Percentage of carcass bone was higher for CxH and SxH breed crosses, which also had the largest cannon and metacarpal measurements and bone scores. Carcass bone percentage generally showed no relationship with cannon and metacarpal measurements or ruggedness of bone scores. A tendency existed for percentage of carcass bone to decrease from slaughter groups 1 to 3 which is probably due to a greater increase in carcass finish.

Metacarpal weight and circumference tended to increase from slaughter group 1 to 3 while metacarpal length did not

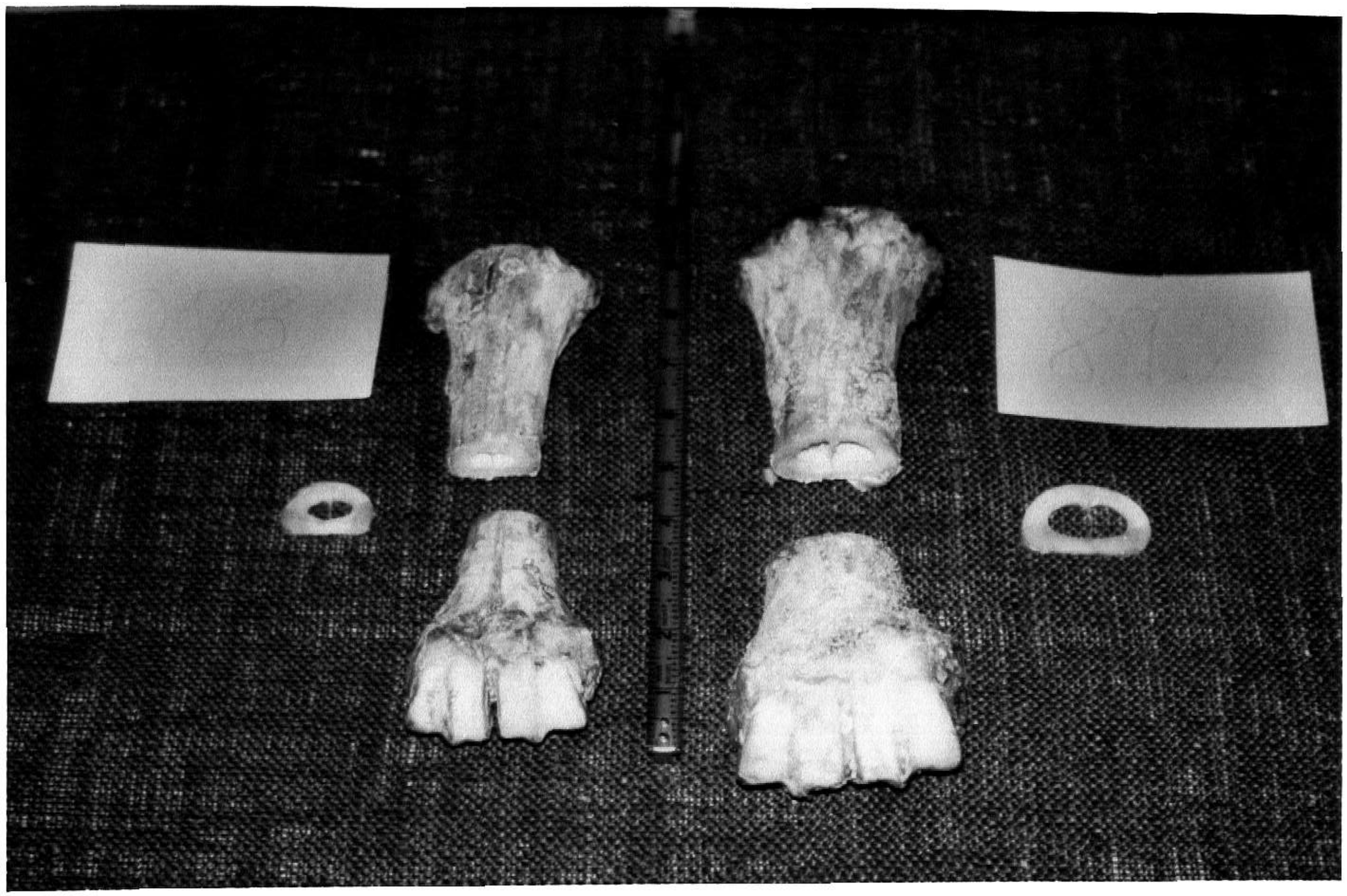

Figure 8. Metacarpal bone and cross-section comparisons showing extremes in size and shape.

significantly increase with slaughter periods. The weight and circumference increase with length remaining constant may explain why specific gravity increased with slaughter period. These results agree with those of Hammond (1932) and Palsson (1939), who found that metacarpal bones in sheep first develop in length and later show an increase in circumference.

Breed Cross and Slaughter Group Affects on Metacarpal Cross-Sectional Measurements

Metacarpal total cross-sectional area and marrow cavity area listed in table IV were significantly greater for the SxH and CxH breed crosses, which were also visually the most rugged. Jersey crosses, the least rugged, had significantly small metacarpal total cross-sectional areas and marrow cavity areas. However, bone wall area showed little variation among breed crosses and was inconsistent with the breed differences for total cross-sectional area and marrow cavity area. Differences in total cross-sectional area and marrow cavity area are shown in figure 8. A large variation in shape may also be observed.

Little variation was found among the large and small breed crosses for metacarpal bone wall thickness although the Limousin, Jersey and CxH breed crosses had significantly the thickest bone walls. Figure 9 shows differences in metacarpal cross-section bone wall thickness. Cross-section measurements varied quite inconsistently between slaughter groups with no trend to increase with later slaughter groups.

TABLE IV.

Least Square Means for Metacarpal Cross-Section Measurements by Breed and Slaughter Group[1]

Breed	Total Area (cm^2)	Marrow Cavity Area (cm^2)	Bone Wall Area (cm^2)	Average Wall Thickness (mm)	MC Circ/ TA[2] (cm)	TA/MCA[3]
SxH	10.51^{a}	3.29^{a}	7.22^{a}	7.95^{bcd}	1.20^{h}	3.23^{f}
CxH	10.00^{b}	3.03^{b}	6.90^{ab}	8.06^{abc}	1.24^{fgh}	3.36^{ef}
CxA	9.61^{bc}	2.77^{cd}	6.84^{b}	7.87^{bcde}	1.24^{fgh}	3.49^{def}
HxH	8.58^{def}	2.32^{efg}	6.26^{d}	7.92^{bcd}	1.34^{bc}	3.72^{bcd}
SxA	9.55^{c}	2.90^{bc}	6.64^{bc}	7.86^{cde}	1.26^{fg}	3.42^{bc}
HxA	8.51^{ef}	2.32^{efg}	6.26^{d}	7.92^{bcd}	1.33^{bcd}	3.79^{bc}
AxH	8.71^{de}	2.45^{efg}	6.32^{cd}	7.90^{bcd}	1.32^{bcde}	3.75^{bcd}
LxH	8.97^{d}	2.32^{efg}	6.64^{bc}	8.29^{a}	1.28^{defg}	3.96^{b}
LxA	8.71^{de}	2.32^{efg}	6.39^{cd}	8.12^{abc}	1.31^{cde}	3.85^{bc}
AxA	8.19^{fg}	2.26^{g}	6.00^{d}	7.61^{e}	1.36^{ab}	3.70^{bcd}
SDxH	8.97^{d}	2.52^{def}	6.45^{cd}	7.81^{cde}	1.28^{defg}	3.61^{bcde}
SDxA	8.90^{de}	2.58^{de}	6.32^{cd}	7.68^{de}	1.29^{def}	3.54^{cde}
JxA	7.80^{h}	1.74^{h}	6.06^{d}	8.14^{ab}	1.40^{a}	4.54^{a}
JxH	8.06^{h}	1.87^{h}	6.26^{d}	8.22^{a}	1.35^{abc}	4.48^{a}
Slaughter Group						
1	8.90^{a}	2.39^{a}	6.58^{a}	8.18^{a}	1.28^{a}	3.90^{a}
2	9.09^{a}	2.64^{b}	6.45^{ab}	7.65^{b}	1.27^{a}	3.55^{b}
3	8.90^{a}	2.39^{a}	6.51^{a}	8.10^{a}	1.33^{b}	3.88^{a}
4	8.84^{a}	2.52^{c}	6.45^{b}	7.88^{c}	1.32^{b}	3.65^{b}

[1]Means in the same column having different superscripts are significantly ($P<.05$) different.
[2]Metacarpal Circumference/Total Area.
[3]Total Area/Marrow Cavity Area.

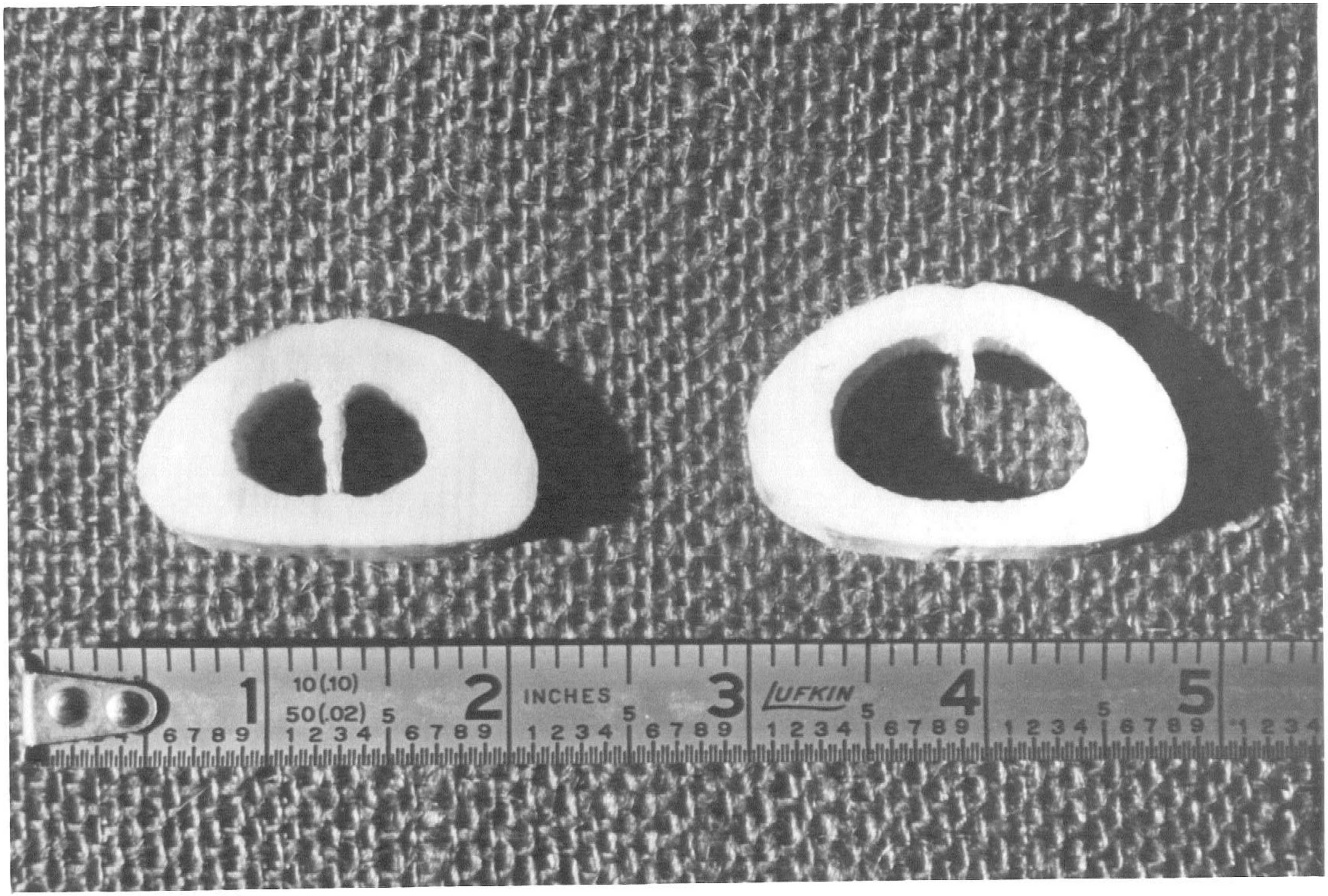

Figure 9. Metacarpal cross-section comparison showing extremes in marrow cavity area and bone wall thickness.

Ratios of metacarpal circumference:total cross-sectional area and total area:marrow cavity area were significantly greater for the smaller, lighter boned Jersey cross steers. The SxH, SxA, CxH and CxA breed crosses had smaller ratios than the other breed crosses. A general overlapping existed between the remaining breed crosses. Significant differences were found in bone ratios between slaughter groups but no tendency to increase or decrease existed.

Interpretation of Results

Rugged boned feeder steers are also rugged boned at slaughter and have larger cannon and metacarpal measurements. Rugged boned steers, however, do not necessarily have the longest metacarpals.

The rugged boned steers have larger metacarpal cross-sectional areas but smaller bone wall thickness measurements than the light boned steers. Selection for larger boned steers would not generally increase carcass bone percent but it would lower metacarpal specific gravity and metacarpal circumference:total cross-sectional area and total cross-sectional area:marrow cavity area ratios.

The Relationship of Visual Bone Scores and Bone Measurements with Performance and Carcass Traits

It was apparent that significant differences in bone ruggedness, cannon size and metacarpal measurements existed from the analysis of variance and least square means. Simple and partial correlation coefficients were then computed on 484 steers to evaluate the relationships of bone scores and cannon measurements with performance and carcass traits.

The simple and partial correlations between metacarpal measurements and growth and carcass traits are listed in the Appendix along with simple correlations calculated within breed groupings based on the least square means. Partial correlations for carcass traits were computed holding final live weight constant to remove the effect that live weight would have on bone size, cannon, and metacarpal measurements. Partial correlation coefficients for performance characteristics were not computed as they were not affected by final live weight.

Correlation coefficients ≥ 0.10 were significant ($P<.05$) while correlations ≥ 0.12 were highly significant ($P<.01$). On the whole, highly significant correlations were found between feeder bone scores, slaughter bone scores, weight of the four cannons, right forecannon circumference and performance and carcass traits. Therefore, this discussion centers around the relative value of the correlation coefficients rather than the significance levels with correlations $<.25$

referred to as low, ≥.25 and ≤.50 as moderate, ≥.51 and ≤.75 as high, and ≥.76 as very high correlations.

The Relationship of Feeder Bone Score with Bone Measurements and Performance and Carcass Traits

Steers with heavy birth weights and heavy weaning weights showed a moderate tendency to be rugged boned as feeder steers (-.49 and -.31, respectively) as indicated in tables V and VI. These rugged boned steers also had a slightly higher average daily gain (ADG) prior to weaning. In addition, steers scored as rugged boned at weaning had better growth potential scores, gained moderately faster in the feedlot, and were somewhat heavier at slaughter.

Feeder bone size was moderately related to hide weight (-.50) which may affect cannon circumference, but showed no significant relationship with dressing percent. Slightly larger loin eye areas (-.10) were also associated with rugged bone scores when live weight was held constant. Fat thickness, however, was not related to feeder bone scores.

Carcass meatiness was also associated with ruggedness of bone. Ruggedness of bone was moderately correlated with adjusted cutability, adjusted retail product, and yield of roast meat from the round, loin, rib and chuck (RLRC) (-.30, -.28, and -.38, respectively). A high percentage of carcass fat was moderately associated with lighter boned feeder steers and a high percentage carcass bone was associated with larger boned feeder steers.

TABLE V.

Overall Simple Correlation Coefficients of Bone Scores and Cannon Bone Measurements with Performance and Carcass Traits

Performance Characteristics:	Feeder Bone Score	Slaughter Bone Score	Total Cannon Weight	Right Cannon Circ.
Birth Weight	-.49**	-.56**	0.66**	0.58**
ADG Birth to Weaning	-.24**	-.12**	0.39**	0.19**
200-Day Weight	-.31**	-.21**	0.48**	0.28**
ADG Weaning to Final	-.36**	-.48**	0.41**	0.49**
Final Live Weight	-.41**	-.40**	0.77**	0.60**
Av. Growth Potential Score	0.51**	0.51**	-.70**	-.55**
Carcass Traits:				
Dressing %	-.16**	-.05**	0.08**	0.08**
Hide Weight	-.61**	-.66**	0.72**	0.78**
Loin Eye Area	-.30**	-.34**	0.49**	0.40**
Adj. Fat Thickness	0.01**	0.22**	-.17**	-.13**
Chilled Carcass Weight	-.41**	-.37**	0.73**	0.57**
Marbling Score	0.25**	0.32**	-.14**	-.26**
Quality Grade	0.18**	0.26**	-.12**	-.23**
Yield Grade	0.17**	0.34**	-.19**	-.23**
% Adj. Cutability	-.25**	-.42**	0.29**	0.35**
% Retail Product	-.21**	-.39**	0.23**	0.30**
% Trimmed RLRC	-.27**	-.45**	0.35**	0.39**
% Roasts (RLRC)	-.24**	-.40**	0.29**	0.32**
% Carcass Fat Trim	0.20**	0.39**	-.25**	-.30**
% Carcass Bone	-.15**	-.31**	0.30**	0.22**

*Significant at the .05 level.

**Significant at the .01 level.

TABLE VI.

Overall Partial Correlation Coefficients of Bone Scores and Cannon Bone Measurements with Carcass Traits[1]

Carcass Traits:	Feeder Bone Score	Slaughter Bone Score	Total Cannon Weight	Right Cannon Circ.
Dressing %	-.06	0.06	-.20**	-.10*
Hide Weight	-.50**	-.58**	0.43**	0.64**
Loin Eye Area	-.10*	-.16**	0.12**	0.10*
Adj. Fat Thickness	0.09	0.32**	-.48**	-.29**
Chilled Carcass Weight	-.05	0.12**	-.19**	-.11*
Marbling Score	0.31**	0.38**	-.30**	-.38**
Quality Grade	0.24**	0.32**	-.30**	-.36**
Yield Grade	0.26**	0.44**	-.48**	-.40**
% Adj. Cutability	-.30**	-.49**	0.53**	0.48**
% Adj. Retail Product	-.28**	-.48**	0.50**	0.46**
% Trimmed RLRC	-.31**	-.50**	0.57**	0.50**
% Roasts (RLRC)	-.28**	-.45**	0.50**	0.43**
% Carcass Fat Trim	0.28**	0.49**	-.55**	-.48**
% Carcass Bone	-.24**	-.41**	0.67**	0.40**

[1]Final live weight held constant.

*Significant at the .05 level.

**Significant at the .01 level.

Feeder bone scores were very highly correlated with slaughter bone scores with simple (table VII) and partial (table VIII) correlations of 0.80 and 0.76 respectively. This indicates that animals which appeared heavy boned as feeder animals also appeared rugged boned at slaughter. The fact that holding live weight constant did not adversely affect the correlation also gives support to the judges' ability to visually score bone size relative to live animal body size. Simple and partial correlations between feeder bone score and cannon weight (-.59 and -.47), cannon circumference (-.67 and -.58), and metacarpal circumference (-.57 and -.45) were found. Metacarpal length and bone wall thickness were not significantly related to feeder bone size while metacarpal cross-sectional area and marrow cavity area were moderately related to feeder bone score.

The Relationship of Slaughter Bone Scores, Total Cannon Weight and Right Cannon Circumference with Performance and Carcass Traits

Correlations in table V indicate that steers with heavier birth weights, slightly faster gains prior to weaning and somewhat heavier weaning weights were also scored as heavier boned at slaughter, and had heavier cannons with larger fore-cannon circumferences. Furthermore, correlations of bone scores, cannon weights, and cannon circumference were moderately high with feedlot average daily gain, slaughter weight,

TABLE VII.

Overall Simple Correlation Coefficients between Bone Scores and Measurements

	Feeder Bone Score	Sl. Bone Score	Total Cannon Weight	Right Cannon Circ.	Percent Carcass Bone
Feeder Bone Score	1.00				
Slaughter Bone Score	0.80**	1.00			
Total Cannon Weight	-.59**	-.67**	1.00		
Right Cannon Circ.	-.67**	-.77**	0.80**	1.00	
% Carcass Bone	-.15**	-.31**	0.30**	0.22**	1.00
Metacarpal Weight	-.49**	-.57**	0.84**	0.65**	0.45**
Metacarpal Length	-.18**	-.26**	0.60**	0.36**	0.39**
Metacarpal Circ.	-.57**	-.61**	0.74**	0.67**	0.34**
Specific Gravity	0.29**	0.30**	-.25**	-.20**	-.27**
M.C. Cross-Section Total Area	-.52**	-.59**	0.65**	0.63**	0.37**
M.C. Cross-Section Marrow Cavity Area	-.53**	-.57**	0.60**	0.58**	0.30**
M.C. Cross-Section Bone Wall Area	-.35**	-.42**	0.48**	0.47**	0.31**
M.C. Cross-Section Av. Bone Wall Thickness	-.01	-.05	0.14**	0.13**	0.16**
M.C. Circ./Total Area	0.34**	0.41**	-.39**	-.43**	-.28**
Total Area/Marrow Cavity Area	0.39**	0.40**	-.36**	-.37**	-.12**

* Significant at the .05 level.

** Significant at the .01 level.

TABLE VIII.

Overall Partial Correlation Coefficients between Bone Scores and Measurements[1]

	Feeder Bone Score	Sl. Bone Score	Total Cannon Weight	Right Cannon Circ.	Percent Carcass Bone
Feeder Bone Score	1.00				
Slaughter Bone Score	0.76**	1.00			
Total Cannon Weight	-.47**	-.62**	1.00		
Right Cannon Circ.	-.58**	-.72**	0.66**	1.00	
% Carcass Bone	-.24**	-.41**	0.67**	0.40**	1.00
Metacarpal Weight	-.31**	-.44**	0.67**	0.41**	0.78**
Metacarpal Length	0.03	-.08	0.40**	0.09	0.54**
Metacarpal Circ.	-.45**	-.51**	0.57**	0.50**	0.53**
Specific Gravity	0.28**	0.29**	-.30**	-.19**	-.29**
M.C. Cross-Section Total Area	-.40**	-.49**	0.49**	0.48**	0.52**
M.C. Cross-Section Marrow Cavity Area	-.42**	-.48**	0.44**	0.43**	0.42**
M.C. Cross-Section Bone Wall Area	-.23**	-.32**	0.33**	0.33**	0.40**
M.C. Cross-Section Av. Bone Wall Thickness	0.03	-.02	0.11*	0.10*	0.18**
M.C. Circ./Total Area	0.25**	0.34**	-.27**	-.33**	-.35**
Total Area/Marrow Cavity Area	0.32**	0.33**	-.25**	-.27**	-.17**

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1 Final live weight held constant.

* Significant at the .05 level.

** Significant at the .01 level.

and growth potential scores at weaning. These results agree with Adams et al. (1971) where they found a positive relationship ($P<.01$) of bone ruggedness with weight per day of age to weaning, final weight, feedlot average daily gain, and weight per day of age to slaughter with correlations ranging from 0.29 to 0.51.

Slaughter steers with heavy cannon weights and large cannon circumferences were found (when live weight was held constant) to have slightly higher dressing percentages, even though slaughter bone score was not related to dressing percent. Hide weight, however, was moderately related to ruggedness of bone, heavier cannon weights, and larger cannon circumferences (-.58, 0.43, and 0.64 respectively).

Loin eye area was related to slaughter bone score, cannon weight, and forecannon circumference as indicated by simple correlations (-.30, 0.49 and 0.40 respectively), but when partial correlations were calculated, the correlations were lowered (-.16, 0.12 and 0.10 respectively), showing only a slight association between loin eye area, ruggedness of bone, and cannon measurements. That is in agreement with research by Weseli (1957) and Boughton (1958) where they found the correlation between bone score and loin eye area lowered when live weight was constant for steers.

Steers that were visually rugged boned with larger cannon measurements were found to have less fat covering over the twelfth rib. That agrees with Weseli (1957) who found larger boned steers had less fat covering. Like feeder scores, slaughter bone scores and cannon measurements were associated with less marbling and lower quality and yield grades.

Partial correlations showed that rugged boned slaughter steers with the heaviest total cannon weights and larger forecannon circumferences had higher cutability, greater percentages of retail product, and yielded a higher percentage of roast meat from the trimmed RLRC. Percentage of carcass fat trim was also less for the rugged boned steers with a partial correlation of 0.49, while percentage of carcass bone was moderately greater for the more rugged boned steers.

Slaughter bone scores in tables VII and VIII were related with most cannon and metacarpal measurements. High simple and partial correlations were obtained between slaughter bone score and cannon weight (-.67 and -.62), cannon circumference (-.77 and -.72), metacarpal weight (-.57 and -.44) and metacarpal circumference (-.61 and -.51), supporting the judges' ability to accurately visually determine bone size. These results agree with Weseli (1957) and Adams et al. (1971) who found visual estimates of bone size associated with metacarpal measurements. Metacarpal length was not related to slaughter bone scores when live weight was constant. Specific gravity and metacarpal cross-section measurements were associated with visual bone size, while bone wall thickness was not related to ruggedness of bone.

Cannon weight (tables VII and VIII) showed high simple and partial correlations with cannon circumference (0.80 and 0.66), metacarpal weight (0.84 and 0.67) and metacarpal circumference (0.74 and 0.57). These results indicate that weight of the four cannons with hide, hair and hoof intact is a good indicator of bone size. Percentage carcass bone (when live weight was constant) showed a high relationship (0.67) with cannon weight, agreeing with Lush (1926) who found the most practical indication of percentage of carcass bone to be the weight of the four legs below the knees and hocks. Metacarpal length, specific gravity and most metacarpal cross-section measurements were moderately related to the weight of the four cannons while bone wall thickness showed a slight tendency to increase with cannon weight.

The partial correlations for cannon circumference generally showed a moderate relationship with metacarpal weight and circumference, percentage of carcass bone, and most metacarpal cross-sectional measurements. Metacarpal length was not related to cannon circumference, while bone wall thickness only showed a slight tendency to increase with cannon circumference.

The Relationship Between Percentage of Carcass Bone and Metacarpal Measurements

Percentage of carcass bone showed high partial correlations with metacarpal weight, metacarpal length, metacarpal circumference, and metacarpal cross-sectional area (0.78, 0.54, 0.53 and 0.52, respectively).

Relationships Among Metacarpal Measurements

Metacarpal weight was highly related (simple and partial correlations, tables IX and X) to metacarpal length (0.77 and 0.68) and metacarpal circumference (0.82 and 0.72). Simple and partial correlations (0.51 and 0.32 respectively) were observed between metacarpal length and metacarpal circumference. These correlations may indicate that a heavy metacarpal bone will generally be long and have a large circumference while a long metacarpal bone would not always have a large metacarpal circumference. Metacarpal specific gravity showed a tendency to decrease as metacarpal weight, length and circumference increased.

Metacarpal weight and circumference showed a high relationship (0.46 to 0.80) with metacarpal cross-sectional area, marrow cavity area, and bone wall area while metacarpal length was moderately related (0.27 to 0.55) to the cross-sectional measurements. Bone wall thickness was not related to metacarpal circumference and only showed a slight relationship with metacarpal weight and length.

Specific gravity was inversely correlated with metacarpal total cross-sectional area and marrow cavity area, while bone wall area was not related to specific gravity. Metacarpal

TABLE IX.

Overall Simple Correlation Coefficients Between Metacarpal and Metacarpal Cross-Section Measurements

	M.C. Weight	M.C. Length	M.C. Circ.	Specific Gravity
Metacarpal Weight	1.00			
Metacarpal Length	0.77**	1.00		
Metacarpal Circ.	0.82**	0.51**	1.00	
Specific Gravity	-.32**	-.18**	-.37**	1.00
M.C. Cross-Section Total Area	0.77**	0.55**	0.80**	-.31**
M.C. Cross-Section Marrow Cavity Area	0.65**	0.43**	0.75**	-.49**
M.C. Cross-Section Bone Wall Area	0.62**	0.47**	0.59**	-.05
M.C. Cross-Section Av. Bone Wall Thickness	0.22**	0.18**	0.08	0.30**
M.C. Circ./Total Area	-.51**	-.42**	-.42**	0.19**
Total Area/Marrow Cavity Area	-.35**	-.20**	-.47**	0.49**

* Significant at the .05 level.

** Significant at the .01 level.

TABLE X.

Overall Partial Correlation Coefficients Between Metacarpal and Metacarpal Cross-Section Measurements[1]

	M.C. Weight	M.C. Length	M.C. Circ.	Specific Gravity
Metacarpal Weight	1.00			
Metacarpal Length	0.68**	1.00		
Metacarpal Circ.	0.72**	0.32**	1.00	
Specific Gravity	-.37**	-.16**	-.40**	1.00
M.C. Cross-Section Total Area	0.68**	0.41**	0.73**	-.31**
M.C. Cross-Section Marrow Cavity Area	0.46**	0.27**	0.67**	-.51**
M.C. Cross-Section Bone Wall Area	0.54**	0.36**	0.50**	-.02
M.C. Cross-Section Av. Bone Wall Thickness	0.22**	0.16**	0.04	0.31**
M.C. Circ./Total Area	-.45**	-.33**	-.32**	0.17**
Total Area/Marrow Cavity Area	-.23**	-.08	-.40**	0.49**

---

[1] Final live weight held constant.

* Significant at the .05 level.

** Significant at the .01 level.

bones with large total cross-sectional areas would have more porous (more air space) bone walls and large marrow cavity areas with large air spaces which would lower specific gravity. Bone wall thickness showed a moderate tendency to increase as specific gravity increased. That would indicate smaller boned animals would tend to have thicker, denser bone walls.

Relationships Between Metacarpal Cross-Sectional Measurements

Metacarpal bones with large total cross-sectional areas (tables XI and XII) also had large marrow cavity areas and bone wall areas with partial correlations of 0.74 and 0.84 respectively. Bone wall thickness showed only a slight tendency to increase with larger metacarpal cross-sectional areas.

Marrow cavity area showed a low correlation (0.25) with bone wall area (when live weight was constant) while a moderate relationship existed between marrow cavity area and bone wall thickness (-.42). Partial correlations indicate that bone wall area increased as bone wall thickness increased.

Total cross-sectional area (-.87) and bone wall area (-.81) showed high partial correlations with metacarpal circumference:total cross-sectional area, while metacarpal circumference was related (-.32) to metacarpal circumference: total cross-sectional area. Small metacarpal circumference: total cross-sectional area ratios would be associated with large total cross-sectional areas and bone wall areas but not necessarily to large metacarpal circumferences.

TABLE XI.

Overall Simple Correlation Coefficients
Among Metacarpal Cross-Section Measurements

Metacarpal Cross-Section Measurements:	Total Area	Marrow Cavity Area	Bone Wall Area	Av. Bone Wall Thickness	MC Circ/[1] TA	TA/MCA[3]
Total Area	1.00					
Marrow Cavity Area	0.80**	1.00				
Bone Wall Area	0.86**	0.37**	1.00			
Av. Bone Wall Thickness	0.14**	-.33**	0.49**	1.00		
M.C. Circ./ Total Area	-.87**	-.60**	-.83**	-.14**	1.00	
Total Area/ Marrow Cavity Area	-.40**	-.82**	0.09	0.61**	0.23**	1.00

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1 Metacarpal Circumference/Total Area.

2 Total Area/Marrow Cavity Area.

* Significant at the .05 level.

** Significant at the .01 level.

TABLE XII.

Overall Partial Correlation Coefficients Among Metacarpal Cross-Section Measurements[1]

Metacarpal Cross-Section Measurements:	Total Area	Marrow Cavity Area	Bone Wall Area	Av. Bone Wall Thickness	MC Circ/ TA[2]	TA/MCA[3]
Total Area	1.00					
Marrow Cavity Area	0.74**	1.00				
Bone Wall Area	0.84**	0.25**	1.00			
Av. Bone Wall Thickness	0.11*	-.42**	0.49**	1.00		
M.C. Circ./ Total Area	-.87**	-.55**	-.81**	-.12**	1.00	
Total Area/ Marrow Cavity Area	-.32**	-.81**	0.21**	0.66**	0.16**	1.00

---

[1] Final live weight held constant.

[2] Metacarpal Circumference/Total Area.

[3] Total Area/Marrow Cavity Area.

* Significant at the .05 level.

** Significant at the .01 level.

Marrow cavity area and bone wall thickness were highly correlated with total cross-sectional area:marrow cavity area with partial correlations of -.81 and 0.66 respectively. Large total cross-sectional area:marrow cavity area ratios would be associated with small marrow cavities and thick bone walls.

SUMMARY

Steers visually scored as rugged boned had heavier cannon weights and larger forecannon circumferences. These same steers were heavier at birth, gained slightly faster prior to weaning and were heavier at weaning. Steers with rugged bones, heavy cannons and large cannon circumferences also gained faster in the feedlot and were heavier at slaughter. Rugged boned steers were trimmer internally, lower grading and had higher cutability, yielding higher percentages of total retail product and roast meat from the round, loin, rib and chuck.

Slaughter bone scores were more highly correlated with bone measurements than feeder bone scores as would be expected. Steers visually scored as having larger cannon bones relative to body size had heavier metacarpal weights and larger metacarpal circumferences. Metacarpal length, however, was not related to feeder or slaughter bone scores. Metacarpal cross-sectional area, marrow cavity area, and bone wall area were moderately greater for the rugged boned steers while bone wall thickness showed no relationship.

Large cannon measurements were associated with large metacarpal measurements with the exception of metacarpal length which was not related to cannon circumference. Metacarpal length, weight and circumference were also related to large metacarpal cross-section measurements. Metacarpal circumference, however, was not related to bone wall thickness.

Metacarpal specific gravity showed a tendency to decrease as the cannon and metacarpal measurements increased. No relationship was observed between specific gravity and bone wall area, while bone wall thickness tended to increase with specific gravity.

Metacarpal bones with large cross-sectional areas had large marrow cavity areas and bone wall areas with only slightly thicker bone walls. Bones with large marrow cavities tended to have thinner bone walls but somewhat larger bone wall areas, while large metacarpal bone wall areas were moderately associated with thicker bone walls.

A large total cross-sectional area and bone wall area were associated with a small metacarpal circumference:total cross-sectional area ratio, while a large marrow cavity area was related to a low total cross-sectional area:marrow cavity area ratio.

INTERPRETATION OF RESULTS

Ruggedness of bone is an accurate tool in the prediction of growth rate, carcass meatiness and actual bone size. Steers scored as rugged boned at weaning are also rugged boned at slaughter. The visually rugged boned steers are heavier at birth and gain faster in the feedlot, reaching heavier slaughter weights than light boned steers. Large boned steers are trimmer externally and internally with high cutability, yielding a high percentage of roast meat from the loin, round, rib and chuck but are low grading.

Contrary to contentions that visual estimates of bone size are merely estimates of hair, hide, tendons and bone, visual appraisal is a relatively accurate estimate of cannon and metacarpal size. Rugged boned steers have heavier cannon weights and larger forecannon circumferences. When the hide, hair and tendons are removed, the rugged boned steers have the heaviest metacarpals and the largest metacarpal circumferences. In addition, the rugged boned steers have the largest metacarpal cross-sectional total areas, marrow cavity areas and bone wall areas but do not have the thickest bone walls.

Visual appraisal is an accurate measure of bone size in the feeder and slaughter steer. As such, it is a valuable tool for livestockmen who, with only little training, can use it effectively in animal selection. Furthermore, bone ruggedness does not increase drastically the proportion of bone in the carcass, so selection of large boned steers would not necessarily increase the percentage of carcass bone.

The high heritability of cannon size and the fact rugged boned steers grow faster and are heavier muscled, coupled with the fact that bone size can be accurately estimated with a little amount of training makes visual ruggedness of bone a potentially valuable trait to use in live animal selection of breeding and market animals.

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APPENDICES

APPENDIX IA.

Overall Simple Correlation Coefficients of Metacarpal Measurements and Percentage of Carcass Bone with Performance and Carcass Traits

Performance Characteristics:	M.C. Weight	M.C. Length	M.C. Circ.	M.C. Specific Gravity	Percent Carcass Bone
Birth Weight	0.67**	0.55**	0.56**	-.31**	0.26**
ADG Birth to Weaning	0.40**	0.32**	0.30**	-.18**	-.12**
200-Day Weight	0.50**	0.39**	0.38**	-.23**	-.06
ADG Weaning to Final	0.41**	0.40**	0.40**	-.14**	0.12**
Final Live Weight	0.69**	0.49**	0.57**	-.08	-.16**
Av. Growth Potential Score	-.76**	-.71**	-.61**	0.21**	-.30**
Carcass Traits:					
Dressing %	0.07	0.02	0.07	0.07	-.49**
Hide Weight	0.55**	0.33**	0.54**	-.10*	0.04
Loin Eye Area	0.50**	0.39**	0.40**	-.06	0.01
Adj. Fat Thickness	-.33**	-.39**	-.23**	0.12**	-.70**
Chilled Carcass Weight	0.65**	0.45**	0.53**	-.06	-.25**
Marbling Score	-.19**	-.20**	-.16**	0.13**	-.32**
Quality Grade	-.17**	-.22**	-.13**	0.07	-.33**
Yield Grade	-.29**	-.28**	-.25**	0.13**	-.57**
% Adj. Cutability	0.35**	0.36**	0.31**	-.01	0.54**
% Adj. Retail Product	0.31**	0.34**	0.27**	-.03	0.53**
% Trimmed RLRC	0.40**	0.37**	0.34**	-.04	0.58**
% Roasts (RLRC)	0.36**	0.37**	0.30**	-.04	0.55**
% Carcass Fat Trim	-.34**	-.38**	-.29**	0.04	0.55**
% Carcass Bone	0.45**	0.39**	0.34**	-.27**	1.00

*Significant at the .05 level.

**Significant at the .01 level.

APPENDIX IB.

Overall Partial Correlation Coefficients of Metacarpal Measurements and Percentage of Carcass Bone with Carcass Traits[1]

Carcass Traits:	M.C. Weight	M.C. Length	M.C. Circ.	M.C. Specific Gravity	Percent Carcass Bone
Dressing %	-.16**	-.13**	-.10*	0.09	-.47**
Hide Weight	0.16**	0.00	0.26**	-.06	0.20**
Loin Eye Area	0.20**	0.17**	0.13**	-.02	0.12**
Adj. Fat Thickness	-.63**	-.55**	-.40**	0.14**	-.69**
Chilled Carcass Weight	-.18**	-.17**	-.17**	0.09	-.47**
Marbling Score	-.33**	-.27**	-.24**	0.14**	-.31**
Quality Grade	-.32**	-.30**	-.22**	0.08	-.32**
Yield Grade	-.55**	-.41**	-.41**	0.14**	-.56**
% Adj. Cutability	0.54**	0.45**	0.42**	-.01	0.54**
% Adj. Retail Product	0.54**	0.45**	0.41**	-.04	0.52**
% Trimmed RLRC	0.57**	0.44**	0.43**	-.04	0.58**
% Roasts (RLRC)	0.54**	0.45**	0.39**	-.04	0.55**
% Carcass Fat Trim	-.60**	-.51**	-.45**	0.05	-.64**
% Carcass Bone	0.78**	0.54**	0.53**	-.29**	

[1]Final live weight held constant.

*Significant at the .05 level.

**Significant at the .01 level.

APPENDIX IC.

Overall Simple Correlation Coefficients of Metacarpal Cross-Section Measurements with Performance and Carcass Traits

Performance Characteristics:	Total Area	Marrow Cavity Area	Bone Wall Area	Av. Wall Thickness	MC Circ/TA[1]	TA/MCA[2]
Birth Weight	0.56**	0.52**	0.42**	0.06	-.42**	-.33**
ADG Birth to Weaning	0.26**	0.22**	0.22**	0.05	-.17**	-.12**
200-Day Weight	0.35**	0.30**	0.28**	0.06	-.24**	0.17**
ADG Weaning to Final	0.46**	0.40**	0.38**	0.14**	-.39**	-.24**
Final Live Weight	0.49**	0.45**	0.37**	0.09	-.29**	-.27**
Av. Growth Potential Score	-.63**	-.52**	-.53**	-.15**	0.48**	0.27**
Carcass Traits:						
Dressing %	0.04	0.06	0.01	-.08	-.02	-.09
Hide Weight	0.48**	0.41**	0.39**	0.14**	-.30**	-.24**
Loin Eye Area	0.41**	0.34**	0.34**	0.09	-.30**	-.16**
Adj. Fat Thickness	-.30**	-.21**	-.28**	-.11*	0.26**	0.05
Chilled Carcass Weight	0.46**	0.42**	0.34**	0.06	-.27**	-.27**
Marbling Score	-.27**	-.21**	-.23**	-.03	0.31**	0.14**
Quality Grade	-.23**	-.17**	-.22**	-.06	0.27**	0.08
Yield Grade	-.32**	-.26**	-.27**	-.07	0.29**	0.11*
% Adj. Cutability	0.38**	0.29**	0.34**	0.12**	-.33**	-.13**
% Adj. Retail Product	0.35**	0.27**	0.31**	0.11*	-.32**	-.12**
% Trimmed RLRC	0.40**	0.32**	0.43**	0.13**	-.33**	-.15**
% Roasts (RLRC)	0.37**	0.29**	0.32**	0.11*	-.32**	-.14**
% Carcass Fat Trim	-.37**	-.27**	-.43**	-.15**	0.33**	0.10*
% Carcass Bone	0.37**	0.30**	0.31**	0.16**	-.28**	-.12**

[1]Metacarpal Circumference/Total Area.
[2]Total Area/Marrow Cavity Area.
*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX ID.

Overall Partial Correlation Coefficients of Metacarpal Cross-Section Measurements with Carcass Traits[1]

Carcass Traits:	Total Area	Marrow Cavity Area	Bone Wall Area	Av. Wall Thickness	MC Circ/[2] TA	TA/MCA[3]
Dressing %	-.10*	-.07	-.10*	-.11*	0.06	-.02
Hide Weight	0.23**	0.16**	0.21**	0.11*	-.15**	-.08
Loin Eye Area	0.19**	0.12**	0.18**	0.05	-.18**	-.01
Adj. Fat Thickness	-.45**	-.33**	-.37**	-.13**	0.33**	0.10*
Chilled Carcass Weight	-.12**	-.12**	-.12**	-.14**	0.07	-.03
Marbling Score	-.35**	-.27**	-.28**	-.04	0.35**	0.17**
Quality Grade	-.32**	-.24**	-.27**	-.07	0.31**	0.11*
Yield Grade	-.46**	-.37**	-.35**	-.08	0.35**	0.16**
% Adj. Cutability	0.47**	0.36**	0.39**	0.13**	-.36**	-.15**
% Adj. Retail Product	0.47**	0.36**	0.38**	0.12**	-.37**	-.16**
% Trimmed RLRC	0.47**	0.37**	0.37**	0.13**	-.35**	-.16**
% Roasts (RLRC)	0.45**	0.35**	0.36**	0.11*	-.35**	-.16**
% Carcass Fat Trim	-.50**	-.37**	-.42**	-.16**	0.39**	0.14**
% Carcass Bone	0.52**	0.42**	0.40**	0.18**	-.35**	-.17**

[1]Final live weight held constant.
[2]Metacarpal Circumference/Total Area.
[3]Total Area/Marrow Cavity Area.
*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX IE.

Overall Partial Correlation Coefficients of
Final Live Weight with
Performance Characteristics and Carcass Traits

Performance Characteristics:	Final Live Weight
Birth Weight	0.53**
ADG Birth to Weaning	0.59**
200-Day Weight	0.64**
ADG Weaning to Final	0.40**
Av. Growth Potential Score	-.63**
Carcass Traits:	
Dressing %	0.26**
Hide Weight	0.67**
Loin Eye Area	0.55**
Adj. Fat Thickness	0.17**
Chilled Carcass Weight	0.98**
Marbling Score	0.07
Quality Grade	0.09
Yield Grade	0.15**
% Adj. Cutability	-.06
% Adj. Retail Product	-.11*
% Trimmed RLRC	-.02
% Roasts (RLRC)	-.04
% Carcass Fat Trim	0.13**

*Significant at the .05 level.

**Significant at the .01 level.

APPENDIX IIA.

Correlation Coefficients of SxH and CxH Breed Crosses for Bone Scores and Cannon Bone Measurements with Performance and Carcass Traits

Performance Characteristics:	Feeder Bone Score	Slaughter Bone Score	Total Cannon Weight	Right Cannon Circ.
Birth Weight	-.14	-.25*	0.38**	0.28*
ADG Birth to Weaning	-.34**	-.19	0.50**	0.27*
200-Day Weight	-.34**	-.22	0.53**	0.30*
ADG Weaning to Final	-.09	0.00	0.03	0.12
Final Live Weight	-.30*	-.19	0.82**	0.58**
Av. Growth Potential Score	0.51**	0.18	-.53**	-.32**
Carcass Traits:				
Dressing %	-.06	0.20	0.23*	0.05
Hide Weight	-.46**	-.44**	0.70**	0.65**
Loin Eye Area	-.08	-.02	0.40**	0.41**
Adj. Fat Thickness	-.10	0.06	0.17	0.05
Chilled Carcass Weight	-.27*	-.12	0.77**	0.52**
Marbling Score	0.14	0.11	0.10	-.10
Quality Grade	0.09	0.12	0.11	-.14
Yield Grade	-.09	-.02	0.21	-.05
% Adj. Cutability	-.04	-.01	-.15	0.03
% Adj. Retail Product	0.01	0.00	-.19	0.00
% Trimmed RLRC	-.07	-.02	-.05	0.08
% Roasts (RLRC)	0.01	0.04	-.18	-.02
% Carcass Fat Trim	0.00	0.01	0.21	0.21
% Carcass Bone	0.07	-.26*	-.09	-.11

*Significant at the .05 level.

**Significant at the .01 level.

APPENDIX IIB.

Correlation Coefficients of SxH and CxH Breed Crosses for Metacarpal Measurements and Percentage of Carcass Bone with Performance and Carcass Traits

Performance Characteristics:	M.C. Weight	M.C. Length	M.C. Circ.	M.C. Specific Gravity	Percent Carcass Bone
Birth Weight	0.35**	0.24*	0.14	0.00	-.06
ADG Birth to Weaning	0.49**	0.22	0.21	-.05	-.25*
200-Day Weight	0.52**	0.25*	0.22	-.04	-.25*
ADG Weaning to Final	0.05	0.33**	0.18	0.06	-.19
Final Live Weight	0.64**	0.24*	0.28*	0.34**	-.51**
Av. Growth Potential Score	-.44**	-.56**	-.37**	-.06	0.13
Carcass Traits:					
Dressing %	0.24*	0.08	-.02	0.08	-.51**
Hide Weight	0.43**	0.14	0.35**	0.14	-.25*
Loin Eye Area	0.34**	0.16	0.11	0.17	-.42**
Adj. Fat Thickness	0.01	-.23*	0.03	0.02	-.40**
Chilled Carcass Weight	0.62**	0.23*	0.25*	0.32**	-.55**
Marbling Score	0.08	-.03	-.15	0.07	-.03
Quality Grade	0.08	-.09	-.11	0.00	-.08
Yield Grade	0.15	-.04	0.11	0.07	-.22
% Adj. Cutability	-.20	0.09	-.06	0.08	0.11
% Adj. Retail Product	-.20	0.05	-.08	0.06	0.12
% Trimmed RLRC	-.07	0.28*	0.00	-.03	0.25*
% Roasts (RLRC)	-.13	0.13	-.07	0.03	0.12
% Carcass Fat Trim	0.21	-.14	0.05	0.01	-.30*
% Carcass Bone	0.09	0.11	0.13	-.33**	1.00

*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX IIC.

Correlation Coefficients of SxH and CxH Breed Crosses for Metacarpal Cross-Sectional Measurements with Performance and Carcass Traits

Performance Characteristics:	Total Area	Marrow Cavity Area	Bone Wall Area	Av. Wall Thickness	MC Circ/TA[1]	TA/MCA[2]
Birth Weight	0.05	0.03	0.05	0.07	0.07	-.03
ADG Birth to Weaning	0.17	0.07	0.18	0.12	-.07	-.06
200-Day Weight	0.17	0.07	0.18	0.12	-.06	-.06
ADG Weaning to Final	0.18	0.06	0.05	0.16	-.10	0.01
Final Live Weight	0.19	0.10	0.18	0.15	-.13	-.04
Av. Growth Potential Score	-.41**	-.24*	-.38**	0.05	0.27*	0.07
Carcass Traits:						
Dressing %	-.09	-.01	-.12	-.09	0.10	-.07
Hide Weight	0.30**	0.16	0.29*	0.15	-.13	-.04
Loin Eye Area	0.20	0.17	0.13	0.16	-.15	-.10
Adj. Fat Thickness	-.09	-.05	-.09	-.04	0.12	0.00
Chilled Carcass Weight	0.15	0.09	0.13	0.14	0.02	-.06
Marbling Score	-.34**	-.19	-.33**	0.15	0.39**	0.03
Quality Grade	-.31**	-.16	-.30**	0.05	0.35**	0.02
Yield Grade	-.10	-.16	-.01	0.00	0.20	0.12
% Adj. Cutability	0.17	0.11	0.15	0.01	-.27*	0.01
% Adj. Retail Product	0.12	0.10	0.09	0.00	-.22	-.02
% Trimmed RLRC	0.25*	0.21	0.17	-.05	-.32**	-.06
% Roasts (RLRC)	0.09	0.10	0.05	0.04	-.17	-.02
% Carcass Fat Trim	-.16	-.13	-.11	0.00	0.24*	0.03
% Carcass Bone	0.17	0.16	0.09	-.01	-.10	-.08

[1]Metacarpal Circumference/Total Area.
[2]Total Area/Marrow Cavity Area.
*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX IIIA.

Correlation Coefficients of SxA, CxA and HxH Breed Crosses for Bone Scores and Cannon Bone Measurements with Performance and Carcass Traits

Performance Characteristics:	Feeder Bone Score	Slaughter Bone Score	Total Cannon Weight	Right Cannon Circ.
Birth Weight	-.21*	-.20*	0.45**	0.27**
ADG Birth to Weaning	-.20*	-.10	0.47**	0.13
200-Day Weight	-.22*	-.12	0.51**	0.16
ADG Weaning to Final	-.15	-.26**	0.24*	0.32**
Final Live Weight	-.11	-.16	0.73**	0.45**
Av. Growth Potential Score	0.22*	0.19*	-.50**	-.25**
Carcass Traits:				
Dressing %	-.12	0.12	0.06	-.06
Hide Weight	-.12	-.19*	0.62**	0.49**
Loin Eye Area	-.06	-.12	0.35**	0.09
Adj. Fat Thickness	-.18	0.11	0.10	0.14
Chilled Carcass Weight	-.13	-.14	0.69**	0.40**
Marbling Score	0.13	0.07	0.12	-.07
Quality Grade	0.06	0.15	0.11	-.12
Yield Grade	-.12	0.06	0.18	0.19*
% Adj. Cutability	0.15	-.11	-.16	-.05
% Adj. Retail Product	0.15	-.10	-.18	-.09
% Trimmed RLRC	0.17	-.17	-.05	0.04
% Roasts (RLRC)	0.15	-.10	-.14	-.11
% Carcass Fat Trim	-.18	0.13	0.15	0.04
% Carcass Bone	0.27**	-.10	0.02	-.04

*Significant at the .05 level.

**Significant at the .01 level.

APPENDIX IIIB.

Correlation Coefficients of SxA, CxA and HxH Breed Crosses for Metacarpal Measurements and Percentage of Carcass Bone with Performance and Carcass Traits

Performance Characteristics:	M.C. Weight	M.C. Length	M.C. Circ.	M.C. Specific Gravity	Percent Carcass Bone
Birth Weight	0.56**	0.58**	0.33**	-.26**	-.03
ADG Birth to Weaning	0.63**	0.57**	0.49**	-.14	-.16
200-Day Weight	0.66**	0.61**	0.50**	-.17	-.15
ADG Weaning to Final	0.28**	0.35**	0.22*	-.14	-.07
Final Live Weight	0.76**	0.67**	0.54**	-.07	-.32**
Av. Growth Potential Score	-.66**	-.75**	-.48**	0.06	0.10
Carcass Traits:					
Dressing %	0.76**	0.67**	0.54**	0.30**	-.44**
Hide Weight	0.28**	0.25**	0.21*	0.13	-.14
Loin Eye Area	0.44**	0.34**	0.41**	-.02	-.23*
Adj. Fat Thickness	-.02	0.01	-.02	0.31**	-.54**
Chilled Carcass Weight	0.75**	0.66**	0.53**	-.01	-.39**
Marbling Score	0.13	0.08	0.10	-.01	-.08
Quality Grade	0.16	0.08	0.11	-.03	-.06
Yield Grade	0.13	0.17	0.04	0.14	-.34**
% Adj. Cutability	-.18	-.11	-.11	0.17	0.24*
% Adj. Retail Product	-.13	-.07	-.07	0.07	0.30**
% Trimmed RLRC	-.15	-.10	-.11	0.16	0.28**
% Roasts (RLRC)	-.07	-.10	0.08	0.11	0.23*
% Carcass Fat Trim	0.14	0.08	0.10	-.06	-.43**
% Carcass Bone	0.17	0.02	0.13	-.39**	1.00

*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX IIIC.

Correlation Coefficients of SxA, CxA and HxH Breed Crosses for Metacarpal Cross-Sectional Measurements with Performance anc Carcass Traits

Performance Characteristics:	Total Area	Marrow Cavity Area	Bone Wall Area	Av. Wall Thickness	MC Circ/[1] TA	TA/MCA[2]
Birth Weight	0.40**	0.34**	0.28**	0.01	-.32**	-.21*
ADG Birth to Weaning	0.40**	0.32**	0.30**	0.18	-.20*	0.18
200-Day Weight	0.43**	0.34**	0.32**	0.17	-.23*	-.16
ADG Weaning to Final	0.32**	0.25**	0.24*	0.12	-.26**	-.09
Final Live Weight	0.47**	0.39**	0.34**	0.14	-.23*	-.19
Av. Growth Potential Score	-.49**	-.34**	-.40**	-.20*	0.32**	0.12
Carcass Traits:						
Dressing %	0.17	0.10	0.16	-.04	-.12	-.04
Hide Weight	0.09	-.04	0.15	0.27**	0.06	0.13
Loin Eye Area	0.43**	0.38**	0.29**	-.09	-.30**	-.22*
Adj. Fat Thickness	-.14	-.19*	-.05	0.25**	0.19*	0.16
Chilled Carcass Weight	0.48**	0.38**	0.37**	0.15	-.27**	-.17
Marbling Score	0.01	0.00	0.01	0.02	0.07	0.02
Quality Grade	0.00	0.01	0.00	0.04	0.09	0.00
Yield Grade	-.09	-.13	-.02	0.29**	0.18	0.13
% Adj. Cutability	0.07	0.06	0.05	-.23*	-.19*	-.04
% Adj. Retail Product	0.12	0.12	0.07	-.23*	-.23*	-.08
% Trimmed RLRC	0.04	0.04	0.03	-.19*	-.14	-.02
% Roasts (RLRC)	0.08	0.11	0.02	-.29**	-.19*	-.10
% Carcass Fat Trim	-.08	-.05	-.06	0.17	0.19*	0.02
% Carcass Bone	0.13	0.23*	0.00	-.05	-.08	-.21*

[1]Metacarpal Circumference/Total Area.
[2]Total Area/Marrow Cavity Area.
*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX IVA.

Correlation Coefficients of LxH, LxA, HxA, AxH, SDxH, SDxA and AxA Breed Crosses for Bone Scores and Cannon Bone Measurements with Performance and Carcass Traits

Performance Characteristics:	Feeder Bone Score	Slaughter Bone Score	Total Cannon Weight	Right Cannon Circ.
Birth Weight	-.06	-.21**	0.54**	0.36**
ADG Birth to Weaning	-.11	0.16*	0.29**	0.04
200-Day Weight	-.12	0.11	0.36**	0.09
ADG Weaning to Final	-.09	-.37**	0.26**	0.37**
Final Live Weight	-.15*	-.11	0.70**	0.49**
Av. Growth Potential Score	0.03	0.06	-.56**	-.26**
Carcass Traits:				
Dressing %	-.02	0.25**	-.02	-.12
Hide Weight	-.38**	-.50**	0.57**	0.66**
Loin Eye Area	0.03	-.02	0.37**	0.22**
Adj. Fat Thickness	-.31**	0.08	-.04	-.04
Chilled Carcass Weight	-.14*	-.03	0.64**	0.41**
Marbling Score	0.05	0.17**	-.02	-.10
Quality Grade	0.03	0.16*	-.02	-.10
Yield Grade	-.19**	0.10	0.00	-.02
% Adj. Cutability	0.12	-.17**	0.10	0.14*
% Adj. Retail Product	0.15*	-.16*	0.06	0.11
% Trimmed RLRC	0.12	-.17**	0.14*	0.16*
% Roasts (RLRC)	0.15*	-.12	0.10	0.08
% Carcass Fat Trim	-.15*	0.19**	-.08	-.11
% Carcass Bone	0.08	-.14*	0.19**	0.07

*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX IVB.

Correlation Coefficients of LxH, LxA, HxA, AxH SDxH, SDxA and AxA Breed Crosses for Metacarpal Measurements and Percentage of Carcass Bone with Performance and Carcass Traits

Performance Characteristics:	M.C. Weight	M.C. Length	M.C. Circ.	M.C. Specific Gravity	Percent Carcass Bone
Birth Weight	0.58^{**}	0.54^{**}	0.38^{**}	-.16	0.22^{**}
ADG Birth to Weaning	0.22^{**}	0.21^{**}	0.13^{*}	-.12	$-.20^{**}$
200-Day Weight	0.30^{**}	0.29^{**}	0.19^{**}	$-.14^{*}$	$-.16^{*}$
ADG Weaning to Final	0.26^{**}	0.23^{**}	0.31^{**}	-.02	-.02
Final Live Weight	0.51^{**}	0.37^{**}	0.46^{**}	0.07	$-.38^{**}$
Av. Growth Potential Score	$-.67^{**}$	$-.73^{**}$	$-.36^{**}$	-.01	$-.26^{**}$
Carcass Traits:					
Dressing %	0.00	0.05	-.02	0.12	$-.52^{**}$
Hide Weight	0.31^{**}	0.21^{**}	0.31^{**}	0.12	$-.18^{**}$
Loin Eye Area	0.37^{**}	0.38^{**}	0.18^{**}	0.12	-.04
Adj. Fat Thickness	$-.29^{**}$	$-.38^{**}$	-.10	0.04	$-.69^{**}$
Chilled Carcass Weight	0.48^{**}	0.36^{**}	0.41^{**}	0.08	$-.46^{**}$
Marbling Score	$-.15^{*}$	$-.27^{**}$	0.02	0.04	$-.37^{**}$
Quality Grade	$-.14^{*}$	$-.28^{**}$	0.02	-.03	$-.34^{**}$
Yield Grade	$-.21^{**}$	$-.29^{**}$	-.05	0.00	$-.61^{**}$
% Adj. Cutability	0.28^{**}	0.36^{**}	0.11	0.14^{*}	0.58^{**}
% Adj. Retail Product	0.25^{**}	0.35^{**}	0.08	0.12	0.59^{**}
% Trimmed RLRC	0.32^{**}	0.34^{**}	0.15^{*}	0.11	0.64^{**}
% Roasts (RLRC)	0.27^{**}	0.36^{**}	0.07	0.12	0.59^{**}
% Carcass Fat Trim	$-.28^{**}$	$-.37^{**}$	-.11	-.09	$-.69^{**}$
% Carcass Bone	0.37^{**}	0.35^{**}	0.16^{*}	$-.13^{*}$	1.00

*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX IVC.

Correlation Coefficients of LxH, LxA, HxA, AxH, SDxH, SDxA and AxA Breed Crosses for Metacarpal Cross-Sectional Measurements with Performance and Carcass Traits

Performance Characteristics:	Total Area	Marrow Cavity Area	Bone Wall Area	Av. Wall Thickness	MC Circ/TA[1]	TA/MCA[2]
Birth Weight	0.39**	0.28**	0.32**	0.16*	-.28**	-.03
ADG Birth to Weaning	0.10	0.07	0.08	-.02	-.07	-.01
200-Day Weight	0.16*	0.12	0.13*	0.01	-.11	-.02
ADG Weaning to Final	0.33**	0.24**	0.27**	0.10	-.31**	-.12
Final Live Weight	0.32**	0.28**	0.23**	0.05	-.15*	-.11
Av. Growth Potential Score	-.42**	-.24**	-.39**	-.25**	0.36**	0.01
Carcass Traits:						
Dressing %	-.07	-.09	-.03	0.00	0.08	0.07
Hide Weight	0.25**	0.12	0.24**	0.17**	-.13*	0.02
Loin Eye Area	0.20**	0.01	0.26**	0.22**	-.17**	0.13*
Adj. Fat Thickness	-.21**	-.06	-.24**	-.20**	0.23**	-.06
Chilled Carcass Weight	0.28**	0.24**	0.19**	0.03	-.11	-.10
Marbling Score	-.12	-.05	-.12	-.07	0.20**	0.03
Quality Grade	-.09	-.02	-.11	-.09	0.16*	0.00
Yield Grade	-.16*	0.02	-.23**	-.22**	0.19**	-.12
% Adj. Cutability	0.18**	-.02	0.25**	0.29**	-.18**	0.13*
% Adj. Retail Product	0.18**	-.01	0.24**	0.26**	-.20**	0.11
% Trimmed RLRC	0.20**	0.00	0.27**	0.30**	-.18**	0.13*
% Roasts (RLRC)	0.17**	-.05	0.25**	0.29**	-.19**	0.16*
% Carcass Fat Trim	-.21**	0.00	-.28**	-.29**	0.22**	-.12
% Carcass Bone	0.24**	0.09	0.25**	0.25**	-.23**	0.05

[1]Metacarpal Circumference/Total Area.
[2]Total Area/Marrow Cavity Area.
*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX VA.

Correlation Coefficients of JxH and JxA Breed Crosses for Bone Scores and Cannon Bone Measurements with Performance and Carcass Traits

Performance Characteristics:	Feeder Bone Score	Slaughter Bone Score	Total Cannon Weight	Right Cannon Circ.
Birth Weight	0.00	0.10	0.31*	0.23
ADG Birth to Weaning	-.27*	0.03	0.48**	0.31*
200-Day Weight	-.26*	0.05	0.52**	0.34**
ADG Weaning to Final	0.04	-.48**	0.14	0.27*
Final Live Weight	-.28*	-.02	0.81**	0.59**
Av. Growth Potential Score	0.48**	0.23	-.60**	-.51**
Carcass Traits:				
Dressing %	-.16	-.02	0.21	0.15
Hide Weight	-.11	-.32**	0.61**	0.67**
Loin Eye Area	-.08	-.05	0.25*	0.24*
Adj. Fat Thickness	-.34**	0.03	0.26*	0.18
Chilled Carcass Weight	-.29*	-.04	0.78**	0.57**
Marbling Score	-.03	0.40**	0.02	-.15
Quality Grade	0.02	0.35**	-.07	-.19
Yield Grade	-.27*	0.12	0.25*	0.10
% Adj. Cutability	0.34**	-.18	-.10	0.09
% Adj. Retail Product	0.25*	-.24*	-.21	-.04
% Trimmed RLRC	0.27*	-.19	-.02	0.19
% Roasts (RLRC)	0.34**	-.06	-.07	0.07
% Carcass Fat Trim	-.39**	0.19	0.16	0.00
% Carcass Bone	0.11	-.16	0.12	0.16

*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX VB.

Correlation Coefficients of JxH and JxA Breed Crosses for Metacarpal Measurements and Percentage of Carcass Bone with Performance and Carcass Traits

Performance Characteristics:	M.C. Weight	M.C. Length	M.C. Circ.	M.C. Specific Gravity	Percent Carcass Bone
Birth Weight	0.29*	0.23*	0.15	-.09	-.02
ADG Birth to Weaning	0.43**	0.17	0.32**	-.38**	-.12
200-Day Weight	0.47**	0.21	0.34**	-.39**	-.11
ADG Weaning to Final	0.28*	0.24	0.01	0.21	0.14
Final Live Weight	0.65**	0.27*	0.38**	-.04	-.28*
Av. Growth Potential Score	-.63**	-.26*	-.40**	0.33**	-.14
Carcass Traits:					
Dressing %	0.10	-.05	-.11	0.16	-.43**
Hide Weight	0.46**	0.22	0.24*	0.11	-.15
Loin Eye Area	0.28*	0.07	0.17	-.01	-.03
Adj. Fat Thickness	0.04	-.11	-.08	-.14	-.58**
Chilled Carcass Weight	0.61**	0.22	0.33**	-.01	-.33**
Marbling Score	-.16	-.14	0.04	0.05	-.60**
Quality Grade	-.25*	-.18	-.07	0.12	-.65**
Yield Grade	0.06	-.04	-.06	-.14	-.45**
% Adj. Cutability	0.07	0.21	0.05	0.28*	0.42**
% Adj. Retail Product	-.04	0.14	-.06	0.24	0.27*
% Trimmed RLRC	0.06	0.17	0.05	0.31*	0.32**
% Roasts (RLRC)	0.10	0.19	0.14	0.22	0.44**
% Carcass Fat Trim	-.03	-.18	-.04	-.27*	-.43**
% Carcass Bone	0.40**	0.34**	0.29*	-.21	1.00

*Significant at the .05 level.
**Significant at the .01 level.

APPENDIX VC.

Correlation Coefficients of JxH and JxA Breed Crosses for Metacarpal Cross-Section Measurements with Performance and Carcass Traits

Performance Characteristics:	Total Area	Marrow Cavity Area	Bone Wall Area	Av. Wall Thickness	MC Circ/TA[1]	TA/MCA[2]
Birth Weight	0.25*	0.29*	0.17	0.08	-.24	-.17
ADG Birth to Weaning	0.31*	0.27*	0.25*	0.10	-.23	-.10
200-Day Weight	0.35**	0.32**	0.27*	0.11	-.27*	-.13
ADG Weaning to Final	0.27*	0.13	0.27*	0.48**	-.34**	0.04
Final Live Weight	0.27*	0.23	0.22	0.23	-.16	-.08
Av. Growth Potential Score	-.54**	-.41**	-.46**	-.18	0.44**	0.12
Carcass Traits:						
Dressing %	-.04	-.10	0.01	0.02	-.01	0.11
Hide Weight	0.30*	0.09	0.32**	0.47**	-.26*	0.12
Loin Eye Area	0.09	0.06	0.08	0.11	-.04	0.04
Adj. Fat Thickness	-.14	-.13	-.11	0.01	0.12	0.08
Chilled Carcass Weight	0.25*	0.19	0.21	0.22	-.16	-.05
Marbling Score	-.27*	-.08	-.29*	-.26*	0.36**	-.07
Quality Grade	-.30*	-.11	-.31*	-.23	0.33**	-.05
Yield Grade	-.07	0.00	-.08	-.04	0.04	-.04
% Adj. Cutability	0.20	0.13	0.18	0.15	-.20	-.02
% Adj. Retail Product	0.12	0.04	0.13	0.12	-.15	0.05
% Trimmed RLRC	0.13	0.12	0.10	0.14	-.14	-.06
% Roasts (RLRC)	0.21	0.21	0.15	0.05	-.16	-.11
% Carcass Fat Trim	-.17	-.08	-.17	-.15	0.17	-.01
% Carcass Bone	0.32**	0.32**	0.24	0.15	-.26*	-.20

[1]Metacarpal Circumference/Total Area.
[2]Total Area/Marrow Cavity Area.
*Significant at the .05 level.
**Significant at the .01 level.

VISUAL APPRAISAL OF BOVINE CANNON BONE SIZE
AS RELATED TO PERFORMANCE AND CARCASS TRAITS
AND METACARPAL MEASUREMENTS

by

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B. S., Kansas State University, 1971

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1973

Visually rugged boned feeder and slaughter steers had large cannon and metacarpal measurements, gained faster in the feedlot and produced heavier muscled carcasses with higher cutability. The investigation involved 484 steers representing 14 different breed crosses over a two year period. These steers, with a large variability of type, were from the same cowherd, were similar in age, were fed the same ration and were raised under the same environmental conditions.

Visual bone size was scored on the steers by a committee of three once after weaning and just prior to slaughter. Numerical scores from 1 to 10 were placed on the steers with 1 representing a rugged and 10 a light boned steer.

At slaughter, typical carcass data and the weight of the four cannons and right forecannon circumference with hide, hair, tendons and hoof intact were obtained. Cutability, total retail product, roasts from the round, loin, rib and chuck, carcass fat trim and carcass bone were recorded and expressed as a percentage of carcass weight. The right metacarpus was cleaned of all extraneous material and weight, length, circumference and specific gravity were obtained. A cross-section was removed at the midpoint of the metacarpus and traced on acetate paper with various cross-sectional measurements taken.

Simple and partial correlations were computed with the partial correlations calculated holding final live weight constant to remove the effect of live weight on the carcass traits and bone measurements. Nearly all correlation coefficients were highly significant, so the relative value of each correlation was of importance rather than the significance level.

Steers scored as rugged boned at weaning were also rugged boned at slaughter with simple and partial correlations of 0.80 and 0.76. Steers with heavy birth weights and heavy weaning weights showed a tendency to be rugged boned as feeder steers (-.49 and -.31 respectively) and as slaughter steers (-.56 and -.21 respectively). In addition, steers scored as rugged boned at weaning and at slaughter gained moderately faster in the feedlot and were heavier at slaughter. Large boned feeder and slaughter steers had less internal fat (0.28 and 0.49) with a higher percentage of cutability (-.30 and -.49), a higher percentage of total retail product (-.28 and -.48) and a higher percentage yield of roast meat from the round, loin, rib and chuck (-.38 and -.45) but were lower grading when partial correlations were computed. Fat thickness was less for the rugged boned slaughter steers but was not related to feeder bone ruggedness.

Moderate simple and partial correlations were found between feeder bone score and cannon weight (-.59 and -.47), cannon circumference (-.67 and -.58), metacarpal weight (-.49 and -.31) and metacarpal circumference (-.57 and -.45). Slaughter bone scores were more highly related to cannon and metacarpal measurements than feeder bone scores. High simple and partial correlations were obtained between slaughter bone score and cannon weight (-.67 and -.62), cannon circumference (-.77 and -.72), metacarpal weight (-.57 and -.44) and metacarpal circumference (-.61 and -.51), supporting the judges' ability to accurately visually determine bone size. In addition, the rugged boned steers had larger metacarpal cross-sectional total areas, marrow cavity areas and bone wall areas but did not have the thickest bone walls.