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Relationships Between Beef Palatability and Bone Density, Bone Hardness and Other Maturity Indicators

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RELATIONSHIPS BETWEEN BEEF PALATABILITY AND BONE DENSITY, BONE HARDNESS AND OTHER MATURITY INDICATORS

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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LIST OF ABBREVIATIONS

ma - milliamperes

pKv - peak Kilovolts

PR - partial regression coefficients

R^2 - coefficient of determination

STE - slice tenderness evaluator

INTRODUCTION

A trend in recent years has been for meat scientists to concentrate much of their effort on obtaining a more complete understanding of those factors which affect or contribute to meat quality or palatability. Some of these topics have ranged from the effect of nutritional regime on palatability to the effects of hormone treatments, antemortem stress conditions, breeds or types, sex, marbling levels, maturity or age, cooking techniques, chemistry of muscle and fat, measurement of muscle fiber diameter and extensibility, connective tissues and, finally, color of muscle and fat.

This emphasis on factors relating to beef palatability has also caused a proliferation of studies devoted to elucidating what beef palatability actually is and how it can be measured more objectively. As a result, we also find a number of reports on comparisons of different shearing and press techniques, histological examinations of muscle and connective tissue morphology and biochemical studies of the components which comprise what we know as meat.

Only a limited amount of study has been given to the relationship which may exist between bone characteristics and palatability in our meat-producing animals. About the only reference to bone is made when development of ossification is discussed in the light of advancing "physiological maturity" in beef carcasses. This particular characteristic takes on added importance when we realize that every Federal meat grader must assess this rather subjective measure of carcass maturity on every carcass he grades. Therefore, "physiological

maturity" plays a role in the marketing of federally graded meat and consequently has economic significance. Results of studies on carcass maturity have been somewhat mixed, but it appears there is at least some relationship between measures of maturity and organoleptic tenderness.

Since there is some indication of a relationship between measures of maturity and tenderness, two methods of bone analysis have been developed in this study in an attempt to make bone development measurements more objective as well as to see if the bone characteristics measured are more closely related to beef eatability than carcass maturity alone.

Many past studies in the area of beef quality have been carried out either on a limited number of animals with known history but usually similar backgrounds or on more animals with less knowledge of their individual backgrounds concerning genetic makeup, nutritional status or chronological age. Furthermore, many of these experiments have been based on filling blocks with a specific number of animals or carcasses which possess certain well-defined characteristics. The resulting sample is skewed and may not represent the population being studied. Economically and aesthetically important traits may not be properly evaluated in experiments so designed.

This particular study may be criticized for the paucity of information concerning genetics, nutrition and chronological age of the animals selected; however, the time and expense involved in obtaining such information on large numbers of cattle make this approach rather prohibitive.

Strong points of this experiment are the relatively large number of animals and the random selection of live animals from the female slaughter population of a major packing company over the period of slightly more than one week. Random selection should provide some indication of the importance of some of these traits in the total slaughter population. Information about breed and type as well as factors which may influence carcass grade, particularly an estimate of animal age, can be obtained by selecting the animals before slaughter.

Considering that animal age as it may influence carcass maturity is economically important, this study permits some conclusions to be drawn from the use of live animal indicators of maturity as they are used by beef cattle buyers every day in practice.

Only females were selected to remove sex as a source of variation and still have as wide a range in all other characteristics, particularly age, as possible. Data was collected on as many live, carcass and tissue traits as was deemed feasible.

The primary objectives of this study were:

1. To study the effectiveness of present methods of evaluating live animals and beef carcasses for eventual palatability characteristics.

2. To reflect the differences actually important in our present slaughter population. This was to be accomplished by selecting female bovines as randomly as possible from the slaughter population.

3. To study the effectiveness of two newly developed methods of bone analyses in predicting eventual palatability of the meat.

REVIEW OF LITERATURE

This review may not include all articles pertaining to the topics discussed herein, but a strong attempt was made to have all viewpoints relating to phases of this study represented.

Live Cattle Traits

Palatability of beef from a number of different breeds of cattle has been studied. Branaman et al. (1962) reported comparisons between a group of 25 Hereford beef-type cattle and a group of 25 Holstein cattle fed and handled similarly from three separate trials. Beef-type cattle had a greater shrinkage during cooking of the meat, a significantly higher intensity of lean flavor and greater quantity of juiciness which possibly was a reflection of the higher carcass grades attained by the Herefords. No significant differences in aroma, texture of lean, flavor of fat or tenderness as measured either by taste panel or Warner-Bratzler shear were attributed to breed differences. Herefords dressed higher but showed no appreciable differences in percentage of high priced wholesale cuts or total trimmed retail steaks when compared with the Holsteins.

Callow (1961) in comparing Hereford, Dairy Shorthorn and Friesian (Holstein) steers on four levels of nutrition allotted only two steers of each breed to each level of nutrition. Therefore, the results may not be entirely representative of the breeds studied; however, Herefords had heavier hides by approximately 1.5% than either the Dairy Shorthorn or Friesians. Yet, the dressing percent did not vary significantly with

breed but did vary significantly between nutrition levels. This was probably to be expected since one group of these steers was on pasture only until slaughtered while two others were fed combinations of pasture and concentrates and one group was fed completely on a concentrated ration until slaughter. The individual breeds averaged 1,419 pounds, 1,289 pounds and 1,208 pounds, respectively, at slaughter for the Friesians, Shorthorns and Herefords. The Friesians possessed the leanest carcasses with 33.0% of live weight or 60.0% of carcass weight in lean meat followed by the Herefords with 32.2% and 57.1%, respectively, and the Dairy Shorthorn with 30.9% and 55.1%, respectively. A relatively high correlation of r = 0.67 was noted between the weight of blood collected on the slaughter floor and weight of muscle in the carcass. Blood equaled slightly more than one-tenth the muscle weight. Friesians possessed the most internal fats while the Herefords had the least. No palatability differences due to breed or treatment were shown.

Dunsing (1959) reported on comparisons between eight pairs of Hereford and Holstein steers where the later maturing Holsteins were six months older than the Herefords at slaughter. The Herefords graded higher, but the higher grade was almost entirely due to the influence of conformation since quality grades were almost equal. Visual preference for the meat did not appear to be related to breed except for color where a preference was indicated for the darker colored Holstein steaks. This observation seemed rather strange to this author unless this darker color was only slightly darker. Eating preferences seemed more closely related to quality grade than final carcass grade.

Carroll et al. (1964) reporting on the above Hereford and Holstein steers as well as another group of 18-month-old Herefords and 30-month-old Holsteins with carcass weights and conformations of 717 pounds, high Choice and 846 pounds, high Standard, respectively, found that Holstein steaks were less tender but more flavorful. This may be a reflection of the age differences rather than breed. Specific gravity of the cannon bone and a rib bone from each animal showed a surprising similarity between breeds which may indicate this characteristic is more closely related to physiological maturity than chronological age. Herefords were fatter subcutaneously but not in marbling while the Holsteins possessed a higher proportion of bone and a noticeably greater amount of kidney and pelvic fat.

Ramsey et al. (1963) in a five-year study to determine palatability and cooking loss differences for 151 steers of seven different breeds and crosses found that among breeds loin and round steaks of Brahman steers were scored least tender by the taste panel. Jersey steaks scored most tender but differences between Jersey and Hereford steaks were not significant. Hereford, Angus, Brahman-British cross, Santa Gertrudis and Holstein steaks did not differ significantly in tenderness. Shear values generally agreed with this conclusion. Although Angus steer carcasses had the most marbling and graded highest of all breeds, their steaks generally rated lower in palatability than Jersey or Hereford steaks. Factors other than marbling seemed to be playing a role here. Among breeds, total cooking losses did not parallel external fatness.

In a report studying the differences between the palatability of round and 9-10-11 rib roasts from 156 Hereford, Angus, Charbray straightbreds and Hereford crossbreds, varying in animal replications, sex and grade, Sharrah et al. (1965) summarized their findings by saying round roasts from Hereford straightbreds were higher in all quality factors than roasts from the other breeds while the Angus breed and its crosses generally produced more tender, juicy and flavorful rib roasts. Sensory tenderness correlated more highly with Warner-Bratzler shear than with L.E.E.-Kramer-Warner-Bratzler modification shear values.

Blackmon et al. (1960) reported that 16 Hereford females, four in each age category of 6 months, 18 months, 42 months and 90 months at slaughter, were selected on the basis of approaching or averaging a slight degree of marbling. Animal age did not significantly influence dressing percent nor percent fat, lean and bone. Percent loin, chuck and plate increased with age while percent round decreased. Correlation between panel tenderness and Warner-Bratzler shear was highly significant ($r = 0.84$). Tenderness of the broiled loin steaks, aged 14 days, decreased significantly with increased age of animal. However, the differences in tenderness of the steaks frozen after the 48-hour chill period and later cooked were not significant. Influence of age may not be as great as has been commonly thought but rather the tenderizing effect of aging beef may be greater for younger cattle. Juiciness and flavor were only slightly influenced by animal age while percent moisture decreased with increased age.

Hiner and Hankins (1950) studied 52 beef animals in five age groups as follows: 8 cows, five and one-half years of age; 8 heifers, barren, three years old; 25 steers, 900 pounds, 16 months old; 8 calves, 500 pounds, seven months old and 3 veal calves, two and one-half months old. These workers found the cows graded Commercial, the heifers high Commercial, the steers Good, the 500 pound calves high Standard and the veal calves Good. Among the muscle groups studied in all these cattle, the neck and fore shank muscles were found to be least tender followed by the muscles in the round, the muscles in the chuck, rib, shortloin and sirloin and finally the most tender muscle was the tenderloin. Differences in tenderness between the groups of muscles were not as great for the three-year old heifers as for the cows. The three large muscles in the round were not significantly different in tenderness. As the age of animals increased, tenderness decreased for each of the nine muscles sampled. Differences between veal calves and cows were highly significant, whereas those between veal and 500 pound steer calves were not significant. Hiner and Hankins (1953) in another report on this same group of cattle found that fiber diameter increased in all nine muscles with increasing age with the exception of two muscles in the veal and 500 pound calves. As fiber diameter increased, resistance to shearing increased. In general, the less active muscle fibers increased in size with advancing age more than those fibers that were more active. The relationship between tenderness and fiber diameter for all samples was shown to be curvilinear with a curvilinear correlation of $r = 0.83$.

An interesting observation by Orme et al. (1959) on x-ray radiograph measurements of lumbar vertebra and their tranverse processes in live cattle showed a significant relationship between width of the vertical process of the lumbar vertebra and ribeye area in the carcass. This particular measurement accounted for from 20 to 22 percent of the variation.

In a small palatability study of 16 animals equally divided between 18 and 30 months of age, Simone et al. (1959) reported a significant effect of the age difference on the tenderness factor only of the three palatability characteristics studied. Significant differences in the panel's palatability scores were related to differences in U.S.D.A. grade within and between age groups. Panelists rated Choice grade cuts higher in tenderness, juiciness and flavor when compared with those of Good grade carcasses. Anterior location in each of the semimembranosus, adductor and longissimus dorsi muscles resulted in higher quality scores in the above factors than did posterior locations. Reflectance measurements of the raw, ground rectus femoris muscle indicated a darker (lower Y value) meat from the 30-month old steers and from the Choice grade steers than from the younger, lower grading steers.

Tuma et al. (1962) using 24 Hereford females, 18, 42 and 90 months old, with slight and slightly abundant amounts of marbling and sampling two and 14 days after slaughter, found a significant difference in tenderness was related to animal age. The higher marbling level was associated with slightly greater tenderness, both panel and

Warner-Bratzler shear, than the lower amount. Older steaks were scored more tender after aging 14 days while steaks from the 18-month old heifers did not show any improvement. Color of steaks was darker red as animal age increased. These older steaks showed a significant decrease in hue, value and chroma. Aging produced a brighter, more intense color. Marbling level did not seem to influence color. Taste panel flavor and juiciness scores did not appear to be related to animal age, marbling level or aging period.

Webb et al. (1964) in a similar type of study reported on carcasses from 66 cattle, 12, 24 and 60 months of age, which were selected to differ in method of antemortem stress treatment, method of aging and grade. Significant differences in tenderness were found when comparisons between the stressed and nonstressed cattle were made early in the aging period and when older cattle were compared with younger cattle. The differences noted in the early part of the aging period were largely resolved as time passed. Tenderness improved during aging, but no significant differences were shown between carcasses aged at high and low temperatures for three and 15 days, respectively. Panel tenderness values were significantly correlated, $r = 0.67$, with Warner-Bratzler shear values but not with the hydroxyproline content of beef muscle.

Wanderstock and Miller (1948), while studying four methods of feeding cattle, found among other things that there was less expressable juice from the fatter cattle when using the Carver hydraulic press as the measuring device. All beef produced under these trials was

acceptable; however, beef produced with grain in the ration was higher in grade and palatability than beef produced on pasture alone, due largely to differences in fatness. Grades ranged from low Commercial (presently Standard grade) to low Good for the straight pasture-feds while the cattle fed some grain and full-fed grain graded from low Good to average Choice depending on the amount of concentrate in the ration.

A study on the tenderness and biochemical characteristics of meat three and 13 days post-mortem from 32 animals was conducted by Wierbicki et al. (1956). These animals included heifers, bulls, bulls implanted with diethylstilbestrol, steers and steers implanted with diethylstilbestrol. They noted no great differences in tenderness between groups at 13 days post-mortem, although the hormone treatment tended to produce slightly tougher meat at both three and 13 days after slaughter. Intramuscular fat was greatest in steers and heifers and least in bulls and hormone-treated steers.

Jacobson and Fenton (1956), reporting on the effect of three levels of nutrition and age of animal on the quality of beef, found individual muscle weights increased with higher feeding regime as well as with age. The levels of nutrition were 60, 100 and 160 percent of Morrison's recommendations and age groups at slaughter were 32, 48, 64 and 80 weeks for the 24 experimental heifers. Intramuscular fat increased with higher nutrition level; however, no significant differences in Warner-Bratzler shear values could be attributed to the level of nutrition. Also, no consistent evidence was found that shear force value was changed with increased animal age up to 80 weeks. Shear force

was less for psoas major than for longissimus dorsi or semimembranosus at each age. Flavor of lean from medium and high levels of feeding was scored higher by a panel than that from the low level. For one muscle, the longissimus dorsi, tenderness scores were higher at the medium and high nutrition level than at the low level. The other muscles studied did not show this relationship. Flavor and aroma were most desirable at 48 weeks of age. Tenderness score decreased slightly with age, particularly in the semimembranosus.

Correlations for carcass grade after ribbing with live slaughter grade in uniform groups of fed cattle generally have been shown to be very low. Wheat and Holland (1960) reported a study where 688 Hereford slaughter cattle fed in 15 experimental groups were graded on an individual basis for expected carcass grade to one-third of a grade. From three to 10 and on the average 6.6 individuals with varying amounts of training live graded the cattle. Eighty-one percent of the carcasses graded from average Good to average Choice, after ribbing. Average correlations between slaughter grade and carcass grade ranged from $r = 0.07$ to 0.39. Average correlation between carcass grade after ribbing and degree of marbling was $r = 0.89$, which points up the strong dependence of carcass grade on marbling level in youthful animals.

Gregory et al. (1962) in a somewhat similar type study reported that group means for live and carcass traits can be estimated with a reasonable degree of accuracy if the experienced graders have a knowledge of the feeding and management programs as well as the live weights of the cattle. Also, quantitative differences are more easily appraised

than qualitative differences because of the very close relationship between quality and marbling. They emphasized that live evaluation alone is not good enough for selecting breeding stock.

Beef Carcass Traits

Blumer (1963) in a review of the literature on factors affecting the palatability of beef noted that various workers have reported differences in tenderness (taste panel and Warner-Bratzler shear) due to breeds, sire and sire within breed. Also, he stated that exact chronological age of animal may be useful in relating palatability to age of animal; however, there may be something said in defense of carcass maturity as it has been influenced by genetic, metabolic and other biological factors as an indicator of the condition of the meat. Although there are exceptions, in general, the older the animal, the lower the palatability score but no one is sure when this decline in palatability begins. Nutrition level may influence the quantity as well as the types of fat deposited in the carcass. Aging periods must be accounted for in palatability studies since they definitely can influence results. Conditions of storage and length of holding time should be controlled and reported with the data. Also, cooking procedures may greatly influence juiciness and tenderness and should therefore be carefully controlled and reported. Taste panel selection and procedures for tasting are other areas where close attention to detail should be given. The type of panel as well as their variation or error should be noted if at all possible. From available information, chemically determined fat and tenderness do not appear to be related

although a number of researchers have found a small, but positive, relationship between marbling level and tenderness. Flavor appears to be only slightly related to marbling level. To conclude this review, the author gives three short admonitions. First, report the extent to which the taste panel has been trained. Second, state the exact time and conditions of holding and storage. Finally, use sufficient samples within a definable population to make results valid and meaningful.

Cover et al. (1956) recorded fatness by physical separation, by estimation of marbling and by determinations of ether extracts all on the 9-10-11 rib section. Broiled and braised rib steaks were compared for juiciness and tenderness. The strongest association was established between fatness and juiciness but only about 30 percent of the variation was accounted for. Tenderness was not associated with any of the measures of fatness other than ether extract in the longissimus dorsi and bottom round. Ether extract accounted for 10 and 30 percent of the tenderness variation of the two muscles, respectively. The authors comment that it certainly is disconcerting to find that something which has appeared so obvious to so many for so long should be so extraordinarily difficult to prove in the laboratory. It is not surprising, therefore, that a consumer who buys a well-marbled or fat loin steak may sometimes be disappointed by its lack of tenderness.

Rib and eye of round steaks from 20 high and low marbled carcasses ranging in age from 15 to 26 months of age were evaluated both uncooked and after they were broiled to internal temperatures of 140, 160 and 180° F. by Gilpin et al. (1965). The marbling levels studied

were moderately abundant and slight in the rib steaks and moderate and slight in the eye of the round steaks. Evaluations included fat and moisture content and shear values of the major muscle in each steak and palatability characteristics of cooked steaks. Variations in the palatability characteristics of broiled steaks were due primarily to the kind of steak and the internal temperature to which they were broiled. Rib steaks were scored higher in tenderness, flavor and juiciness than eye of round steaks. As steaks were broiled to higher internal temperatures, they were usually scored lower in tenderness, flavor and juiciness. The relationships of marbling or fat (ether extract) with the palatability characteristics of tenderness, flavor and juiciness of the two muscles studied were generally inconsistent and correlation coefficients were very low.

Hiner (1956) stated that color of red meat is not necessarily a guide to the eating quality of beef, but it is always a psychological factor which has real importance for many people. Color, alone, has not been shown to have any influence on palatability; however, older, more mature animals generally have a darker colored lean. Tenderness generally decreases with animal age while intensity of flavor of lean tends to increase. Correlations for marbling level with tenderness, flavor and juiciness on 293 beef and dual purpose Shorthorn steers were 0.15, 0.35 and 0.25, respectively. Because of the very close relationship between carcass grade and marbling level, correlations between carcass grade and each of the above were approximately the same. Marbling level and richness or quality of juice gave a higher correlation

of r = 0.46. Yellow fat was not considered detrimental to carcass quality. It only indicates a high deposition of carotene.

Results of a three year study conducted by Simone et al. (1958) indicated that differences in tenderness, juiciness and flavor became more apparent with wider differences in degrees of finish and carcass grade. The relationship between percent carcass fat and quality scores did not reveal striking correlations. Flavor, however, appears to be associated with intramuscular fat to the extent of r = 0.54. This study consisted of 48 steers, 16 per year of which half were on different rations to produce different degrees of finish. Most differences in eating quality were found between Choice and Good and Choice and Commercial (now Standard) grade comparisons. When sizable differences in intramuscular fat (marbling) occurred, the taste panel consistently and significantly preferred the meat from carcasses with more marbling.

Romans et al. (1965a) studied the influence of carcass maturity and marbling on the physical and chemical characteristics of beef. Eighty beef ribs representing four maturity levels (A, B, C, D, presently A, B, C) and two marbling levels (slight and moderate) were used in this study. Neither maturity, marbling nor core location had a significant effect on tenderness as determined by Warner-Bratzler shear. Steaks from the longissimus dorsi of the more mature carcasses were generally considered less tender than those from less mature carcasses by a taste panel. The taste panel could detect no differences in tenderness due to marbling or sample location. The flavor of the

steaks from the less mature carcasses was generally preferred by the panel. Steaks containing a moderate amount of marbling were significantly more juicy than those containing a slight amount. Muscle fiber diameters were significantly larger in moderate marbling level steaks than slight marbling level steaks. A trend toward larger fiber diameter was noted in the more mature carcasses. Moderate marbling steaks possessed significantly more fat and less moisture while the slight amount steaks had significantly more protein. Warner-Bratzler shear measurements and taste panel tenderness were significantly correlated while fiber diameter was not significantly correlated with tenderness.

In another part of the same study Romans et al. (1965b) found that of the three Munsell color components only value was affected significantly by maturity, while only hue was affected by marbling. Value decreased significantly with increasing maturity, but the differences were significant only at the A maturity level. Hue increased significantly with increased marbling. Hemoglobin was negatively correlated with flavor, indicating that higher hemoglobin content was associated with desirable flavor using the rating 1 being the most desirable and 8 the least desirable.

Goll et al. (1965) in a similar study using 72 carcasses of A, B and F maturity groups (presently A and F) and marbling scores of moderately abundant, slightly abundant, modest, small, traces and practically devoid found that marbling had no effect on tenderness, flavor or juiciness as determined by sensory scores. Older animals were significantly less tender but did not differ significantly in flavor

intensity scores. Marbling level was inversely related to moisture content. Also, more mature carcasses had a lower moisture content of the raw meat, but this difference was removed by cooking. Sensory evaluation of tenderness and L.E.E.-Kramer shear values were highly significantly correlated. Finer textured, more evenly distributed marbling was associated with increased tenderness. Differences between A and B maturity groups were not significant.

Alsmeyer et al. (1959) reported on a study of factors influencing tenderness in 281 animals of predominantly Brahman and Shorthorn breeding. Ages at the time of slaughter ranged from 5 to 87 months with an average of 18.8 months. Carcass grades ranged from low Canner to low Prime and averaged between high Standard and low Good. Marbling scores given by the federal grader ranged from devoid to moderately abundant and averaged between traces and slight amount of marbling. The multiple correlation coefficient for shear tenderness with marbling and animal age was $r = 0.39$. A partial correlation coefficient of 0.25 was found between slaughter age and tenderness by shear with marbling held constant, whereas a partial correlation coefficient of -.35 was obtained between marbling and tenderness shear when age was held constant. Using data from 180 of these carcasses ranging in age from 5 to 30 months along with 322 other carcasses of undetermined genetic background but known to be in the same age range, a highly significant correlation coefficient of 0.15 was obtained between tenderness and slaughter age. Marbling alone only accounted for 8.0 percent of the panel tenderness variability.

Malphrus (1957) reported on the effect of beef fat color on flavor of steaks and roasts. Only 12 carcasses, six with yellow fat and six with white fat but otherwise very similar in grade, age, weight and cooler aging were used. A panel of 105 tasters sampled steaks and 139 sampled roasts for a total of 244 taste evaluations. These included 189 different individuals.

The conclusions made were:

1. A significant number of judges for beef steak and roast detected a difference in the taste of beef with yellow fat and that with white fat. Of those who detected a difference in steaks, a highly significant proportion stated a preference for white fat over yellow fat.

2. Some (two out of four) of the comparisons made by each panel member were on samples from the same animal to check their ability to detect differences. Many noted differences where there should have been none.

3. No flavor preference was given for white or yellow fat roasts, although differences were noted by a significant number of tasters.

This study leaves some question about the conclusions drawn from such a small sample of the population with the opportunity for wide intra- and intermuscle location differences between such a large number of tasters.

Hornstein and Crowe (1964) in a review of information on meat flavor reported that it is generally agreed that (a) beef flavor

precursors are water soluble, (b) heat is necessary for the production of flavor, (c) the precursors are amino acids and reducing sugars (or perhaps a single glycoprotein combining the required sugars and amino acids in one molecule) and (d) a major flavor-producing reaction may be a Maillard-type reaction between amino acids and sugar. There is considerable evidence that volatiles from lean meats, such as beef, pork and lamb and presumably from other lean meats, contribute an identical meaty flavor and that species flavor differences can be traced to the fat. The studies on beef and pork fat indicate that oxidation of unsaturated fatty acids may account, in part, for the different species flavor. The studies on lamb fat indicate that fat may act also as a depot for fat-soluble materials that can influence flavor.

Bone-muscle relationships were studied by Wythe et al. (1958) on 73 Hereford x Brahman crossbred steers and 16 Hereford and Hereford x Angus heifers. Correlations between bone weights and bone lengths of the trimmed metacarpus, tibia, femur, metatarsus and ulna-radius were all above r = 0.80. This would indicate bones within the same animal tend to grow at about the same rate. Bone weights per unit length ratios were correlated to the extent of about r = 0.65. No adjustments were made for weight or age in these data.

Physical and Chemical Characteristics of Beef and Their Relation to Palatability

In a transition area from actual carcass characteristics to the more refined physical and chemical measures of meat samples Walter et al. (1965) in another part of the study conducted by Goll et al. (1965)

found that broiled longissimus dorsi steaks were more tender than deep fat fried steaks as measured by Warner-Bratzler shear. Cores from the medial position, which corresponds to the dorsal position in the study of Alsmeyer et al. (1965), were significantly more tender than those from the lateral position. L.E.E.-Kramer shear measurements on raw samples were of little value in evaluating tenderness. Longissimus dorsi from the more mature carcasses was firmer, darker, coarser and had significantly higher pH values measured five days post-mortem than the longissimus dorsi from less mature carcasses. Water-binding capacity and pH were significantly correlated. An increase in muscle pH value was associated with subjective scores for darker color and coarser texture.

Mjoseth (1962) conducted a study of tenderness variation in longissimus dorsi and semitendinosus bovine muscles from the left side of 12 Hereford heifer carcasses. Objectives were to determine the variation in tenderness, gross chemical composition, pH and cooking loss due to carcass and position effect. Results indicated carcass differences accounted for more variation in all variables except cooking losses than steak position in the longissimus dorsi. However, the reverse was true in the semitendinosus muscle where more differences were found between positions than between animals. Indications were that posterior position of the longissimus dorsi may be best suited for tenderness studies where animal variation is of prime importance. The 13th thoracic and first lumbar vertebrae area possessed the least intramuscular fat and had the greatest resistance to Warner-Bratzler shear.

A study of somewhat the same nature by Alsmeyer et al. (1965) on some dorsal-lateral location tenderness differences in the longissimus dorsi muscle of beef and pork found that beef STE (Slice Tenderness Evaluator) shear values of the dorsal location were significantly lower (more tender) than those from medial or lateral locations. When nine locations within a beef slice were tested, the dorsal position again was the most tender. This study was conducted on 84 cattle, 70 swine and rib roasts from another 136 cattle in a second study. The longissimus dorsi steak samples were rated for tenderness by panel, the STE shear and puncture and by the Warner-Bratzler shear. Among beef samples more panel tenderness variance was explained by Warner-Bratzler than by STE values with correlations of r = -.81, -.71 and -.55, respectively, for Warner-Bratzler shear and STE shear and puncture methods. Among pork samples the STE accounted for over twice as much panel variance as Warner-Bratzler shear. Pork chops and beef steaks also differed in areas of greatest tenderness. Conclusions from these data emphasized the importance of careful selection and control of sampling locations where tenderness is a factor being considered.

Blumer et al. (1962) reported on the nature and variability of marbling deposited in longissimus dorsi muscle of the 9-10-11th rib section of 22 cattle. These 9-10-11th rib sections were examined for patterns and amount of variation in marbling deposition after they had been frozen and cut into 1/4 inch thick slices. Marbling level within the same carcass varied from 2/3 of a degree of marbling to 2 2/3 degrees of marbling. Even adjacent slices showed up to 1 1/3 degrees of marbling

difference. The amount and type of marbling exposed when the ribeye is cut, therefore, seems to be somewhat subject to chance. The range in grade of these cattle was from low Standard to low Prime. Twenty of the 22 cattle were in the Standard and Good grades.

Comparisons Between Mechanical and Sensory Methods of Evaluating Tenderness. Bockian et al. (1958) reported a study on 145 rib roasts using the 10th and 11th rib section where a food grinder, specially wired, was used to measure the energy required to break down cubes of sample. These results were compared with trained laboratory taste panel evaluations. A correlation of -.60 was obtained between these objective and subjective tenderness measurements. Duplicate samples showed about a 10 percent variation in the energy required to grind the sample. The samples used ranged in grade from Prime through the Utility grade.

Burill et al. (1962) compared two mechanical devices (Warner-Bratzler shear and L.E.E.-Kramer shear) with taste panel evaluation for measuring tenderness. The three major muscles of 18 Canner or Cutter grade cow rounds provided 54 samples. In addition 28 Good and Choice grade ribs were used to make a total of 82 samples. Five methods of measuring tenderness were used. These included taste panel scores, panel chews, Warner-Bratzler shear, L.E.E.-Kramer shear maximum force and Kramer shear total work performed. Highly significant correlations were found for all the various combinations of tenderness measures. The lowest was 0.65 for panel chews x Kramer maximum force while the highest was between panel scores and panel chews (-.91). Warner-Bratzler shear and panel score was r = -.83. Kramer maximum force and panel score

correlation was r = -.72. Relationships between individual muscles were lower than for all combined, undoubtedly because of the lower amount of variation. Further measurement of total work performed in shearing the sample with the Kramer shear does not provide any better measure of tenderness than measurement of maximum force.

Conclusions drawn from a comparison of sensory methods with the Warner-Bratzler and L.E.E.-Kramer shear presses by Sharrah et al. (1965) include:

1. Sensory quality factors (tenderness, flavor and juiciness) appeared to be closely interrelated.

2. Warner-Bratzler shear gave slightly higher correlations with panel tenderness than L.E.E.-Kramer shear or Kramer-Warner-Bratzler modification using the Warner-Bratzler shear plate attachment.

3. Mechanical devices differ in sensitivity and reproducibility and appear to measure different properties of meat.

4. Variations may exist within the same muscle.

5. Judges vary considerably in sensitivity and reproducibility and tend to give relative judgments within a set of variables.

6. Use of only the correlation coefficient in relating subjective and objective measurements may be insufficient.

Alsmeyer et al. (1966) reported a study of 375 beef rib roasts and 226 pork loin roasts which were measured and compared for tenderness by the modified tenderness press, Warner-Bratzler shear and STE measurement techniques. The meat, as measured by instrument and panel, became progressively more tender as beef carcass and pork marbling increased.

Objective tenderness measures tended to correlate more closely with panel tenderness score among Standard and Utility grades of beef than among Choice and Good grades. Among pork samples, however, the objective measures tended to correlate more closely with panel tenderness score for pork with greater amounts of marbling. Carcass grade and objective tenderness measures of beef accounted for 6.9 and 53.8 percent, respectively, of the panel tenderness score variation, while marbling score and the objective measures of pork accounted for 7.7 and 46.3 percent, respectively, of the panel score variation.

Cookery Methods. Cooking method may have a distinct influence on results in meat palatability studies. Simers and Hanning (1953) found that increasing temperature of braising and length of cooking time significantly increased juice loss. Suet-covered samples of lean gave similar results.

Paul et al. (1952) reported a study of steaks and roasts from the biceps femoris and semitendinosus from six animals (two Prime, two Good and two Commercial) cooked after 0, 5, 12, 24, 48 to 53 and 144 to 149 hours of cold storage following the stunning and slaughtering of the animal. The pH decreased with increased cold storage time. The tenderness, as measured by shear force, changed with length of storage time. Roasts were least tender immediately after slaughter and increased in tenderness with time. Steaks were tender at slaughter, became less tender and then more tender again. This phenomenon may be explained by the relationship of heat penetration to the stage of rigor

mortis at the various time periods the meat was cooked. The slow heat penetration of roasts cooked immediately following slaughter probably hastened the onset of rigor before the muscle proteins were denatured, whereas the steaks could be heated rapidly and more thoroughly before rigor mortis could occur fully thus remaining quite tender. A short time later, however, the steaks and roasts would be naturally in a state of rigor and cooking at this time with slow rate of heat penetration in roasts may actually accelerate the resolution of rigor while the faster cooking steaks may become denatured in this toughened state of rigor mortis. With increased passage of time, both roasts and steaks may be quite tender as natural resolution of rigor is given a chance to occur before the meat is cooked.

Cover (1958) stated, "Because tenderness is such an important component of the eating satisfaction of meat, a reliable method of detecting it is greatly needed. Such a method ought to be suitable for detecting tenderness or toughness in the steak before it is cooked, in the wholesale cut, in the carcass, and in the live animal." This particular study reported on comparisons between longissimus dorsi and bottom round steaks using two different final temperatures reached by two different methods of cookery. Results indicate that all steaks are more juicy at the lower final temperature. Broiled loin steaks were the most tender at lower final temperatures, while braised bottom round became most tender at the higher final temperature. Other combinations were all tougher to about the same degree according to shear values. Connective tissue and muscle fiber proteins seem to

react differently to cooking by different methods when the muscles come from different locations in the carcass.

In another study by Cover (1959) on longissimus dorsi and bottom round steaks from 55 beef cattle, a discussion of factors affecting sensory tenderness is presented. These factors include:

1. Softness--rated according to the sensations from the tongue and cheek and by the ease with which the teeth sank into the meat at the first bite.

2. Friability--the ease with which the muscle fibers broke--whether they tended to be crumbly or rubbery.

3. Tenderness of connective tissue--rated by the quantity of connective tissue and its resistance to chewing.

Four steaks from each muscle system were used. Each of the four steaks was cooked differently. Two were oven-broiled (one to 61° C., rare; and one to 80° C., well-done) and two were braised (one to 85° C., medium-rare; and one to 100° C. and held there for 25 minutes, very well-done). Shear force values and judges' scores for juiciness were obtained in the usual manner but instead of a single score for tenderness, scores were obtained for all three of the above. Scores for juiciness were remarkably similar to those of a previous study. The tenderness of connective tissue in bottom round was scored low (3.1) when broiled rare, medium when broiled well-done (5.5) and braised medium rare (5.0) but very tender (9.3) when braised very well-done. Thus the connective tissue in bottom round was made tender by braising to a high internal temperature (100° C.) and holding for 25 minutes. No

significant effect was obtained in loin steaks because of low connective tissue. Scores for softness were highest in the steaks broiled rare (61° C.). Broiling well-done (80° C.) and braising (85° C. and 100° C. plus) seemed to harden the muscle fibers in both loin and bottom round. Scores for friability indicated that the muscle fibers in the loin steaks broke apart most readily when broiled rare and were less friable after the other three conditions of cooking. Contrast was marked. Judges apparently were able to distinguish successfully between the three components of tenderness.

Other Characteristics of Meat Which May Be Related to Palatability and Particularly Tenderness. Parrish et al. (1962) reported on a study involving 32 loin and 60 round steaks. Hydroxyproline content was used as an indicator of the amount of connective tissue. The correlation coefficient for all steaks examined for hydroxyproline content and sensory tenderness was -.69 ($P<.001$). Hydroxyproline content was a better measure of the tenderness of less tender steaks than of tender steaks.

Another study on the character of connective tissue conducted by Hiner et al. (1955) on 52 cattle noted that elastic fibers as well as collagen fibers were larger and more numerous in more often used muscles. The presence of fat caused a looser network of collagen. Elastin or collagen's relationship with tenderness seems to be obscure.

Study of the economically important trait of lean color with particular emphasis on the phenomenon of dark-cutting beef was conducted by Munns and Burrell (1965). These Canadian researchers found that

ribeye pH proved highly correlated with the ribeye color if the pH was taken at the normal place of ribbing a carcass in Canadian plants between the 11th and 12th ribs. The results indicate that approximately 90 percent of dark-cutting carcasses have an ultimate pH of 6.0 and above at the 11th and 12th rib. When one uses this pH as a criterion for dark-cutting beef, the likelihood of incorrectly classifying bright-cutting beef is very small, less than 1 percent. This permits the meat processor to identify dark-cutting carcasses quickly and makes it possible to use pH as a reference standard for settling visual claims as to dark-cutting beef. Sampling pH in other areas is not very highly related to ribeye color. Normal beef should have a pH of about 5.4 or 5.5.

In another study on the actual incidence and, therefore, an indication of the economic significance of dark-cutting beef, Munns and Burrell (1966) checked 14,000 cattle between 1957 and 1961 and found an incidence of 8 percent. In Choice steers this incidence was 3.5 percent while in lower quality Commercial steers 12 percent were classified as dark cutters. Shorter period studies indicate no real differences between steers and heifers but a much higher incidence in cows. Also, a strong seasonal trend is indicated with highest incidence in fall and the next highest period in spring. Hedrick of Missouri has been able to produce dark cutters at will by the injection of adrenalin; therefore, it seems the dark-cutting condition is probably related to periods of stress. Sixty-five hundred of the above 14,000 cattle were selected on a somewhat random basis with the only restrictions being

that steers at the rate of 10 head per day were selected with only one steer from any one lot. More highly finished cattle probably have on the average higher tissue glycogen levels, therefore, being less subject to dark cutting.

In a very limited (four pairs of muscles) study, degree of muscular contraction was observed as it related to tenderness by Locker (1960). The various muscles of the beef carcass go into rigor in widely differing states of contraction as defined by the striation patterns of the myofibrils. The final state of a muscle appeared to depend on the strain imposed on it in the hung carcass. It may be modified by cutting or excising the muscle. There was no correlation between the tenderness grading of the muscles and their contraction state in the carcass in rigor, but this could be due to the more dominant effect of connective tissue in some of the muscles. Taste tests conducted on psoas muscles which had been cut at death and allowed to shorten were tougher than on the controls. It was concluded that relaxed muscles are more tender than partly contracted muscles and that this effect may be significant in the scoring of muscles with low connective tissue content. Muscles excised from the carcass before rigor may shorten from 20 to 30 percent. All shortened psoas major and minor muscles tested were tougher than non-excised muscles.

Husaini et al. (1950) studied the relationship between muscle plasma as represented by muscle hemoglobin (myoglobin) and alkali-insoluble protein upon beef tenderness. The experimental animals included ten Hereford and ten Holstein two and one-half year old steers, four well-finished yearlings and four market cattle. No relationship

between carcass grade and tenderness was found in this study. Neither were there any significant differences (for tenderness) between breeds. Myoglobin levels showed no relation to tenderness at three days post-mortem, but a very significant correlation with tenderness was observed 15 days post-mortem.

Deatherage (1957) reported on some basic chemical considerations regarding the tenderness of meat. Briefly, aging of beef can influence tenderness to a degree. Upon post-mortem aging, pH tends to go up while juice expressed on cooking goes down. Actomyosin does not appear to be the key to tenderness. Finally, salt infused into meat can improve tenderness, water holding capacity as well as reduced drip on freezing.

A study by Gaddis et al. (1950) found no relationship existed between percentage of press fluid and panel scores for quantity of juice. There was a direct curvilinear relationship between percent of fat in press fluid and scores for quantity and quality of juice. Percentage of press fluid tended to decrease with increase in its fat content. Consistent relationships between these factors were not found in lamb, mutton and chevon (goat).

Cole et al. (1960) studied specific gravity as an objective measure of beef eating quality. One hundred ribs evenly divided for the five grades, Prime through Commercial, were selected to study the variation in eating quality. Ribs were aged 14 days prior to sampling. Fat cover decreased with decreasing grade on the average of 0.41 centimeter per grade while marbling level decreased 1.78 degrees per

grade. Specific gravity values for excised longissimus dorsi muscle range from Prime, 1.056; Choice, 1.060; Good, 1.064; Standard, 1.067 and Commercial, 1.057. Flavor of lean, tenderness, juiciness and total palatability decreased progressively from Prime through Commercial grades. With the exception of Good grade which sheared on the average 1.03 pounds less than Choice, shear values showed the same linear trend to grade. When leaving out Commercial ribs, only 10 to 20 percent of the variation in beef eating quality was explained by specific gravity. Most of this was due to juiciness and flavor, not tenderness.

Use of Enzymes. As has been the case in many fields of endeavor, sometimes solutions for the problem are found before the problem is fully understood. In the case of meat tenderness, the use of enzyme preparations in various ways can produce tender meat.

Weir et al. (1958) reported that Gottschall and Kies in 1942 found the most rapid digestion by papain occurred between 158 and 185° F. with very little taking place below 85° F. The basic problem in using enzymes to tenderize meat appears to be that of obtaining uniform distribution. In this particular study ribeye steaks from Utility grade cow carcasses were made more tender by treatment with liquid preparations containing papain, NaCl and hydrolyzed vegetable protein. The sarcolemma and muscle fiber envelopes were disintegrated and extensive granulation of the endomysial collagen occurred. Aging of meat from two to five days did not affect the eventual tenderness of the enzyme-treated steaks. Thawing at 70° F. resulted in mushiness of the steak surface and a greater increase in over-all tenderness than thawing and holding at 40° F.

In another study by the same group, Wang et al. (1958) found a close relationship between enzyme-induced changes in the tissue structure and panel response to tenderness differences. The ability of an enzyme to hydrolyze hemoglobin and gelatin did not reflect its activity as a meat tenderizer. The initial tenderness was interpreted as being associated with disintegration of the sarcolemma and muscle fiber envelopes and with reduced muscle fiber extensibility. Residue was interpreted as being associated with degradation of collagen and elastin fibers.

Larger quantities of enzymes were needed to produce tenderness in steaks from semitendinosus than from longissimus dorsi muscles. In the latter steaks, the presence of 2 percent NaCl in the rehydrating media produced a marked increase in tenderness.

A further step in the use of enzymes to tenderize beef was reported by Swift and Company (1960). A papain enzyme solution is injected into the animal 8 to 10 minutes before slaughter. The amount of solution administered varies with animal weight but about eight ounces is used for an average size steer. Tenderizing does not begin until the meat is cooked. Advantages listed for this patented Proten process are that no aging period is necessary and therefore shrinkage and discoloration losses are reduced. Also, the process allows a change in cooking methods for some of the previously less tender cuts of meat. One disadvantage may be that meat may become overly tender or mushy if improper cooking techniques are used. Palatability will suffer greatly, particularly if the meat is left in a steam table or at warm temperatures for a prolonged period of time.

Bone Characteristics

Only a small amount of study has been given to bone and its properties in meat animals. Discussion of bone characteristics has been largely in relation to carcass maturity or physiological age. This is characterized by the development of cartilage ossification as the animal matures. Ossification sequence tends to follow a specific pattern among animals of the same species, although this may be altered by genetics, nutrition regime, disease, endocrine situation and possible other unknown factors.

Since studies on objective measurements of bone properties in meat animals are extremely limited, much of the following literature will relate to the study of laboratory animal or human bone.

Heaney (1965) presented a paper on possible applications of techniques used in medical bone research for meat animal studies. First, a material engineering approach could be taken where such tests as stress analyses and bone hardness could be made. Secondly, microradiographs of a thin section of undecalcified bone on a fine grain x-ray film and subjected to soft x-rays can demonstrate remarkable variation of the mineral density in various regions of a bone or between bones. Comparing a two and one-half year old child, a 17-year old adolescent and a 77-year old woman, the degree of porosity in the cortex drops from about 40 percent in the child to about 3 to 4 percent in the middle teen-ages and then gradually builds back up until sometime late in life one has up to 30 or 40 percent porosity. Third, tetracycline can be used as a tracer because of its unique capability of

being deposited at the site of new bone formation. With the use of an ultraviolet microscope on a section of bone from an animal which has been administered tetracycline over a specified period of time, information can be gathered about the sites and rate of new bone formation. Finally, a new development in the use of x-ray densitometry involves using a collimated gamma ray source rather than the ordinary x-ray tube. Advantages for this technique are the relative portability of the unit and the monochromatic wave length of a gamma ray source. This will produce rays which will only be absorbed by specific components of the material exposed. For example, calcium or phosphorus may be exposed without interference from the soft tissue components. Of course, this is normally a problem only when dealing with live animals where soft tissue cannot be removed.

Concerning the same technique, Cameron and Sorenson (1963) discuss the use of iodine-125 at 27.3 Kev or Americium-241 at 59.6 Kev as the gamma ray source. These substances provide the desired monochromatic, low-energy photon beam. The photon source and detector are well dollimated to reduce errors from scattered radiation. Rather than using an x-ray film with its associated errors and inaccuracies to record the intensity of the transmitted beam, a scintillation detector is used to measure the transmitted radiation. While the bone sample is being moved through the photon beam at a constant rate, the scintillation readings can be recorded and plotted with automatic equipment very rapidly and with a minimum of error give the total mineral content of a section of bone. The results are accurate and reproducible to within about 3 percent.

Brown (1959) also described a machine which can measure the density of a specific section of bone in relation to a standard step wedge while automatically making corrections for the area of the bone section. This procedure still employs the use of an x-ray tube and radiographs, however.

Step wedges similar to the one mentioned in the previous article have been employed by many workers as a means of standardizing film exposure and development differences. Materials most commonly used are ivory or an aluminum alloy as well as a standard bone sample because of their similarities in density to bone. Authors reporting this standardizing technique include Engstrom (1949), Koch and Kaplan (1961), Mack (1939, 1949, 1959), Mainland (1963), McFarland (1954), Morgan (1962) and Williams (1962).

A number of researchers have conducted studies of several slightly different techniques of measuring bone density in live animals.

Baker et al. (1959) makes the statement that in radiographic densitometry the largest error is introduced by the soft tissue surrounding the bone in live animals.

Jackson (1951) arrived at the same conclusion and suggested a simple method of standardizing these effects is to radiograph the part (in this case, a hand) in a tray with added water to make a constant volume.

McFarland (1954) using a standardized aluminum alloy step wedge along with the subject being x-rayed constructed a calibration curve by

measuring the light transmitted through various points along the wedge image. This calibration curve can be expected to differ for each film, owing to the differences in exposure and developing. When the light transmitted through the bone image on the film is measured, the result is computed automatically in terms of the calibration curve previously determined. This feature makes the method reproducible with an error in the order of 5 percent. Corrections for soft tissue must be made for living humans. Extremities are most often used because soft tissue is more easily corrected for in those areas.

Wagenen and Asling (1958) conducted a study of bone age in the Rhesus monkey (Macaca mulatta). Since monkeys are increasingly being used in laboratory studies and since many of them are captured in the wild, it is often desirable and sometimes necessary to determine their ages. Weight and body length provide a means of approximation but this can be greatly influenced by nutritional stress. Sixty-eight female and 43 male monkeys born and raised under standardized lab conditions of optimal nutrition and health were studied. Ages ranged from birth to nine and one-half years in females and eight years in males. Serial studies were made on 54 of these mixed sex monkeys from birth to five years of age. Notations were made of the first appearance of spots of ossification in different parts of the body. Roentgenograms provided age estimates throughout the developmental period. In Rhesus monkeys, both females and males, the sequence of regional maturation or ossification (elbow, hip, ankle and foot, knee, wrist and shoulder) compares with data from other primates. This technique was tested on

monkeys of a known age from another lab and predicted ages were within three months of the known age. Epiphyseal fusion occurred six to ten months earlier in females than males. Ossification of the extremities was complete in females at five and one-quarter years and in males at six to six and one-half years of age. Therefore, sex distinctions should be made whenever possible in the examination of skeletal material.

Schraer et al. (1959) observed that bone density increased with increased age to adulthood and then decreased in old age in humans. They also made the observation that bone density may indicate the past nutritional history of the subject. Further, rat bone mineral content can be accurately determined from roentgenograms. Calcium changes of less than 4 percent are detectable.

Morgan et al. (1962) used the procedure of Mack et al. (1949) to study bone density of left ankles (os calcis) and left hand little fingers (phalanx 5-2) on 524 subjects mostly in Colorado, California and Utah and mostly over 50 years of age. Differences between areas and sexes, as well as ages, were noted. Also, those people in a county home on lower nutritional levels were noted to have lower bone density areas. Another study found the mean density in 16- to 20-year old males about the same as aging male subjects in this study. Thirteen to 15 year old females compared with aged females.

Mason and Ruthven (1965) developed an x-ray bone densitometer which makes direct tracings of absorption curves on a nearly linear scale. Speed and precision are increased by elimination of x-ray film. Results were reproducible to within 3 percent on a phantom finger and

within 6 percent on human subjects compared with 12 to 14 percent when film is used. Settings for exposures of the left phalanx 5-2 were 40 pKv and 5 ma which gives about 500 millirads per trace exposure. X-ray tube head and collimator on x-ray detector head are located much closer to the subject's finger to reduce scatter and exposure to the subject. Readings are automatically recorded on graph paper. Figures of density curves of two subjects both the same age showed that one, a female on a low calcium and fairly low protein intake, had less than one-half the bone density index of a male subject on a much higher level of nutrition.

Mack et al. (1959) stated that the pathological or nutritional condition of a human being or animal often is indicated by changes in the mineral content of certain parts of the skeleton. A brief history of technique development in bone densitometry was given. Using a range of settings on a 10 cm. thick bone sample from 5 through 320 ma.-sec. at a constant Kv peak of 50, it was found that the greatest approach to linearity in the uncorrected wedge trace is 40 ma.-sec. at 50 Kv peak.

An earlier background paper by Mack et al. (1949) stated the advantages of measuring density over a cross section of bone rather than in a single spot. There were too many chances for erroneous measurements at only a single spot. At that time they concluded that the measurement of bone density appeared to have considerable promise as a clinical tool for determining the calcium nutritional status of an individual and for detecting changes in calcium nutritional status caused by pregnancy, illness, change in diet or other causes. They also reported that organic material in bone, including ossein and fat, makes up about 35 percent

of the total bone weight, yet true x-ray absorption from this material has been estimated to be only about 2 percent of the actual absorption occasioned by the bone ash.

Frost (1962) discussed the usefulness of tetracycline administration in bone labeling on the Haversian canal surface of osteoid seams. Tetracycline will fluoresce which makes it suitable for observation under a fluoroscope in a live animal. Tetracycline will also remain in the bones for long periods of time relatively undisturbed until remodeling of bone occurs. This characteristic contributes to its usefulness in the study of bone building and remodeling rates.

Goldhaber (1964) in a study of collagen and bone postulated that collagenous tissue throughout the body does not calcify due to the presence of calcification inhibitors. In mineralizing tissues, it is thought that pyrophosphate (the probable inhibitor) is destroyed locally by the enzyme pyrophosphatase.

Pryor (1939) reported that variations in carpal sequence or chronological order of ossification is controlled by genetic factors in humans. A discussion is given on classifying members of multiple births as identical or fraternal on the basis of sequence of ossification of the small bones in the hands and wrist.

In contrast to this, Sontag and Reynolds (1944) studied the roentgenograms of known identical triplets for signs of ossification development in different bones of the body over the period from 2 to 14 years of age. They emphasized that any <u>one</u> radiograph of different centers of ossification in the body may be misleading because

ossification occurred at varying rates at different points among the three individuals and the onset of ossification at these points may not, and probably will not, all take the same sequence.

Mainland (1963) reported that bone in infants does not appear to become more dense in a linear manner. It appears that as bone growth occurs, there is a constant tearing down as new bone tissue is laid down. After soft tissue and increase in bone size have been removed as variables, there may even be a negative trend in bone density.

Bohatirchuk (1963) made the observation that human bones after 60 years of age become calcium impoverished (atrophic). Organic and inorganic matrices, however, do not disappear until the eighth or ninth decade.

Williams and Mason (1962) in a review of the principles involved in x-ray densitometry stated that when x-rays are absorbed by a uniform material, the intensity of radiation is reduced by a constant fraction per unit length of the path through the material (linear absorption coefficient or μ). An equivalent definition for μ is obtained when a beam of x-rays of unit area in cross section traverses unit volume of the substance. The fraction of energy absorbed when a beam of unit cross section traverses a unit mass of material is called the mass absorption coefficient (μ/p, where p is the density of the material). This coefficient is identical for substances of the same atomic number. In this particular study a reference wedge of homogeneous alloy 92.8 percent aluminum and 7.2 percent zinc was used since its

effective atomic number approximates that of hydroxy apatite (16.65), and its mass absorption coefficient is closely equivalent to bone mineral. After trying various exposure times, the most suitable was chosen along the linear portion of the film response curve. The standard conditions used were 50 pKv, 10 ma, one second and 36 inches focal distance. Since x-rays and light are absorbed exponentially, the slope of the wedge trace differs from the slope of the wedge. Measured with a planimeter, the areas under the "finger trace" represent integrated mass absorption due to, in this case, the mass of bone plus over- and underlying flesh and due to flesh lateral to the bone.

Hattner and Frost (1963) found that in humans differences in the rates of mineralization as well as the location of such mineral deposition areas or foci cause wide variations in "mean skeletal age" between persons of the same or differing ages as well as variations within the bones of the same person at different locations. They also observed that at age two, bone formation occurs at about 75 times more active rate than at age 35.

In a report on qualitative variables in human bone, Frost (1961) stated that a given unit volume of bone matrix may contain very little mineral, as in osteoid seams, or a great deal of mineral, as in micro-petrosis, these being extremes. A given moiety of bone undergoes a definite and orderly progression of mineral accretion during its biological lifetime. A number of diseases may affect this orderly progression, leading to qualitative abnormalities. When the matrix is first formed and is completely unmineralized, the water content is

maximal. When maximum mineralization has been achieved, the water content is minimal. Increasing mineralization occurs with increasing age of any given bone moiety. The average age of the skeleton is dependent on the rate of remodeling.

Bassett (1962) in a paper on the current concepts of bone formation reported that Fell, in culture studies of endosteum, found that bone frequently passed through a phase when it possessed certain morphological features commonly associated with cartilage. If oxygenation of the culture was adequate, however, this was a transient phase and 90 percent of the specimens ossified. If it was not, osteogenesis was blocked and hyaline or fibrocartilage resulted. Ham in 1930 concluded from his study of fracture healing in vivo that the osteogenic cell had a dual potentiality, being able to form bone or cartilage in response to the degree of vascularization in the area in which it differentiated. The paper by Bassett is much more comprehensive than the above two observations, but these two seem to apply somewhat to this thesis problem.

Thompsen and Mortensen (1946) reported that ossification in cottontail rabbits is expressed by the gradual disappearance of the epiphyseal cartilage and its replacement by bone material. X-ray settings of 50 ma, 36 pKv, 0.15 sec. at a distance of 30 inches were used. These workers had sampled the wild population of rabbits in developing the technique but had not had much chance to sample known age rabbits. The most useful epiphyseal plate may be above the tibia because of less trouble with overlapping bone shadow, but in rabbits

they did not feel this would lend itself to sample collections from hunters because of the greater value of the meat in that area. The next best location seemed to be above the humerus in the shoulder which in addition gives a longer period of transition than the one above the ulna. Photos were presented which very graphically demonstrated the changes.

EXPERIMENTAL MATERIALS AND PROCEDURES

One hundred twenty-three female bovine animals were selected from the slaughter lots of a large midwestern packing company during a seven work day period to provide experimental material for this study. The animals were randomly selected from female lots at the rate of one per every ten or portion of ten head in a lot. The sample approximates the female slaughter population of the plant in kind of animals and in relative distribution of different kinds. By restricting the sample to females, sex differences were eliminated and a wider distribution of slaughter and carcass characteristics was obtained than would have been possible in a male slaughter population. Live animal, carcass and tissue characteristics of each animal were evaluated.

Live Animal

Selection and Identification. Random selection of animals was accomplished by utilizing a standard location in each pen as a reference position. Selected animals were those in close proximity to the pen gate. Duplicate paper back tags were affixed with an adhesive to the top of the shoulder or midback area of the heifers and cows as they were selected. Duplicate tagging reduced loss of identification and was accomplished without difficulty within the holding pen.

As each animal was selected and tagged, evaluations of the animal's type, breed or breeds, color pattern, conformation, slaughter grade, muzzle width, horn diameter, tail length and over-all estimated age were made.

The author and one beef cattle buyer at the packing plant selected and tagged all animals. Evaluation of live traits were made by the buyer with some consultation with the author.

Type. Type was rated on a scale from one to five with one being strictly beef type and five being strictly dairy breeding. This was determined by color patterns and conformation. All variations of type on this scale were represented by at least three animals.

Breeds or Combinations. Breeds and percentages of each as indicated mainly by color patterns and sometimes by conformation were recorded.

Color Patterns. The various color patterns were also recorded.

Live Conformation. Conformation or shape was evaluated as it may relate to carcass conformation. The scale used was the terminology applied to U.S.D.A. slaughter and carcass grades to one-third of a grade.

Slaughter Grade. Condition or fatness as well as conformation and estimated maturity were used to estimate carcass grade in the live animal.

Lip or Muzzle Width. One of the characteristics used by beef cattle buyers to estimate animal age is lip or muzzle width. The younger the animal, the narrower the muzzle width will be. This is a very subjective measure, but differences are quite easily noted. Five

categories were established with one being a very narrow muzzle and five an extremely broad muzzle.

Horn Size. Those animals which had horns were evaluated for horn diameter at the base. The thinking behind this estimation is that as an animal ages the horn size also increases.

Tail Length. One other characteristic used by buyers as an estimator of live animal age is tail length. As the animal grows older, it is thought the tail becomes proportionately longer. Five categories were established here as in muzzle width.

Estimated Age. A composite of the above along with an over-all subjective appraisal of age was made. The categories used were 10 to 18 months, 18 to 24 months, 24 to 30 months, 30 to 36 months, 36 to 48 months, 48 to 60 months and finally, aged cows.

As the animals were slaughtered, carcasses were tagged for future identification. Each animal was also checked for pregnancy and stage of pregnancy as they were being eviscerated. Time of slaughter as well as lot number were recorded. Time of slaughter was recorded so length of time before grading would be known.

Carcasses

Carcasses were quality and cutability graded by a U.S.D.A. Federal grader. All carcasses were graded between 20 and 28 hours post-mortem according to present standard packing company procedure. Each of the individual factors contributing to these grades plus a few additional traits were recorded.

Carcass Conformation. The relative shape of the carcass rated on a scale from 1, low Canner, to 24, high Prime, was evaluated.

Carcass Maturity. The degree of ossification of cartilage along the dorsal processes of the vertebrae was used to evaluate carcass maturity. The carcasses were rated from 1, E +, to 15, A -, on the U.S.D.A. notation. One or E + is the most mature while 15 or A - is the most youthful. E + is completely ossified or hard-boned while A - has a very soft, pearly white cartilage button on all dorsal processes of the vertebrae.

Marbling. Intramuscular fat level was established from observing the cut surface of the ribeye (longissimus dorsi) between the 12th and 13th rib. Each degree of marbling above devoid was divided into thirds and rated from devoid, 1; practically devoid minus, 2; practically devoid, 3; practically devoid plus, 4; traces minus, 5; and so forth up to abundant plus, 28.

U.S.D.A. Carcass Grade. Carcass grade was derived from the above three factors and rated from 1, low Canner, to 24, high Prime.

Warm Carcass Weight. This was recorded from the packer's weight tag on each carcass.

Chilled Carcass Weight. Chilled carcass weight was computed from warm carcass weight by applying the standard 2$\frac{1}{2}$ percent cooler shrink.

Ribeye Area. In compliance with standard procedure of the Federal Grading Service, the ribeye was measured with a grid at the 12th rib. Each of the 0.1 square inch squares more than half covered by the ribeye was counted.

Fat Thickness at the 12th Rib. A single fat thickness measurement was taken perpendicular to the fat surface three-fourths of the distance from the medial to the lateral end of the exposed longissimus dorsi at the 12th rib. The measurement was made in tenths of inches.

Lower Rib Fat Thickness. A fat thickness measurement was also made at the point of heaviest deposition past the lateral end of the ribeye at the 12th rib.

Estimated Percent Internal Fats. The Federal grader estimated the percent of kidney, pelvic and heart fat of carcass weight.

U.S.D.A. Yield Grade. A composite of warm carcass weight, ribeye area, single fat thickness measurement over the ribeye and estimated percent internal fats was used in a formula for Yield Grade derivation as follows:

\+ (2.50 x adjusted fat thickness, inches)

\+ (.20 x percent kidney, pelvic and heart fat)

\+ (.0038 x hot carcass weight, pounds)

\- (.32 x ribeye area, square inches)

The fat thickness measurement may occasionally be adjusted upward or downward for unusual fat deposition externally in other areas of the carcass.

In normal practice the numbers behind the decimal point in the final Yield Grade are dropped rather than rounded off. This gives a single grade number from 1 to 5 with 1 being the most desirable or highest cutability. The larger the Yield Grade number, the lower will be the yield of boneless, closely trimmed retail cuts from the round, loin, rib and chuck. The Yield Grade was computed to the 0.1 grade.

Hours After Slaughter. Finally, the number of hours post-mortem, when grading was performed, was recorded.

Tissue Sampling

The left wholesale rib of each carcass was brought to the Meat Laboratory in Brookings for further evaluation. The rib was chosen because of the presence of the longissimus dorsi muscle where palatability characteristics are very important economically. It is also the largest single muscle in the carcass. Furthermore, bone and cartilage samples were easily obtained. Choice of the rib also makes the data contained herein applicable or comparable to a large number of other studies.

At the Meat Laboratory, the ribs were immediately hung in a 38° F. cooler. Seven days post-mortem the ribs were cut and muscle and bone samples were removed.

First, the 12th rib steak was cut from the wholesale rib at a point between the 11th and 12th rib. The bone was removed from the steak. The outside fat was trimmed away and the dried out, exposed surface was trimmed off so the steak was one inch thick. It

was then wrapped, marked and frozen for later testing on the Warner-Bratzler shear machine.

The second step was to remove the 10th and 11th rib section from which two more one-inch ribeye steaks were cut. The 11th rib steak was to be used for taste panel evaluation. The 10th rib steak was for use in chemical analyses and histological studies. Color determinations were made approximately 30 minutes after cutting on the 10th rib steak using a Photovolt Reflectance Meter Model No. 610 according to the procedure outlined by Tuma et al. (1962). The characteristics of hue, value and chroma were determined.

Once the steaks had been prepared, wrapped, marked and frozen, bone samples were collected from the 11th and 12th ribs. The portion of the bones removed for further sampling was cut 4½ inches from the ventral or distal end of the ribs. The buttons (both cartilage and ossified cartilage) were removed from the vertical processes of the thoracic vertebrae. The 11th rib sample was marked and frozen with the buttons for possible future study. The 12th rib was sectioned on a Lipshaw Model 25 bone saw (Figure 1). First, two cross-sectional samples were taken approximately 2 1/4 to 2 3/4 inches from the ventral end of the rib bone. This ventral end was butted up tight against the plate on the right end of the movable platform. The saw blade was set as far in or to the left as possible. The first cut was made moving the platform forward. The platform was returned to its original position. The motor and saw blade mounting were then moved to the right four precise and complete turns of the knob on the right end of the machine.

The second cut was made producing an 0.18 inch thick cross-sectional sample of the rib 2 1/4 to 2 1/2 inches from the ventral end of the 12th rib bone in a wholesale rib. A second 0.18 inch thick cross-section was taken immediately adjacent and dorsal to the first section. More difficulty was encountered in holding this sample with the clamps on the saw so the thickness would be controlled exactly.

Following the removal of the two cross-sections, the remaining 2 1/4 inch long ventral portion of this rib was sectioned longitudinally through the center of the rib for a hardness test sample. This section was exactly three turns of the end knob or 0.135 inch thick. Thickness control was not quite as important here as it was for the cross sections which were to be x-rayed.

Each of these samples was marked as it was cut to prevent identification loss.

Bone Density

The x-ray machine used in evaluating bone density was a Fischer Model "AM" (Figures 2, 3 and 4). Maximum power levels possible with the unit used were 30 milliamperes (ma) and 90 peak Kilovolts (pKv). The line voltage at the unit was 113.5 volts when all other electrical equipment in the building was turned off with the exception of the lights. Exposures were made only when the x-ray unit was the only electrical unit operating in the building. Of the available internal voltage settings in the control unit, the 115 volt setting was closest to the line voltage of 113.5.

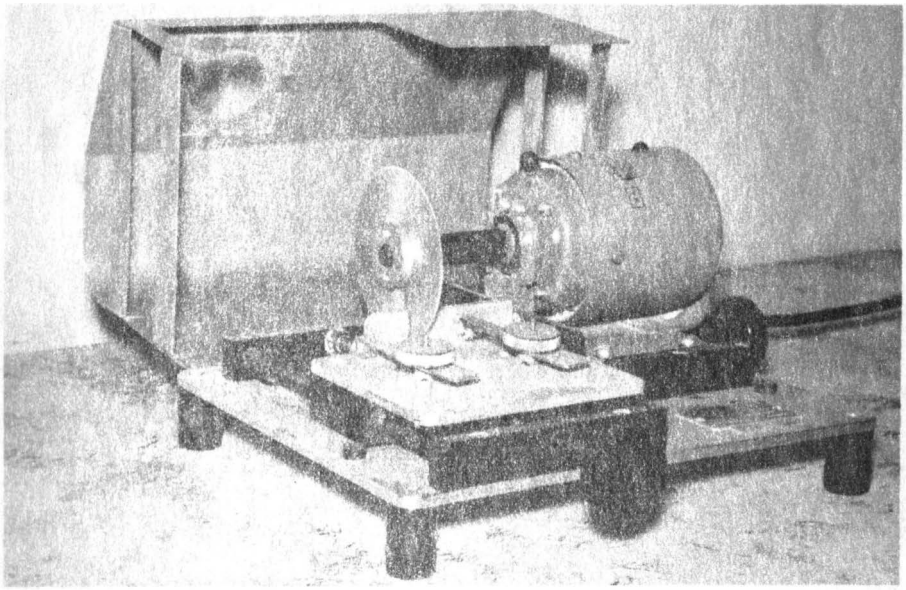

Figure 1. Lipshaw Model 25 bone saw.

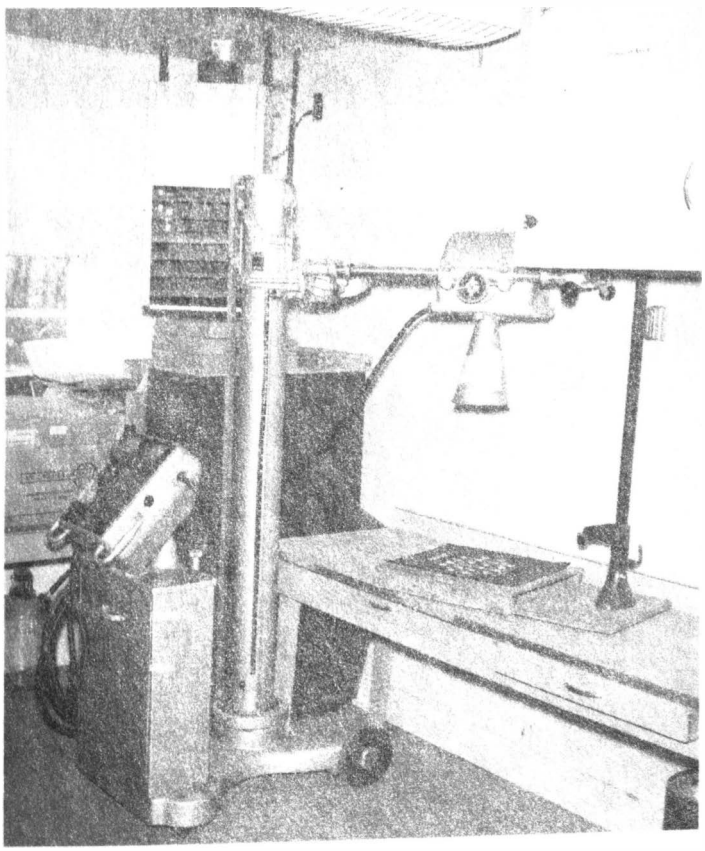

Figure 2. Fischer Model "AM" x-ray unit set up to expose a radiograph.

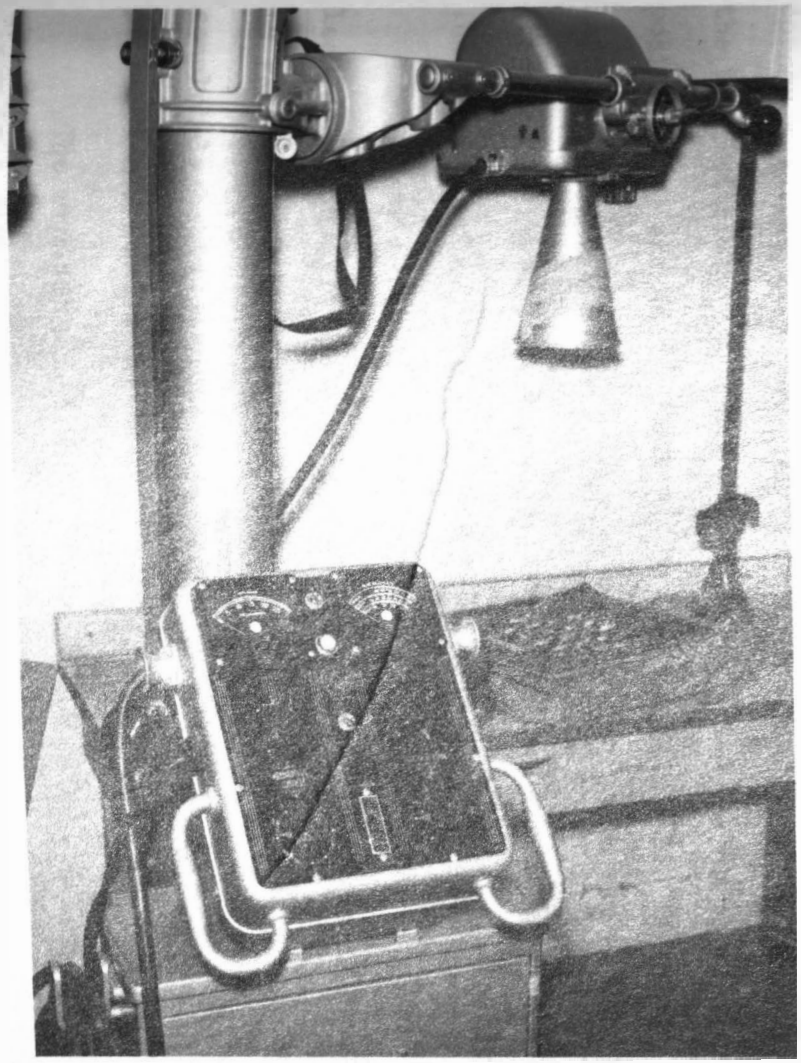

Figure 3. Control panel of Fischer Model "ANM" x-ray unit set up to make an exposure.

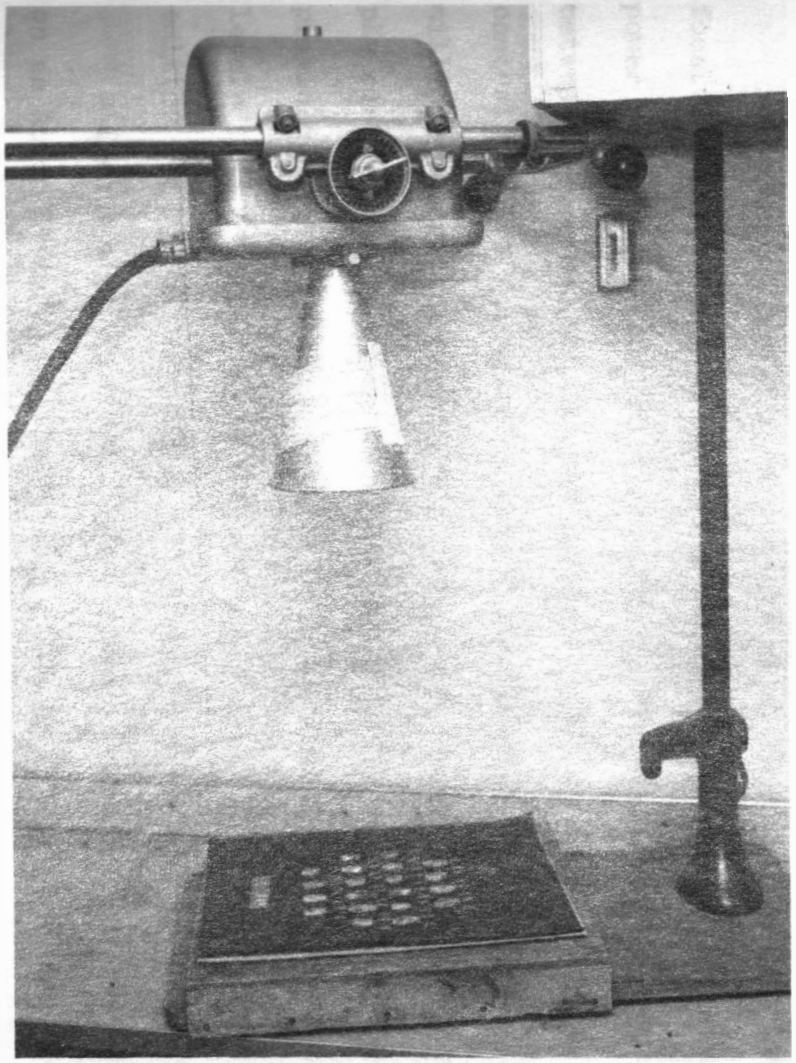

Figure 4. X-ray emission head of the Fischer Model "ANM" unit.

The unit was set to produce 15 ma at 50 pKv for 0.5 second at a focal distance of 30 inches. Preliminary tests indicated that the above power adjustments and timing resulted in the desired degree of contrast between background and exposed samples. The actual settings on the control panel of the machine were 2 and 8.1 on the main and auxiliary milliamp controls, respectively, and 5 and 1 on the main and auxiliary pKv controls, respectively. A warm-up period of 30 minutes was provided before exposures were made. The x-ray emitting head was leveled and set in place so the film could be centered under the emitted beam. A 15 inch cone was used to reduce scattered radiation.

Twenty of the primary cross-sectional bone samples were arrayed on an Ansco 14 x 17 nonscreen film. The samples were arranged as in the accompanying radiograph with the exception of omission of the four corner samples (Figure 5). Preliminary tests had demonstrated less than the desired amount of x-ray exposure at those corner positions. Each position was assigned a number from 1 to 20 starting from the upper left corner of the film on the end closest to the x-ray control unit (Figure 8). Positions 4 and 14 had the same bone samples on every film. These two samples were used as a standard for comparison between films.

Safety precautions were observed. The operator always wore a lead apron and gloves and stood as far from the unit as possible (about 10 feet) when exposures were made. It was possible to stand almost completely behind an intervening refrigerator and wall to aid in protection from the radiation hazard.

The exposed films were developed using Kodak Developer and Kodak Fixer in a dark room. The temperature of the developing, fixing and

washing solutions was kept exactly at 68° F. while processing. Films were left in the developer for 5 minutes. They were washed in tap water for 45 seconds and then left in the fixer for 9 minutes. Finally, the films were rinsed in running tap water for approximately 45 minutes.

Immediately following removal from the water the films on their hangers were hung in a heated dryer to dry for approximately 45 minutes. The radiograph was now ready to be cut into strips between sample images, so the strips could be run through the densitometer.

The densitometer used was a Photovolt Model No. 425 in combination with a Photovolt galvanometer to get more sensitive readings of the amount of light transmitted through the exposed samples on each radiograph (Figure 7). Each time the densitometer was used, it was standardized against a small sample of exposed film whose percent transmittance was set at 15 on the galvanometer. The strips of film were moved through the light at one millimeter intervals. The galvanometer was read to the tenth of a percent transmittance.

Each sample reading was recorded on two-cycle semilogarithmic paper with the horizontal axis divided into 10 units per inch. In plotting, each tenth of one inch represented one millimeter of actual rib bone width. In this cross-sectional sample, width of rib was the longest dimension. For each of the samples, a densitometric curve was plotted. The curve was enclosed by the base line, and the enclosed area was measured with a compensating polar planimeter. Each curve was traced twice to minimize tracing and reading error.

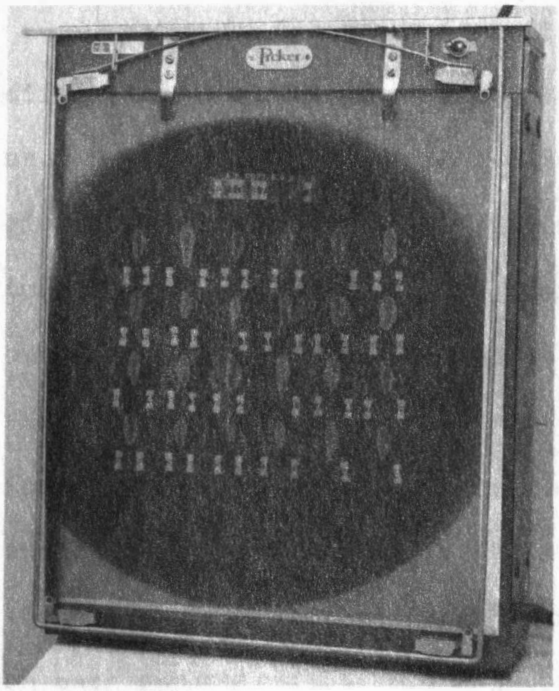

Figure 5. Exposed and developed radiograph of cross-sectional rib bone samples.

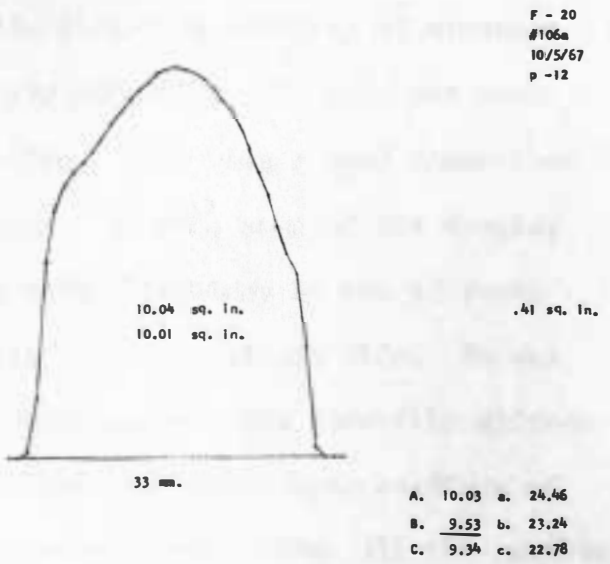

Figure 6. Trace pattern of a bone densitometry sample with each of the important steps in calculation listed.

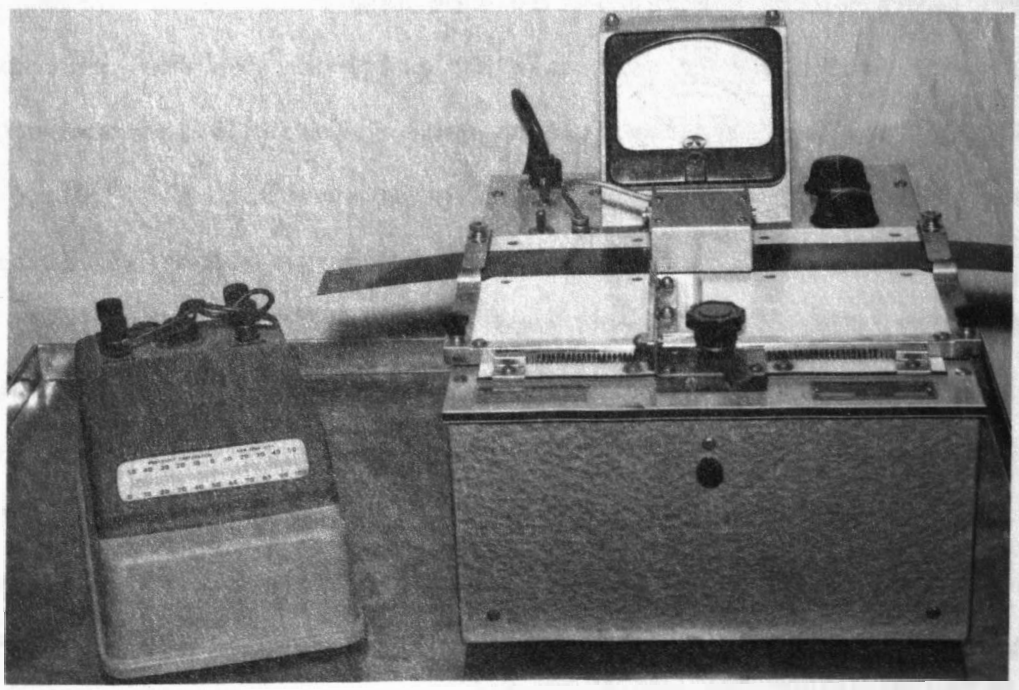

Figure 7. Photovolt Model No. 425 densitometer and a Photovolt galvanometer set up to measure bone density from the light transmitted through the radiograph.

Early in the study indications of some intra- and interfilm differences were observed due possibly to the variability of exposure made by the x-ray unit. An attempt was made to see if this was real. Five films were made of the same samples. This gave a good comparison to check interfilm exposure differences. Second, some of the samples on each of these films were moved to other locations to see if there were exposure differences between locations on a single film. It was found in both cases that there were differences. The interfilm differences were corrected in two steps. First, the total area readings of the two standards on all the films were averaged. Then, all the samples on each separate film were adjusted to the degree the standards on that film differed from the resulting average.

Next, it was found that some of the samples on the periphery of the exposure were not receiving quite as much of the primary beam x-rays as those nearer the center. Those sample readings from positions 1, 2, 3, 4, 5, 10, 11 and 16 were adjusted upward by 2 percent while those samples in the remaining positions were reduced by 2 percent.

Up to this point there have been three bone density values for each sample. The first was the raw data or area of the original densitometric trace (A). The second value represented the adjusted raw data for individual film exposure and developing differences (B). Third, the second value was adjusted for the individual sample's position on the film (C) (Figure 6). Finally, each of the three preceding measurements was adjusted for actual cross-sectional area of the rib bone.

The cross-sectional area of the rib sample was measured on the radiograph over a lighted photographic slide sorter. A planimeter was

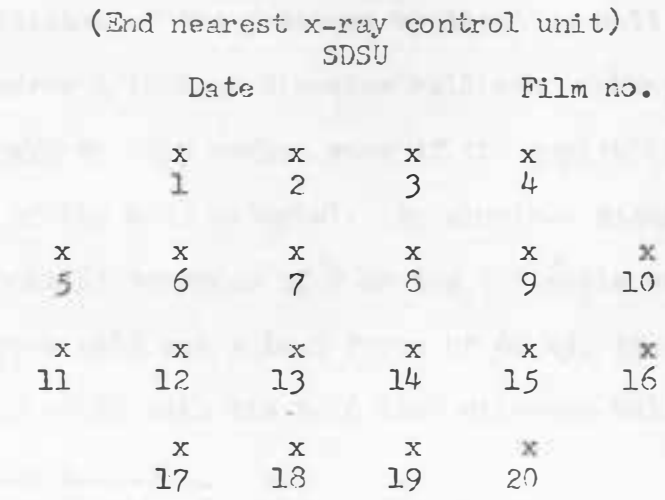

Figure 8. Position numbering system on radiographs.

used to measure the area. This tracing was duplicated until readings were within 0.02 square inch. Then, each of the three foregoing bone densitometric areas was divided by the rib cross-sectional area to give three corresponding areas each corrected for the rib cross-sectional area (a, b, c). The units involved here could be designated square inches of bone density trace per square inch of cross-sectional rib area.

Bone Hardness

The longitudinal section of rib bone was subjected to hardness tests on a Pyro-Electro Hardness tester manufactured by the B. C. Ames Company at Waltham, Massachusetts (Figure 9). Originally, the tester was designed to measure the hardness of metals. Preliminary studies with bone samples indicated that there was considerably more within sample variation in bone hardness than there was in metal sample hardness. However, by using the average of several readings per sample, ranking of samples was quite repeatable.

A modification of the pressure application unit of the tester was made. The standard 1/16 inch diameter ball was exchanged for a 3/16 inch diameter ball to help reduce some of the variability resulting from the elasticity of the bone material. An aluminum standard which registered a Rockwell hardness of 9 on the "B" scale of the unit with a 1/16 inch diameter ball and a load force of 60 kg. gave a corresponding hardness reading of 60 with the 3/16 inch diameter ball and a load force of 150 kg. on the ball.

Each sample was tested by a standardized method. The longitudinal bone section was laid on the testing anvil. First, the ventral end of the inside of the rib was tested. The ventral end could be determined by the acute angle of cut across the end while the dorsal end was cut more nearly at a right angle. The inside of the rib could be determined from the curvature of the sample in the 2 1/4 inch long sample (Figure 10). The hardness of the cortex or outer edges of the bone was determined. The platform was turned up according to standard operating procedure so that the dial needle rotated three times placing a minor load of 10 kg. on the sample. The outside dial was adjusted to start exactly at zero. Then, the 150 kg. load force was released slowly and allowed to stabilize for about 10 seconds. The load force was removed. The dial needle moved back to the hardness reading which actually is a reflection of the distance the ball penetrated the bone. This reading was recorded. The platform was lowered and the sample was set for another reading on the inside, middle of the sample. Third, an inside, dorsal determination was made. This procedure was repeated for the

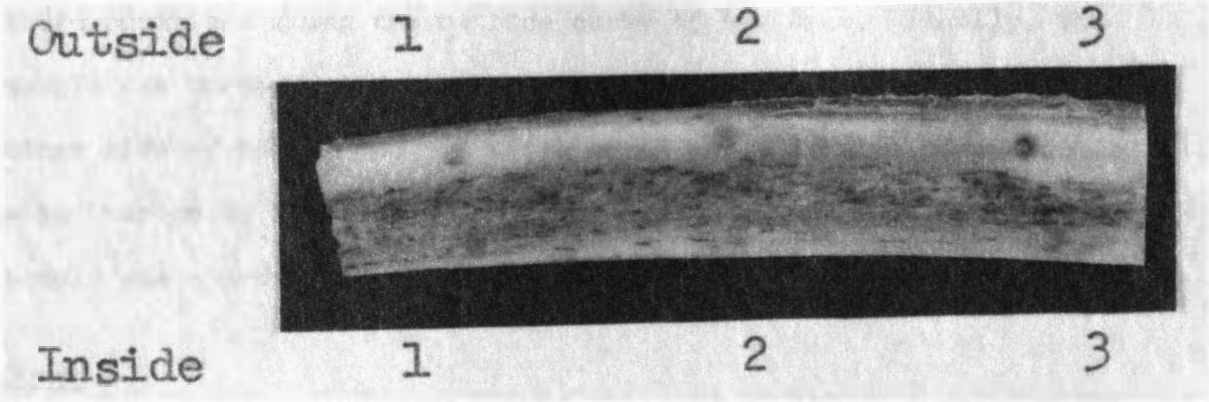

Figure 9. Longitudinal section of rib bone used for hardness testing at the designated locations.

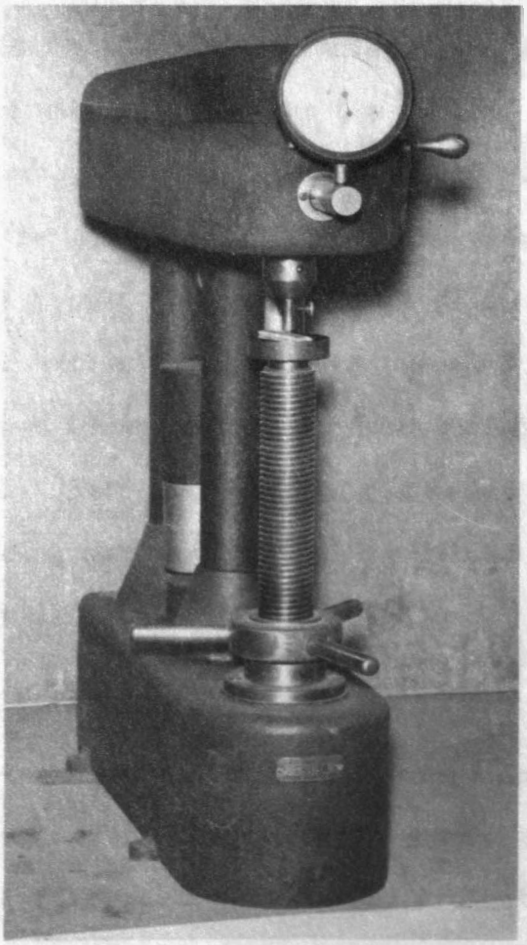

Figure 10. Pyro-Electro metal hardness tester set up for testing bone hardness.

three positions along the outside curve of the bone. Finally, the sample was turned over and the entire procedure was replicated on the other side of the sample. A total of 12 readings were taken each of which was coded for location. The total time required to test one bone sample was approximately 7 to 8 minutes.

Shear

The 12th rib steaks were removed from the freezer within three weeks after they had been stored. Twelve or 18 samples at a time were allowed to thaw overnight in a 38° F. cooler. The following morning six samples at a time were removed from the cooler, unwrapped, blotted dry, weighed on a gram scale and placed in a 325° F. oven with a thermometer inserted in each steak. The method of cookery used was oven broiling to an internal temperature of 155° F. The steaks were removed from the oven and weighed when they reached that temperature. One-inch diameter cores were removed from the medial, center and lateral portions of the steak. Each core was sheared twice in the standard Warner-Bratzler shearing device. Core shear values were recorded according to location and replication.

Palatability

Taste panel steaks were in freezer storage for no longer than three months. Thawing and cooking procedures were the same as those described for shear steaks. Six steaks were evaluated per panel sitting. The steaks were cut into seven approximately half-inch wide slices for

RESULTS AND DISCUSSION

Table 1 lists the distribution of individuals in the sample population as they were evaluated for live conformation, slaughter grade, carcass conformation and U.S.D.A. carcass grade.

Means and Standard Deviations

Means and standard deviations within subclasses of some of the discrete variables were determined to get a comprehensive view of the population studied.

In the analysis of variance for between location sampling differences within individual samples, highly significant location differences were found for both bone hardness and Warner-Bratzler shear measurements. Tables 2 and 3 present the means for the various locations under these two methods of testing bone and muscle samples, respectively. The location differences emphasize the need for standardized sampling techniques. Other tables of means and standard deviations can be found in the appendix.

Simple Correlations

Simple correlation coefficients were determined between all characteristics measured in the total sample population as well as the two halves when they were separated on the basis of carcass maturity. Of the 123 cattle sampled, 62 were in the more youthful U.S.D.A. A and B maturity groups while the remaining 61 were in the more mature C, D and E maturity groups.

TABLE 1. DISTRIBUTION OF SAMPLE POPULATION ACCORDING TO LIVE CONFORMATION, SLAUGHTER GRADE, CARCASS CONFORMATION AND U.S.D.A. CARCASS GRADE

Grade designation		Live conformation	Slaughter grade	Carcass conformation	Carcass grade
1	-				
2	Canner				
3	+				
4	-				
5	Cutter	6		1	3
6	+				
7	-		3	3	19
8	Utility	14	10	7	16
9	+	2		8	4
10	-	8	18	17	10
11	Commercial	20	19	18	6
12	+	6	6	3	3
13	-				
14	Standard	2	1		1
15	+			2	2
16	-	2	3	1	1
17	Good	3	2	2	11
18	+	19	14	5	13
19	-	20	21	21	17
20	Choice	11	17	23	12
21	+	7	7	7	4
22	-	1	1	2	
23	Prime	2	1	3	
24	+				
Total		123	123	123	123

TABLE 2. MEANS BETWEEN LOCATIONS WITHIN SAMPLES FOR BONE HARDNESS DETERMINATIONS ON THE PYRO-ELECTRO HARDNESS TESTER

Location	Mean
Inside of rib	
1. Ventral	42.15
2. Center	45.97
3. Dorsal	47.90
Outside of rib	
1. Ventral	44.49
2. Center	46.81
3. Dorsal	47.14

TABLE 3. MEANS BETWEEN LOCATIONS WITHIN SAMPLES FOR TENDERNESS DETERMINATION BY WARNER-BRATZLER SHEAR TESTS

Location	Mean
Medial	15.21
Center	15.80
Lateral	16.74

It can be noted from the simple correlation tables (tables 4, 5 and 6) that there was a very high relationship between live conformation and slaughter grade (r = 0.99, 0.96, 0.97). It appeared that once an animal had been classified either as youthful or mature that the slaughter grade estimate was largely determined by the shape or form of the animal.

It would be well to point out here that there was a relatively high correlation between live conformation and many of the estimates of maturity. This situation arose because of the confounding of maturity with grade in the U.S.D.A. grade nomenclature. When the population was split on the basis of carcass maturity and simple correlations were determined for the separate groups, the correlation coefficients between conformation and maturity dropped considerably, as did the correlation between slaughter grade and panel palatability characteristics. It might be assumed from this observation that there is a sizable gap in a number of measurable characteristics between the two groups in the slaughter population. Much of the correlation in the entire sample population is due to this interval between the youthful and mature groups. This is borne out when one observes some of the mean tables in the appendix. Dividing the population on the basis previously mentioned was considered justifiable, since carcasses are presently marketed in the wholesale trade in a similar way.

Estimated age in the live animal proved to be very highly correlated with carcass conformation (r = 0.91) and carcass maturity (r = -.90) and quite highly correlated with average bone hardness (r = 0.79), average bone density corrected for inter- and intrafilm

TABLE 4. SIMPLE CORRELATION COEFFICIENTS FOR THE ENTIRE SAMPLE (n = 123)

Trait no.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	0.99	-.73	-.65	-.91		0.92	0.84	0.29	0.86		0.58		0.46	0.74	0.38		0.67	0.21	-.56	-.72	-.51	-.51	-.62	-.18	-.70	-.66	0.38
2		-.73	-.65	-.92		0.92	0.85	0.29	0.86		0.59		0.45	0.72	0.37		0.68	0.19	-.58	-.73	-.51	-.51	-.63	-.16	-.72	-.67	-.37
3			0.69	0.85	0.37	-.76	-.79	-.18	-.73		-.46			-.60			-.52		0.50	0.69	0.52	0.54	0.61	0.12	0.56	0.53	0.24
4				0.70		-.64	-.65		-.64		-.37			-.48			-.47		0.48	0.56	0.43	0.36	0.47	0.02	0.52	0.49	0.23
5						-.91	-.90	-.21	-.87	-.32	-.59		-.35	-.69			-.66		0.54	0.79	0.58	0.57	0.69	0.15	0.67	0.63	0.27
6							-.47	0.39	-.27			0.70	0.32						0.21	0.49	0.67	0.49	0.62	-.15	0.21	0.01	-.15
7							0.89	0.24	0.92		0.61	-.08	0.36	0.71	0.28		0.66	0.23	-.55	-.77	-.56	-.56	-.66	-.14	-.68	-.62	-.31
8								0.11	0.91		0.59			0.60	0.14		0.65	0.20	-.58	-.82	-.63	-.65	-.74	-.17	-.70	-.60	-.25
9									0.40	0.66	0.34	0.25	0.52	0.50	0.52		0.30		-.22	-.04	0.18	0.09	0.15	-.04	-.43	-.46	-.40
10										0.42	0.63	-.07	0.35	0.70	0.29		0.67	0.24	-.59	-.76	-.48	-.52	-.61	-.19	-.74	-.70	-.36
11											0.34		0.42	0.51	0.48		0.33										
12														0.55			0.70	0.31	-.40	-.46	-.36	-.38	-.39	-.04	-.56	-.50	-.31
13															0.13						0.45		0.39		0.00	-.11	-.26
14														0.56	0.95	0.83									-.28	-.29	-.33
15															0.58	0.51	0.61		-.46	-.46	-.25	-.33	-.34	-.16	-.57	-.53	-.33
16																									.21	-.25	-.24
17																									-.23	-.29	-.34
18																		0.27	-.47	-.59	-.37	-.37	-.44	-.09	-.60	-.62	-.31
19																									-.22	-.21	-.19
20																				0.41	0.34	0.40	0.43	0.14	0.79	0.66	0.31
21																					0.65	0.54	0.78	0.13	0.53	0.47	0.09
22																						0.78	0.88	-.36	0.33	0.20	0.00
23																							0.84	0.04	0.39	0.27	0.12
24																								0.08	0.43	0.27	0.04
25																									0.16	0.12	0.11
26																										0.81	0.45
27																											0.51

1. Live conformation
2. Slaughter grade
3. Lip or muzzle width
4. Tail length
5. Estimated age
6. Chilled carcass weight
7. Carcass conformation
8. Carcass maturity
9. Marbling score
10. USDA carcass grade
11. Firmness
12. Subjective color score
13. Ribeye area
14. 12th rib fat thickness
15. Estimated percent internal fats
16. USDA yield grade
17. Lower rib fat thickness
18. Value-objective color
19. Chroma-objective color
20. Average-Warner-Bratzler shear
21. Average bone hardness
22. Cross-sectional area of rib
23. Width of rib
24. Bone density adjusted for inter- and intra-film differences
25. Above bone density corrected for X-S area of rib
26. Panel tenderness
27. Panel flavor
28. Panel juiciness

$r > .18$; significance at $P < .05$ (d.f. = 121).
$r > .23$; significance at $P < .01$ (d.f. = 121).

TABLE 5. SIMPLE CORRELATION COEFFICIENTS WITHIN YOUTHFUL A AND B CARCASS MATURITY GROUP (n = 62)

Trait no.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	0.96	-.49	-.42	-.79		0.81	0.48	0.31	0.56		0.30		0.53	0.57	0.43	0.52	0.41	0.13	-.26	-.35	-.18	-.17	-.21	0.06	-.49	-.42	-.41
2		0.50	-.44	-.83		0.83	0.50	0.29	0.55		0.31		0.51	0.53	0.42	0.45	0.44	0.08	-.30	-.41	-.20	-.18	-.22	0.07	-.53	-.47	-.39
3			0.49	0.72	0.02	-.54	-.61	-.23	-.50		-.10		-.30	-.41	-.25		-.20		0.30	0.38	0.22	0.32	0.26	-.07	0.29	0.29	0.23
4				0.46		-.36	-.36		-.37		-.02		-.35	-.26	-.28	-.33	-.16		0.36	0.23	0.10	0.06	0.07	-.18	0.27	0.27	0.17
5						-.78	-.66	-.23	-.55		0.22	0.00	-.38	-.53	-.31	-.29	-.36	0.00	0.22	0.50	0.32	0.38	0.34	-.12	0.36	0.33	0.23
6							-.30	0.49	0.33	0.33		0.74	0.46	0.32	0.44	0.58	0.13	0.13	-.01	0.36	0.64	0.39	0.57	-.39	-.06	-.41	-.33
7							0.60	0.17	0.51		0.37	-.01	0.36	0.49	0.29	0.33	0.38	0.12	-.25	-.34	-.28	-.32	-.29	0.14	-.41	-.30	-.26
8								0.00	0.42		0.15		0.08	0.28			0.30	0.13	-.24	-.52	-.46	-.52	-.47	0.19	-.37	-.13	-.10
9									0.85	0.68	0.32	0.23	0.59	0.56	0.60	0.56	0.36		0.16	0.11	0.40	0.20	0.37	-.19	-.44	-.50	-.42
10										0.60	0.36	0.16	0.61	0.68	0.60	0.55	0.50	0.10	-.27	-.14	0.11	-.06	0.10	-.02	-.56	-.52	-.47
11											0.23		0.45	0.50	0.50	0.46									-.25	-.32	-.26
12														0.44			0.60	0.25							-.33	-.28	-.35
13																			-.22	0.37	0.48	0.17	0.40	-.37	-.12	-.33	-.33
14														0.58	0.96	0.87	0.33								-.25	-.32	-.36
15															0.60	0.56	0.46								-.38	-.39	-.41
16																0.83									-.20	-.30	-.29
17																									-.21	-.37	-.41
18																		0.41	-.17	-.21	-.10	-.19	-.10	-.11	-.40	-.51	-.44
19																									-.11	-.06	-.10
20																				-.04	0.05	0.19	0.09	-.10	0.69	0.49	0.36
21																					0.60	0.36	0.63	-.31	0.10	0.03	-.11
22																						0.74	0.90	-.64	-.01	-.22	-.12
23																							0.82	-.18	0.15	-.06	0.01
24																								-.26	0.02	-.24	-.12
25																									0.04	0.04	0.04
26																										0.66	0.47
27																											0.53

1. Live conformation
2. Slaughter grade
3. Lip or muzzle width
4. Tail length
5. Estimated age
6. Chilled carcass weight
7. Carcass conformation
8. Carcass maturity
9. Marbling score
10. USDA carcass grade
11. Firmness
12. Subjective color score
13. Ribeye area
14. 12th rib fat thickness
15. Estimated percent internal fats
16. USDA yield grade
17. Lower rib fat thickness
18. Value-objective color
19. Chroma-objective color
20. Average-Warner-Bratzler shear
21. Average bone hardness
22. Cross-sectional area of rib
23. Width of rib
24. Bone density adjusted for inter- and intra-film differences
25. Above bone density corrected for L-S area of rib
26. Panel tenderness
27. Panel flavor
28. Panel juiciness

$r > .25$; significance at $P < .05$ (d.f. = 60).
$r > .33$; significance at $P < .01$ (d.f. = 60).

TABLE 6. SIMPLE CORRELATION COEFFICIENTS WITHIN MATURE C, D AND E CARCASS MATURITY GROUP (n = 61)

Trait no.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	0.97	-.21	-.26	-.63	0.36	0.69	0.27	0.42	0.55	0.40		0.25	0.54	0.58	0.50	0.60	0.30								-.25	-.27	-.12
2		-.13	-.21	-.61	0.38	0.61	0.27	0.45	0.53	0.42		0.23	0.53	0.56	0.50	0.59	0.30								-.27	-.26	-.12
3			0.45	0.56	0.46	-.25	-.36				-.15						-.10				0.36		0.26		0.05	0.00	-.11
4				0.46							-.07						-.17				0.31				0.17	0.12	0.03
5						-.49	-.42	-.19	-.35		-.30		-.34	-.39	-.31	-.29	-.33								0.19	0.22	-.08
6								0.47	0.43			0.62	0.43	0.23	0.39	0.52					0.39		0.33		-.14	-.11	-.23
7								0.53	0.76			0.31	0.49	0.59	0.40	0.49	0.22	0.23							-.16	-.21	-.08
8									0.26		0.41								-.26	-.10	-.33	-.24	-.26		-.31	-.29	0.06
9									0.88	0.63	0.37	0.35	0.38	0.46	0.34	0.40		0.44	-.26					0.27	-.51	-.48	-.34
10										0.58	0.34	0.32	0.41	0.52	0.37	0.43	0.15	0.39	-.21						-.44	-.45	-.28
11												-.01	0.33	0.44	0.41	0.27	0.21	0.24	-.35						-.36	-.33	-.31
12																	0.38	0.30							-.28	-.14	0.00
13																					0.32		0.35		-.16	-.13	-.30
14														0.55	0.94	0.76		0.26							-.14	-.10	-.22
15															0.61	0.54	0.28	0.15							-.22	-.12	0.00
16																0.74	0.15	0.23							-.11	-.07	-.12
17																									-.21	-.14	-.20
18																			-.27	-.25		-.27			-.21	-.18	0.19
19																								0.31	-.20	-.26	-.22
20																									0.66	0.49	0.00
21																							0.37	0.24	0.01	-.05	-.29
22																						0.56	0.64	-.57	-.04	-.06	-.31
23																							0.59		-.12	-.11	-.08
24																									-.06	-.17	-.29
25																									-.01	-.12	0.07
26																										0.74	0.29
27																											0.39

1. Live conformation
2. Slaughter grade
3. Lip or muzzle width
4. Tail length
5. Estimated age
6. Chilled carcass weight
7. Carcass conformation
8. Carcass maturity
9. Marbling score
10. USDA carcass grade
11. Firmness
12. Subjective color score
13. Ribeye area
14. 12th rib fat thickness
15. Estimated percent internal fats
16. USDA yield grade
17. Lower rib fat thickness
18. Value-objective color
19. Chroma-objective color
20. Average-Warner-Bratzler shear
21. Average bone hardness
22. Cross-sectional area of rib
23. Width of rib
24. Bone density adjusted for inter- and intra-film differences
25. Above bone density corrected for X-S area of rib
26. Panel tenderness
27. Panel flavor
28. Panel juiciness

$r \geq .25$; significance at $P < .05$ (d.f. = 59).
$r \geq .33$; significance at $P < .01$ (d.f. = 59).

differences (r = 0.69) and panel tenderness (r = 0.67). When the population was split, however, a large proportion of these relationships disappeared in the mature group but remained relatively strong in the youthful group. If the covariance between traits remained relatively high and variance is reduced by reducing the range in the traits, the correlation would remain at relatively the same level or increase. That does not seem to be the case, however. The same relationship appears evident for nearly all measures of maturity used in this study. It might be postulated from this observation that during the early maturing process changes in tenderness associated with maturity occur at a more regular or predictable rate than in older animals where there is also greater opportunity for environmental factors to influence palatability.

Chilled carcass weight was quite highly correlated with ribeye area (r = 0.70) and rib bone cross-sectional area (r = 0.67) which would be expected.

Carcass conformation and carcass grade with their built-in confounding with maturity in the whole population were each highly correlated with the other (r = 0.92). However, when the sample was split, the correlations were reduced markedly. Then the primary determinant of carcass grade became marbling (r = 0.85) instead of maturity (r = 0.42).

Although marbling level was not highly correlated with panel tenderness before the segments of the sample population were analyzed separately (r = -.43), following the separation, marbling showed the

fourth highest correlation with tenderness in the youthful group ($r = -.44$) and the second highest in the mature group ($r = -.51$).

U.S.D.A. carcass grade derived from carcass conformation, carcass maturity and marbling provided the second and third highest correlations with tenderness in the youthful ($r = -.56$) and mature groups ($r = -.44$), respectively, and the second highest correlation in the entire sample population ($r = -.74$). Therefore, even though carcass grade does not perfectly predict palatability, it shows the closest relationship to eventual palatability of any of the non-destructive, economically feasible methods used in this study.

Measures of external fat thickness were highly correlated with U.S.D.A. yield grade accounting for approximately 90 percent of the variation. The relationship between either of these measures of external fatness and tenderness was quite low. Ramsey et al. (1962) reported that yield grades calculated to the nearest 0.05 were more closely related to separable lean and fat than were yield grades calculated to the whole number only. When ribeye area was omitted from yield grade calculations, the resulting yield grades were more highly related to separable lean and fat than when ribeye area was included. They went on to state that neither carcass grade nor yield grade was superior to a single fat thickness measurement as an estimator of percent separable lean and fat. Carcass grade and yield grade were negatively associated with separable lean and bone but positively associated with separable fat.

Value, that component of color determining its whiteness or blackness, demonstrated a highly significant relationship with

subjective color (r = 0.60) and with carcass maturity (r = 0.65) in the entire sample population. Here, again, the gap between the younger and older groups seemed to account for a large share of the correlation.

Warner-Bratzler shear measurement of tenderness was the best indicator of panel tenderness evaluation irrespective of the part of the population the steak came from.

Bone measurements showed varying degrees of correlation among themselves but generally they were high. However, they were not especially closely related to panel tenderness. Bone density corrected for inter- and intrafilm differences as well as cross-sectional area of the rib sample showed a very low correlation with everything except cross-sectional area of rib (r = -.36).

Tenderness was highly correlated with flavor (r = 0.81) which may indicate the panel had difficulty separating the two characteristics in their minds. Or, possibly, the two characteristics change at approximately the same rate in bovines.

Multiple Regressions

After surveying the correlation coefficients, those characteristics that appeared to have any relationship to panel tenderness were further analyzed for their contribution in predicting tenderness. Correlation coefficients provide useful information on relationships between traits, but often these relationships may be confounded with other traits. Multiple regression analyses were used to determine the relationship between selected traits and panel tenderness. This method of analysis also eliminated the problem of confounding in the data.

Partial and standard partial regression coefficients were determined for each of the 21 characteristics analyzed. The determinations were made for the entire slaughter group as well as the aforementioned youthful and mature segments.

Tables 7, 8 and 9 list the partial regression coefficients for 21 selected characteristics on panel tenderness. It will be noted that in all three tables a number of characteristics were dropped before equation 6 without any significant decrease in the coefficients of determination (R^2). These characteristics included chilled carcass weight, carcass conformation, firmness of lean, estimated percent internal fats and Value-objective color measurement.

In table 7 for the entire sample group, live conformation, muzzle width, tail length, average bone hardness, cross-sectional area of the rib, width of rib and average bone density corrected for inter- and intrafilm differences were all eliminated without a significant decrease in the coefficient of determination. U.S.D.A. carcass grade and subjective color were eliminated next with still no significant loss in predictive capability. This left slaughter grade, estimated age, carcass maturity, marbling score, U.S.D.A. yield grade and Warner-Bratzler shear accounting for nearly 79 percent of the variation in panel tenderness.

TABLE 7. MULTIPLE REGRESSION EQUATIONS FOR PREDICTING TENDERNESS IN A FEMALE SLAUGHTER POPULATION (n = 123)

Trait	PR-E(1)[a]	PR-E(2)	PR-E(3)	PR-E(4)	PR-E(5)	PR-E(6)	PR-E(7)	PR-E(8)
1	-.0255	-.0110						
2	-.0711	-.0780	-.0997	-.0968	-.0943	-.1039	-.0967	-.0976
3	-.1194	-.1024						
4	0.0561							
5	-.0899	-.0889	-.1244	-.1146	-.1260	-.1232	-.1229	-.1173
6	0.0014	0.0013	0.0013					
7	0.0176							
8	-.1310	-.1323	-.1290	-.1403	-.1291	-.1249	-.0855	-.0987
9	-.1113	-.1104	-.1040	-.0986	-.1033	-.1048	-.0900	-.0966
10	0.0503	0.0589	0.0444	0.0506	0.0462	0.0457		
11	0.0222							
12	-.1243	-.1329	-.1322	-.1400	-.1329	-.1177	-.1147	
13	-.8204	-.8896	-.8213	-.6945	-.7837			
14	0.0331							
15	0.3438	0.3675	0.3471	0.3440	0.3587	0.1544	0.1528	0.1389
16	-.1226							
17	0.1644	0.1667	0.1619	0.1619	0.1618	0.1619	0.1621	0.1631
18	0.0122	0.0118						
19	-2.2608	-2.5105	-2.1911	-1.3418				
20	0.0043							
21	-.0333							
R^2	0.8086	0.8069	0.8037	0.8003	0.7980	0.7962	0.7944	0.7895

1. Live conformation
2. Slaughter grade
3. Lip or muzzle width
4. Tail length
5. Estimated age
6. Chilled carcass weight
7. Carcass conformation
8. Carcass maturity
9. Marbling score
10. U.S.D.A. carcass grade
11. Firmness of lean
12. Subjective color
13. 12th rib fat thickness
14. Estimated percent internal fats
15. U.S.D.A. yield grade
16. Value-objective color
17. Av. Warner-Pratzler shear
18. Av. bone hardness
19. Cross-sectional area of rib
20. Width of rib
21. Av. bone density corrected for inter- and intrafilm differences

[a] Partial Regression Coefficients-Equation 1.

The resulting regression equation was:

Panel tenderness score = 4.795 - (.0976 x slaughter grade)
- (.1176 x estimated age group)
- (.0987 x carcass maturity notation)
- (.0966 x marbling score)
+ (.1389 x U.S.D.A. yield grade to 0.1 of a grade)
+ (.1631 x average Warner-Bratzler shear)

It might be argued that some of these traits lack practicality in their collection and cost of collection, but from the data on this sample of the slaughter population, this equation would most adequately predict eatability qualities of rib steaks.

When the over-all sample was split and analyzed separately as youthful and mature, the traits in the youthful group (table 8) which lacked significant predictive capabilities in addition to those already mentioned were live conformation, tail length, marbling score, subjective color and cross-sectional area of rib. From the 6th through the 13th equation, the following traits were eliminated in order with no significant loss of predictability of tenderness: muzzle width, carcass maturity, U.S.D.A. yield grade, 12th rib fat thickness, average bone hardness, average bone density and width of rib. Slaughter grade, estimated age, U.S.D.A. carcass grade and Warner-Bratzler shear remained in the equation to account for slightly over 68 percent of the variation in panel tenderness.

TABLE 8. MULTIPLE REGRESSION EQUATIONS FOR PREDICTING TENDERNESS IN THE YOUTHFUL A AND B CARCASS MATURITY GROUP (n = 62)

Trait	PR-E(1)[a]	PR-E(2)	PR-E(3)	PR-E(4)	PR-E(5)	PR-E(6)	PR-E(7)	PR-E(8)
1	-.0564	-.0544	-.0359	-.0337				
2	-.1697	-.1687	-.1999	-.1669	-.2037	-.1995	-.2285	-.2249
3	-.1640	-.1928	-.2068	-.2185	-.2106	-.2074		
4	-.1100							
5	-.2592	-.2551	-.3245	-.3323	-.3405	-.3407	-.4545	-.4102
6	0.0007							
7	0.0673	0.0734	0.0550					
8	-.1159	-.1096	-.1039	-.0902	-.0912	-.0871	-.0699	
9	-.0133							
10	-.1832	-.2447	-.2457	-.2431	-.2471	-.2493	-.2406	-.2699
11	-.1012							
12	-.1249	-.1334						
13	0.7800	1.2332	1.5814	1.5160	1.3867	1.1115	1.2372	1.1895
14	0.1864	0.1682						
15	-.1737	-.2556	-.3299	-.3140	-.2832	-.2270	-.2363	-.1893
16	0.0462							
17	0.1816	0.1728	0.1711	0.1736	0.1713	0.1715	0.1629	0.1646
18	0.0233	0.0227	0.0265	0.0302	0.0282	0.0264	0.0256	0.0307
19	-2.1255	-2.4533	-2.2690	-2.4381	-2.3128			
20	0.0697	0.0653	0.0745	0.0729	0.0717	0.0715	0.0729	0.0808
21	-.1884	-.1533	-.1690	-.1702	-.1657	-.2577	-.2581	-.2581
R^2	0.7561	0.7445	0.7344	0.7309	0.7304	0.7269	0.7193	0.7134

1. Live conformation
2. Slaughter grade
3. Lip or muzzle width
4. Tail length
5. Estimated age
6. Chilled carcass weight
7. Carcass conformation
8. Carcass maturity
9. Marbling score
10. U.S.D.A. carcass grade
11. Firmness of lean
12. Subjective color
13. 12th rib fat thickness
14. Estimated percent internal fats
15. U.S.D.A. yield grade
16. Value-objective color
17. Av. Warner-Bratzler shear
18. Av. bone hardness
19. Cross-sectional area of rib
20. Width of rib
21. Av. bone density corrected for inter- and intrafilm differences

[a] Partial Regression Coefficients-Equation 1.

TABLE 8 CONTINUED

Trait	PR-E(9)	PR-E(10)	PR-E(11)	PR-E(12)	PR-E(13)
1					
2	-.2135	-.2001	-.1959	-.1815	-.1665
3					
4					
5	-.4109	-.4009	-.3369	-.3351	-.2730
6					
7					
8					
9					
10	-.2820	-.2317	-.2514	-.2793	-.2680
11					
12					
13	0.5462				
14					
15					
16					
17	0.1612	0.1662	0.1592	0.1620	0.1669
18	0.0304	0.0299			
19					
20	0.0797	0.0972	0.0618	0.0266	
21	-.2524	-.2675	-.1114		
R^2	0.7117	0.7049	0.6915	0.6864	0.6812

The resulting regression equation was:

Panel tenderness score = 9.2007 - (0.1665 x slaughter grade)
- (0.2730 x estimated age group)
- (0.2680 x U.S.D.A. carcass grade)
+ (0.1669 x average Warner-Bratzler shear)

In the older half of the sample population, muzzle width, estimated age, subjective color, average bone hardness, width of rib and average bone density were all eliminated before equation 6 in addition to the traits previously mentioned. From equation 6 through 12, the following traits were eliminated in the order listed: tail length, cross-sectional area of rib, U.S.D.A. carcass grade, carcass maturity, live conformation and slaughter grade. Marbling score, 12th rib fat thickness, U.S.D.A. yield grade and Warner-Bratzler shear remained to account for approximately 60 percent of the variation in tenderness in a regression equation. The resulting equation was:

Panel tenderness score = 1.4454 - (0.1082 x marbling score)
- (1.6924 x 12th rib fat thickness)
+ (0.6492 x U.S.D.A. yield grade)
+ (0.1859 x average Warner-Bratzler shear)

An interesting observation concerning the components of this equation are the opposite signs of 12th rib fat thickness and U.S.D.A. yield grade. This is apparently due to a quirk in derivation of the regression equation because it has already been noted there was an

TABLE 9. MULTIPLE REGRESSION EQUATIONS FOR PREDICTING TENDERNESS IN THE MATURE C, D AND E CARCASS MATURITY GROUP (n = 61)

Trait	PR-E(1)[a]	PR-E(2)	PR-E(3)	PR-E(4)	PR-E(5)	PR-E(6)	PR-E(7)
1	0.1916	0.1580	0.1862	0.1968	0.1416	0.1094	0.0802
2	-.1600	-.1343	-.1537	-.1573	-.1169	-.1053	-.0799
3	0.0101						
4	0.1710	0.1704	0.1928	0.1856	0.1758	0.1661	
5	-.0316						
6	0.0004						
7	-.0647	-.0586	-.0827	-.0393	-.0714		
8	-.5487	-.4665	-.4553	-.4434	-.4190	-.3605	-.3769
9	-.2491	-.2334	-.2444	-.2278	-.2047	-.1711	-.1535
10	0.2519	0.2326	0.2648	0.2653	0.2291	0.1289	0.0956
11	0.1347	0.1351	0.1156				
12	0.1142						
13	-2.0690	-1.8584	-1.7901	-2.0588	-1.8287	-1.9778	-2.1171
14	-.0720						
15	0.7225	0.6749	0.6641	0.7591	0.6925	0.7261	0.7483
16	-.0498						
17	0.1653	0.1671	0.1682	0.1663	0.1688	0.1672	0.1681
18	-.0008						
19	-7.3101	-7.1287	-8.1713	-8.0680	-5.7607	-5.2400	-4.2085
20	-.0440	-.0377					
21	0.1792	0.1774	0.1468	0.1469			
R^2	0.7079	0.7013	0.6972	0.6932	0.6854	0.6820	0.6613

1. Live conformation
2. Slaughter grade
3. Lip or muzzle width
4. Tail length
5. Estimated age
6. Chilled carcass weight
7. Carcass conformation
8. Carcass maturity
9. Marbling score
10. U.S.D.A. carcass grade
11. Firmness of lean
12. Subjective color
13. 12th rib fat thickness
14. Estimated percent internal fats
15. U.S.D.A. yield grade
16. Value-objective color
17. Av. Warner-Bratzler shear
18. Av. bone hardness
19. Cross-sectional area of rib
20. Width of rib
21. Av. bone density corrected for inter- and intrafilm differences

[a] Partial Regression Coefficients-Equation 1.

TABLE 9 CONTINUED

Trait	PR-E(8)	PR-E(9)	PR-E(10)	PR-E(11)	PR-E(12)
1	0.0923	0.1457	0.1206		
2	-.0890	-.1346	-.1406	-.0205	
3					
4					
5					
6					
7					
8	-.3027	-.2564			
9	-.1487	-.1063	-.1022	-.1047	-.1082
10	0.0877				
11					
12					
13	-2.1803	-2.2054	-1.8423	-1.6300	-1.6924
14					
15	0.7689	0.7804	0.7040	0.6518	0.6492
16					
17	0.1690	0.1741	0.1859	0.1842	0.1850
18					
19					
20					
21					
R^2	0.6378	0.6341	0.6055	0.6010	0.5997

extremely high positive correlation between 12th rib fat thickness and U.S.D.A. yield grade.

Warner-Bratzler shear was the single best predictor of beef palatability. This method of predicting tenderness is certainly less time consuming and less costly than convening a group of panel members to pass judgment on beef steaks. However, it still requires time to cook and measure each sample besides destroying a steak which makes it economically impractical in a commercial situation. Therefore, further study of other characteristics and particularly some of the bone measurements in youthful carcasses may still be warranted. Even if they were not as effective as Warner-Bratzler shear alone, they might prove to be economically practical and have additive value to the U.S.D.A. carcass grading system now used.

The bone measurements developed and used in this study lacked some of the hoped for close relationship to tenderness. However, average bone hardness, average bone density and width of rib remained in the multiple regression equations longer than carcass maturity in the youthful group. This may indicate possible usefulness for these more objective measurements of bone characteristics in predicting tenderness in youthful carcasses. Perhaps with further refinement of technique or different approaches to this study, stronger relationships might be established.

A simple, inexpensive measure of bone which is closely related to tenderness would be very useful in establishing in-line grading systems where the carcasses could be graded for eventual tenderness while passing through the beef kill and dressing lines. Inventory

control and sales programs in packing plants could be much better coordinated.

A measurement such as bone hardness or width of rib should be economically feasible in a commercial situation if something were to be gained from using it. Bone density, as determined in this study, would entail considerably higher equipment, labor and supply costs. However, all of these require more time than a quick visual appraisal of the degree of ossification or lack of it in the buttons for carcass maturity determination.

Returning to carcass maturity, after observing the distribution of tenderness means within carcass maturities in appendix table 6, the youthful, well-fed portion of the sample population nearly all have acceptable eating qualities. Therefore, the problem of tenderness or lack of it may not be worthy of extensive research time and effort.

Research time and money might be more expeditiously spent on enzyme preparations or other chemical or mechanical means of making meat more tender. Proper education in cooking and handling techniques may also be beneficial. Even if we did know what influenced or caused tenderness in meat genetically, it is questionable whether it would receive much selection pressure because of the much greater economic importance of many production traits.

From this attempt to randomly select female bovines from the slaughter population, it would appear that the Standard and Prime grades as well as the B carcass maturity group are relatively unimportant economically in today's beef production, at least in this area. Perhaps less time, effort and money should be spent studying

such nearly extinct creatures. In the past, this may not have been true. However, with present methods of feeding and handling cattle, they reach market at much earlier ages, therefore, what once may have been a serious problem is no longer such a problem.

SUMMARY AND CONCLUSIONS

Random selection of 123 female bovines from the slaughter population of a large midwestern packing company was performed over a period of seven work days. A full range of measurable traits was represented in this sample population.

Traits recorded for the individual live animals included type, breed or combination, color pattern, live conformation, slaughter grade, lip or muzzle width, horn size, tail length and estimated age.

On the slaughter floor they were checked for pregnancy and stage of pregnancy.

Approximately 24 hours post-mortem, a U.S.D.A. meat grader assisted in the collection of carcass information. This information included warm and chilled carcass weight, carcass conformation, carcass maturity, marbling score, U.S.D.A. carcass grade, firmness of lean, subjective color score, 12th rib fat thickness, estimated percent internal fats, U.S.D.A. yield grade, fat thickness over lower rib and hours after slaughter when grading was performed.

The loft wholesale rib was removed from each carcass and allowed to age seven days post-mortem before muscle, bone and cartilage samples were taken.

Twelfth rib steaks were removed for cooking and testing on the Warner-Bratzler shear machine. Eleventh rib steaks were removed for use by a seven member mixed experience taste panel. Standardized cooking and sampling techniques were used. The samples were rated on an eight-point Hedonic scale for tenderness, flavor and juiciness. Tenth

rib steaks were measured for objective color by a Photovolt Model No. 610 Reflectance Meter.

A four and one-half inch section of the distal end of the 12th rib was removed for bone sectioning. An 0.18 inch thick cross section was cut on a Lipshaw Model 25 bone saw for exposure to x-rays. The resulting radiograph was measured for transmitted light by a Photovolt Model No. 425 densitometer wired to a Photovolt galvanometer to improve the sensitivity of the readings. A tracing was made on semilogarithmic paper which was subsequently measured for area by a compensating polar planimeter. The area was adjusted for various inequities between samples. These measurements were now designated bone density measurements.

A 0.135 inch thick longitudinal section of this same rib bone was removed on the saw to be used for hardness testing. The sample was tested on a Pyro-Electro metal hardness tester after various modifications had been made on the instrument. An average for 12 hardness measurements on each sample was used because of the somewhat wide variability experienced even on the same bone sample. Definite differences between samples were noted, however.

Statistical analyses of the data were performed. Means and standard deviations for a number of characteristics were determined within subclasses of selected traits. Simple correlations were determined between all recorded traits for the entire sample group as well as the youthful and mature halves of the sample group. Some of the important relationships established from these correlations included a relatively strong relationship between any measure of maturity

and panel tenderness in the total sample. The strength of the relationship between maturity measures and tenderness was reduced when the separate segments were analyzed. It could be postulated from this observation that the female slaughter population is not distributed in a smooth, continuous pattern but is separated primarily into two rather specific groups, the youthful and the mature.

Multiple regression equations were derived using 21 of the more highly correlated or interesting recorded traits. Coefficients of determination for the shortest equations on the entire sample, the youthful group and the mature group were R^2 = 0.7895, 0.6812 and 0.5997, respectively.

Warner-Bratzler shear measurements provided the best single predictor of eventual tenderness in each segment of the sample as well as under all methods of statistical analyses.

Subjective evaluations of animal age, slaughter grade and carcass grade supplied some useful contributions in predicting tenderness, particularly in the more youthful group. Warner-Bratzler shear values were the most effective contributors to tenderness predictions, however.

In some portions of the analysis, bone characteristics, such as bone hardness, width of rib and bone density measures, showed enough relation to panel tenderness to warrant further study.

Even though there are exceptions, generally, the youthful carcasses are more tender than the mature carcasses with few examples of objectionable toughness or flavor. If this is a true representation of the slaughter population, meat researchers might be better advised to spend less time and effort trying to find characteristics related to

tenderness in youthful, well-fed cattle and devote their energies to other problems.

However, as long as people enjoy beef and consider tenderness a very desirable attribute, study of the inherent differences in tenderness will probably continue. Perhaps more attention should be devoted to improving tenderness in the more variable and often times more objectionable mature segment of the population.

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APPENDIX

TABLE 1. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITHIN TYPES

Type	Beef 1	2	3	4	Dairy 5	Average
No. of animals	96	6	7	3	11	
Chilled carcass wt.						
Mean	566	540	678	681	651	581
S.D.	87	115	206	63	131	107
Ribeye area						
Mean	10.14	9.98	10.96	11.43	11.07	10.30
S.D.	1.18	1.45	1.77	2.47	2.56	1.45
Av. bone hardness						
Mean	43.9	49.4	45.3	59.1	58.4	45.9
S.D.	11.0	16.1	10.5	6.1	8.5	11.8
Rib bone width						
Mean	30.4	29.3	31.3	31.3	33.4	30.7
S.D.	4.0	2.9	5.8	2.3	4.2	4.1
Av. bone density[a]						
Mean	8.29	8.42	8.87	9.91	10.45	8.57
S.D.	1.73	1.36	2.12	1.52	1.38	1.80
Av. Warner-Bratzler shear						
Mean	15.87	17.21	14.31	19.06	15.66	15.93
S.D.	4.91	5.47	3.33	3.19	3.14	4.68
Av. panel tenderness						
Mean	3.75	4.93	3.04	5.20	4.30	3.85
S.D.	1.57	1.82	1.36	0.93	1.14	1.57
Av. panel flavor						
Mean	3.38	3.89	2.62	3.85	3.61	3.39
S.D.	0.94	0.99	0.63	0.94	0.49	0.92

[a] Raw data corrected for inter- and intrafilm differences.

TABLE 2. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITHIN SLAUGHTER GRADES

Slaughter grade	No. of animals	Ribeye area		USDA yield grade		Av. bone hardness		Av. bone density[a]		Av. Warner-Bratzler shear		Av. panel tenderness		Av. panel flavor	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev
7 -	3	9.23	1.64	2.50	0.56	56.5	8.7	10.17	1.60	19.29	4.07	5.10	1.57	3.90	0.86
8 Utility	10	9.90	1.39	2.55	0.40	53.1	9.5	9.99	1.37	18.27	6.27	5.22	1.54	4.25	0.84
10 -	18	10.32	1.25	2.79	0.96	56.6	9.2	9.21	1.64	18.23	4.06	5.03	1.08	4.18	0.69
11 Commercial	19	11.17	2.21	3.18	1.13	56.3	8.6	10.37	1.69	20.89	4.15	5.23	1.28	4.08	0.91
12 +	6	11.27	1.26	3.40	1.56	56.2	5.8	10.27	1.76	17.45	2.35	4.69	1.32	3.45	0.64
14 Standard	1	9.50	--	2.70	--	42.5	--	8.67	--	12.60	--	3.43	--	2.85	--
16 -	3	9.00	0.75	2.10	0.53	40.7	4.8	7.20	0.65	13.78	2.52	3.82	0.37	3.53	0.35
17 Good	2	10.65	0.92	2.05	0.07	38.1	4.7	7.48	0.28	12.34	2.90	2.32	0.25	2.45	0.17
18 +	14	9.26	1.02	3.39	0.56	37.9	8.3	7.23	0.88	12.37	2.13	2.90	0.75	2.82	0.45
19 -	21	10.37	0.99	3.44	0.83	37.1	6.4	7.40	0.58	13.92	2.94	2.76	0.99	2.82	0.55
20 Choice	17	10.11	1.12	3.48	0.68	35.7	6.1	7.25	1.15	13.07	3.40	2.64	1.06	2.79	0.72
21 +	7	10.85	1.06	4.54	1.11	39.3	5.7	8.11	1.63	13.58	2.93	2.78	0.61	2.91	0.29
22 -	1	11.00	--	3.60	--	41.3	--	8.41	--	11.22	--	2.29	--	2.14	--
23 Prime	1	10.00	--	4.60	--	49.2	--	9.11	--	16.47	--	3.43	--	2.85	--
Average		10.30	1.45	3.22	0.99	45.9	11.8	8.57	1.80	15.93	4.68	3.85	1.57	3.39	0.92

[a] Raw data corrected for inter- and intra-film differences.

TABLE 3. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITHIN MUZZLE WIDTHS

Lip or muzzle width	Narrow 1	2	3	4	Broad 5
No. of animals	19	43	33	20	8
Value-objective color					
Mean	3.95	3.86	3.57	3.49	3.37
S.D.	0.20	0.27	0.37	0.35	0.24
Av. bone hardness					
Mean	35.8	38.3	51.5	59.8	53.8
S.D.	6.2	7.4	10.1	5.1	7.1
Width of rib					
Mean	28.7	28.3	32.2	33.5	35.4
S.D.	2.8	2.6	3.7	4.5	4.0
Av. bone density[a]					
Mean	7.21	7.53	9.39	10.22	9.87
S.D.	1.21	0.93	1.69	1.60	1.76
Av. Warner-Bratzler shear					
Mean	13.13	14.14	17.00	18.45	21.50
S.D.	3.00	3.56	5.37	2.96	5.17
Av. panel tenderness					
Mean	2.76	3.12	4.35	5.03	5.39
S.D.	0.94	1.32	1.56	1.12	1.04
Av. panel flavor					
Mean	2.84	3.02	3.59	3.98	4.48
S.D.	0.55	0.80	0.91	0.69	0.83

[a] Raw data corrected for inter- and intrafilm differences.

TABLE 4. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITHIN ESTIMATED ANIMAL AGES

Estimated age, months	10-18 1	18-24 2	24-30 3	30-36 4	36-48 5	48-60 6	Aged 7
No. of animals	22	28	14	3	11	20	25
Value							
Mean	3.94	3.98	3.79	3.85	3.41	3.48	3.41
S.D.	0.20	0.23	0.14	0.11	0.26	0.31	0.35
Av. bone hardness							
Mean	35.8	37.1	40.4	44.0	50.7	55.9	58.0
S.D.	6.9	6.1	6.1	3.6	10.6	9.1	5.9
Rib bone width							
Mean	28.8	28.8	28.1	27.0	30.9	32.8	34.8
S.D.	2.6	3.0	2.3	2.6	2.1	3.7	4.5
Av. bone density[a]							
Mean	7.29	7.51	7.51	7.80	9.18	9.78	10.32
S.D.	1.15	0.87	1.03	0.82	1.35	1.48	1.81
Av. Warner-Bratzler shear							
Mean	13.79	13.05	13.12	12.29	21.59	17.97	18.93
S.D.	3.33	2.83	2.19	1.86	6.32	3.21	4.14
Av. panel tenderness							
Mean	2.83	2.72	2.86	3.21	5.86	4.77	5.03
S.D.	0.86	0.96	0.90	0.63	1.56	1.17	1.05
Av. panel flavor							
Mean	2.80	2.80	2.93	2.96	4.47	3.75	4.14
S.D.	0.34	0.65	0.62	0.70	0.92	0.70	0.77

[a] Raw data corrected for inter- and intrafilm differences.

TABLE 5. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITHIN PREGNANT OR NONPREGNANT BOVINES

Pregnancy	No	Yes	Average
No. of animals	86	28	
Value			
Mean	3.72	3.61	3.70
S.D.	0.33	0.43	0.36
Chroma			
Mean	5.01	4.71	4.93
S.D.	1.07	1.10	1.07
Av. bone hardness			
Mean	43.7	49.9	45.9
S.D.	11.2	11.0	11.8
Av. Warner-Bratzler shear			
Mean	15.67	16.02	15.93
S.D.	4.51	5.27	4.68
Av. panel tenderness			
Mean	3.73	3.96	3.85
S.D.	1.56	1.59	1.57
Av. panel flavor			
Mean	3.30	3.66	3.39
S.D.	0.92	0.91	0.92

TABLE 6. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITHIN CARCASS MATURITIES

Carcass maturity		No. of animals	Value Mean	Value S.D.	Av. bone hardness Mean	Av. bone hardness S.D.	Rib bone width Mean	Rib bone width S.D.	Av. bone density[a] Mean	Av. bone density[a] S.D.	Av. Warner-Bratzler shear Mean	Av. Warner-Bratzler shear S.D.	Av. panel tenderness Mean	Av. panel tenderness S.D.	Av. panel flavor Mean	Av. panel flavor S.D.
2	E	19	3.41	0.40	60.3	6.6	36.2	3.9	10.93	1.64	18.96	3.14	5.08	0.94	3.84	0.67
3	-	6	3.32	0.29	53.6	5.6	33.8	4.2	9.91	0.93	21.21	4.44	5.81	0.71	4.41	0.75
4	+	8	3.44	0.24	57.6	6.7	31.8	2.2	9.27	1.22	19.90	5.39	5.49	1.26	4.27	1.00
5	D	5	3.39	0.26	57.1	3.4	31.2	4.5	9.88	1.44	17.11	2.06	4.61	1.05	4.02	0.40
6	-	8	3.70	0.11	52.5	10.7	31.1	3.1	9.13	2.06	17.26	2.84	4.56	1.28	3.79	1.00
7	+	5	3.39	0.38	51.2	6.1	32.4	3.3	9.43	1.26	18.72	6.64	4.97	1.59	4.23	1.11
8	C	7	3.58	0.36	48.0	10.5	30.3	4.2	8.65	1.39	17.79	6.44	4.18	1.95	3.85	0.74
9	-	3	3.90	0.40	45.9	3.8	29.0	3.0	8.49	0.57	13.94	3.03	2.62	1.05	2.90	0.50
10	+	1	3.50	--	35.4	--	32.0	--	8.72	--	28.20	--	7.00	--	5.28	--
11	B	1	3.76	--	41.1	--	30.0	--	7.44	--	15.89	--	4.14	--	3.72	--
12	-	2	4.06	0.35	37.6	5.4	34.5	2.1	8.50	1.33	10.50	1.17	1.71	--	2.72	1.91
13	+	35	3.93	0.21	37.4	7.0	28.4	2.0	7.39	0.77	12.94	2.70	2.81	0.82	2.76	0.50
14	A	23	3.92	0.19	35.9	5.1	27.9	2.7	7.18	1.07	13.53	3.04	2.77	0.96	2.86	0.62

[a] Raw data corrected for inter- and intrafilm differences.

TABLE 7. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITH MARBLING LEVELS

Marbling	No. of animals	Chilled carcass wt.		12th rib fat thickness		% internal fats		Av. Warner-Bratzler shear		Av. panel tenderness		Av. panel flavor		Av. panel juiciness	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
3 Prac. dev.	3	533	110	0.12	0.06	1.50	0.50	20.59	8.58	5.62	2.08	4.43	0.49	5.67	1.00
5 -	4	534	47	0.31	0.22	1.63	0.63	17.02	2.36	5.07	0.99	4.68	0.87	4.75	0.14
6 Traces	5	482	56	0.15	0.07	1.70	0.45	18.89	5.75	4.43	1.75	3.77	1.02	4.08	0.41
7 +	5	563	73	0.34	0.15	1.50	0.50	22.11	7.11	5.74	0.83	4.83	0.59	4.63	1.55
8 -	12	560	82	0.26	0.14	1.92	0.76	15.60	4.38	4.27	1.34	3.71	0.68	4.65	0.61
9 Slight	7	554	55	0.51	0.15	2.57	0.73	18.89	6.03	5.08	1.85	4.06	1.12	4.74	0.73
10 +	14	561	97	0.44	0.20	2.86	0.57	16.02	3.81	4.18	1.31	3.18	0.75	3.96	0.53
11 -	7	560	84	0.34	0.14	2.21	0.39	15.92	4.90	3.65	1.20	3.36	0.74	3.47	0.55
12 Small	6	533	69	0.65	0.42	2.75	1.17	13.92	3.49	3.56	1.59	3.29	0.91	3.46	0.88
13 +	12	558	82	0.53	0.22	2.79	0.81	13.95	4.20	3.54	1.50	3.14	0.76	4.31	0.61
14 -	7	601	50	0.59	0.26	3.21	0.81	13.66	2.76	3.27	0.85	3.18	0.45	4.03	1.01
15 Modest	7	580	171	0.66	0.34	3.07	0.53	13.37	2.22	2.80	1.43	2.94	1.07	3.63	0.89
16 +	12	633	110	0.64	0.36	2.96	0.54	15.07	3.57	3.13	1.18	3.16	0.77	3.91	0.68
17 -	8	606	95	0.49	0.17	2.81	0.70	15.19	4.32	3.03	1.86	2.71	0.67	3.53	0.94
18 Moderate	4	732	268	0.83	0.25	3.13	0.48	14.34	4.45	3.26	1.91	2.75	0.61	3.54	0.69
19 +	6	634	73	0.63	0.24	2.75	0.42	17.44	5.03	3.43	1.28	3.02	0.79	3.87	0.80
20 -	1	841	--	0.85	--	2.50	--	20.70	--	6.14	--	4.27	--	4.71	--
21 Sl. abun.	1	578	--	0.70	--	3.00	--	10.88	--	1.86	--	2.00	--	3.57	--
23 Mod. abun.	1	656	--	1.50	--	4.00	--	14.17	--	2.14	--	2.71	--	2.71	--
27 Abundant	1	763	--	0.40	--	2.50	--	19.39	--	2.86	--	3.43	--	3.66	--

TABLE 8. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITHIN CARCASS GRADE

Carcass grade	No. of animals	USDA yield grade		Value		Av. bone hardness		Av. bone density[a]		Av. Warner-Bratzler shear		Av. panel tenderness		Av. panel flavor		Av. panel juiciness	
		Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
5 Cutter	3	3.00	0.36	3.41	0.22	52.9	6.4	8.68	1.39	20.05	2.25	5.48	1.19	4.86	0.15	5.11	0.42
6 +	1	2.90	--	2.89	--	45.3	--	11.51	--	30.07	--	6.14	--	5.43	--	6.29	--
7 -	19	2.39	0.62	3.29	0.25	57.5	9.4	9.64	1.79	18.54	4.41	5.41	1.10	4.15	0.73	4.59	1.00
8 Utility	16	2.59	0.63	3.53	0.32	53.3	6.6	9.58	1.68	18.71	4.81	5.09	1.19	4.06	0.73	4.28	0.65
9 +	4	3.15	1.15	3.43	0.14	59.0	8.0	9.89	1.97	20.23	4.01	5.79	0.63	4.32	0.37	4.11	0.07
10 -	10	4.12	1.24	3.69	0.32	58.9	7.0	10.61	2.02	16.77	3.77	3.96	1.03	3.40	0.72	3.87	0.72
11 Commercial	6	4.17	0.44	3.53	0.35	50.2	5.8	9.24	0.99	17.84	3.15	4.05	1.17	3.50	0.82	4.20	0.55
12 +	3	4.30	1.67	4.13	0.27	45.2	12.9	9.85	1.45	14.71	4.43	2.14	0.72	2.86	0.52	3.03	0.55
14 Standard	1	1.30	--	3.50	--	35.4	--	8.72	--	28.24	--	7.00	--	5.28	--	3.86	--
15 +	2	2.50	0.57	3.72	0.06	37.7	4.9	7.57	0.18	13.24	3.04	3.22	1.31	3.29	0.61	5.29	0.81
16 -	1	2.10	--	4.02	--	34.8	--	7.28	--	14.39	--	2.14	--	2.57	--	4.27	--
17 Good	11	3.34	0.68	3.94	0.21	34.3	7.0	6.80	0.98	13.80	3.47	3.22	0.66	2.82	0.35	3.97	0.78
18 +	13	3.38	0.96	3.86	0.14	40.6	5.3	7.28	0.52	14.00	3.11	3.30	0.82	3.09	0.65	3.75	0.79
19 -	17	3.50	0.62	3.98	0.23	34.8	6.9	7.40	0.71	12.14	1.90	2.61	0.83	2.75	0.50	3.83	0.84
20 Choice	12	3.42	0.92	3.97	0.21	37.5	4.6	7.93	1.24	13.30	3.15	2.20	0.72	2.53	0.54	3.75	0.74
21 +	4	4.03	1.08	3.83	--	37.0	4.6	6.93	1.21	12.04	2.85	2.22	1.09	2.50	0.58	3.39	0.80

[a] Raw data corrected for inter- and intra-film differences.

TABLE 9. MEANS AND STANDARD DEVIATIONS FOR VARIOUS CHARACTERISTICS WITHIN SUBJECTIVE COLORS

Subjective colors	Dark red 2	Mod. dark red 3	Cherry red 4	Light cherry red 5	Very light cherry red 6	Dark pink 7	Average
No. of carcasses	14	27	17	51	12	2	
Hue							
Mean	6.45	5.91	7.13	7.18	5.72	5.24	6.63
S.D.	2.59	1.33	2.12	2.58	2.21	1.38	2.36
Value							
Mean	3.26	3.43	3.78	3.85	4.01	4.31	3.70
S.D.	0.30	0.25	0.27	0.27	0.15	0.07	0.36
Chroma							
Mean	4.12	4.38	4.76	5.04	5.62	5.80	4.93
S.D.	1.26	1.04	1.02	1.00	0.71	0.35	1.07
Av. Warner-Bratzler shear							
Mean	19.05	19.26	13.23	14.68	14.01	15.22	15.93
S.D.	4.96	4.91	2.65	3.63	4.30	8.27	4.68
Av. panel tenderness							
Mean	5.13	5.26	2.94	3.38	2.57	2.86	3.85
S.D.	1.41	1.20	1.15	1.23	0.99	1.62	1.57
Av. panel flavor							
Mean	4.06	4.08	3.07	3.14	2.74	2.71	3.39
S.D.	0.78	0.86	0.88	0.76	0.61	0.20	0.92
Av. panel juiciness							
Mean	4.77	4.27	3.90	3.92	3.37	3.43	4.08
S.D.	0.92	0.82	0.71	0.85	0.80	0.81	0.87

TABLE 10. MEANS FOR VARIOUS CHARACTERISTICS WHICH MAY BE USEFUL IN OTHER REGRESSION EQUATIONS

Trait	Total sample mean n = 123	Youthful group mean n = 62	Mature group mean n = 61
Slaughter grade	14.97	18.75	11.11
Estimated age group	3.92	2.02	5.85
Marbling score	12.24	12.76	11.72
Carcass maturity	8.95	13.26	4.57
U.S.D.A. carcass grade	13.40	18.32	8.39
Chilled carcass weight, lb.	581	538	625
12th rib fat thickness, in.	.490	.544	.435
U.S.D.A. yield grade	3.22	3.35	3.09
Warner-Bratzler shear	15.93	13.37	18.53
Av. bone hardness	45.94	36.88	55.14
Width of rib, mm.	30.72	28.50	32.91
Av. bone density corrected for inter- and intra-film differences	8.57	7.37	9.72
Panel tenderness	3.85	2.85	4.87