A COMPARISON OF METHODS FOR MEASURING TENDERNESS OF RAW AND COOKED MEAT SAMPLES

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ABSTRACT

A COMPARISON OF METHODS FOR MEASURING TENDERNESS OF RAW AND COOKED MEAT SAMPLES

- by Barbara Ann Banks

The performance of a probe-type tenderometer on raw beef and pork was compared with that of the Warner-Bratzler shear, the ALLO-Kramer shear press, and taste panel methods of assessing tenderness on cooked meat. In addition to 18 young bulls used for preliminary work, 43 young bulls and steers from a commercial feedlot and 45 lightweight hogs were evaluated for tenderness and other carcass characteristics.

The tenderometer evaluation on raw beef was shown to be of significant value in predicting cooked tenderness of the beef sample used in this study (bulls and steers of similar maturity, weight and background). For this group, the use of the tenderometer in combination with visual scores for marbling and texture were found to account for approximately 64% of the variation in tenderness as measured by the Warner-Bratzler shear. High degrees of marbling apparently increased resistance to the tenderometer probe, indicating toughness, although marbling was otherwise shown to be associated with tenderness. An adjustment in tenderometer readings to offset this effect would be recommended.

The Warner-Bratzler and ALLO-Kramer shear press measures were highly correlated with each other and with sensory tenderness scores for cooked samples from all groups. Generally, these mechanical measures of the cooked sample demonstrated a higher association with sensory tenderness than did the tenderometer.

The tenderometer was modified by removing four needles from the ten-needle probe to permit its use on the smaller pork loin eye muscle. The

modified device demonstrated a very poor ability to evaluate tenderness on pork. Some observations possibly explaining this poor performance were noted. The sensitivity of the tenderometer may have been altered by the removal of four needles. Also, because of the "sinking" behavior exhibited by softer, PSE-type muscles, tenderometer readings by appropriate procedures were difficult to attain.

A low but positive association was indicated between an increased development of the PSE condition and increased tenderness by Warner-Bratzler shear and taste panel evaluations. Pork tenderness was not influenced by the cold carcass weight of the hogs used in this study.

An analysis of variance indicated that bulls had significantly larger rib eye areas, less fat, less marbling, lower yield grades, a darker color, and were less tender than the steers. A significantly greater variability in the tenderness attribute was exhibited by the bull group. The effects of various carcass traits on the tenderness of the pooled beef sample were examined. The indicators of fatness, higher yield grade and higher marbling scores, were significantly related to increased tenderness. Larger rib eye areas and a darker muscle color were associated with the less tender samples.

No significant differences in cross-sectional tenderness of the beef longissimus dorsi were observed. Cores from three positions (lateral, medial, and dorsal, nearest the backbone) were evaluated using the Warner-Bratzler shear.

A COMPARISON OF METHODS FOR MEASURING TENDERNESS OF RAW AND COOKED MEAT SAMPLES

By

Barbara Ann Banks

A THESIS

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INTRODUCTION

Tenderness is the chief criterion used by consumers in assessing meat quality (Szczesniak and Torgeson, 1965). The literature is replete with attempts to define and measure this very complex characteristic. Because of consumer concern for tenderness, producers, packers and retailers use the information from these studies to improve meat management practices. Producers use records of carcass tenderness to guide animal selection according to breed, sex, age, ration and feedlot treatment. Packers use U.S.D.A. grades and other carcass data to determine the fate of individual carcasses. The need exists for a non-destructive method of reliably predicting cooked meat tenderness from raw meat measurements. A reliable evaluation of fresh meat tenderness would permit better carcass differentiation into those suitable for processing, those needing additional aging or tenderizing treatments, and those ready for immediate consumption as fresh meat. As the ability to assess carcass quality improves, the industry can offer the consumer increased product standardization and quality assurance. In addition, better control of carcass allocation could be realized to the advantage of all -- producer to consumer.

This study was undertaken to compare the performance of a tenderometer* with other methods of evaluating tenderness of beef and pork.

*The Armour Tenderometer, probe type MTT serial number 62445, indicator serial number 1002, used in this study was developed by Armour and Company, Oak Brook, Illinois, and was donated to Michigan State University for research purposes.

The tenderometer was designed to distinguish between tender and tough beef carcasses by a non-destructive method of assessing raw meat tenderness in a packer's cooler, 24 hours postmortem. Both steers and young bulls were evaluated for tenderness in an attempt to gain further information concerning the effects of sex on the tenderness attribute. Beef tenderness was evaluated using the tenderometer on the raw sample and using the Warner-Bratzler shear, the ALLO-Kramer shear press and hedonic evaluation by taste panel on the cooked sample. Shear force readings were recorded for three locations across the beef longissimus dorsi to investigate cross-sectional tenderness differences. Tests were conducted to determine if tenderometer readings varied with different operators.

An attempt was made to adapt the tenderometer for measuring tenderness of pork. Tenderometer readings on pork loin were compared with other tenderness evaluations as measured by the above mentioned methods. Development of the pale, soft and exudative (PSE) condition in pork roasts was scored to determine the effects of this condition on tenderness.

LITERATURE REVIEW

Extensive research has been devoted to the problem of tenderness in meats. This quality has been identified as a critical factor in determining consumer satisfaction of the product. Brady (1957) reviewed studies of consumer preference of beef and reported most consumer dissatisfaction to be associated with lack of tenderness. Means and King (1959) found tenderness of beef steaks highly correlated with overall consumer satisfaction ($r = 0.904$). In his analysis of the characteristics of beef desirability, Pearson (1966) suggests that although tenderness is critical to consumer acceptance, the range of acceptability may be broad.

Relative to the quantity of research on tenderness with beef, little consideration has been apportioned to the problems with pork. Variations in tenderness between animals and between cuts of meat are generally thought to be less for pork than for beef (Bratzler, 1971). A decreased demand for lard and a growing preference for leaner pork prompted the evolution of a leaner, meat type hog. Alterations in pork carcass composition should be monitored to determine possible effects on the components of palatability. Hendrix *et al.* (1963) reported some consumer dissatisfaction with pork attributable to a lack of acceptable tenderness. Tenderness and other palatability factors of pork have been the subject of some recent investigations (Batcher *et al.*, 1962; Harrington and Pearson, 1962; Henry *et al.*, 1963; Gould *et al.*, 1965).

To satisfy the consumer's wants and to remain competitive, those in the industry must concern themselves with supplying meat products of standard, acceptable tenderness. The research directed toward identifying the factors affecting tenderness, designing methods of measuring this property, and, more important, optimizing this quality in terms of consumer preference reflects the meat industry's attempt to satisfy consumer demand.

Factors Affecting Muscle Tenderness

Studies of muscle tenderness are confounded by the complex nature of the tenderness sensation. Many factors have been shown to affect muscle tenderness; however, the literature contains conflicting evidence as to the degree of influence exerted by particular factors. The precise definition and measurement of tenderness remain elusive because of the interactions and variables involved. Researchers have investigated both antemortem and postmortem factors thought to affect muscle tenderness.

Preslaughter factors such as feeding regimen, maturity, conformation or type, breeding, sex, enzyme injection, and stress have been investigated to determine their effect on meat quality and tenderness. In reviews by Szczesniak and Torgeson (1965) and Stringer (1970) the question of diet appears unresolved. Of those studies reviewed by Stringer (1970) low protein diets for hogs were associated with increased marbling and tenderness. The review also indicated that hormonal injections in hogs are not related to tenderness (Stringer, 1970).

Pearson's review (1966) of factors affecting beef eatability indicated that tenderness is influenced by marbling over a wide range. Other studies substantiate this supposition. Walter et al. (1965) and Goll et al. (1965) found tenderness to decrease with maturity (A, B, and F maturity groups, as defined by U.S.D.A. grade standards, were analyzed.) although differences between the A and B groups were not significant. Romans et al. (1965) found no significant differences in tenderness (by shear force) as maturity varied from A through D classifications although more mature carcasses tended to have higher shear force values. Breidenstein et al. (1968) reported significant differences in tenderness (by shear force) between E maturity beef and both A and B maturity groups. As noted in the previously mentioned studies, tenderness differences between A and B maturity groups were not significant. Likewise, Covington et al. (1970) found no significant tenderness differences between the A, AB, and B groups. Zinn et al. (1970) reported that the interaction between time on feed and animal age influenced tenderness. The days on feed improved tenderness up to 180 days, at which time, the authors suggested that the toughening effect associated with age exerted a greater influence on this attribute.

Animal conformation or type is an unlikely indicator of tenderness. In his discussion of beef desirability, Pearson (1966) reviewed work relating beef conformation to tenderness. The data generally indicated that this factor "...has little to do with tenderness although some differences have been found between breed types." (Pearson, 1966). In studies reviewed by Zinn (1964) hereditability of tenderness was reported to be about 60%. Suess et al. (1966) found semimembranosus tenderness significantly affected by sire although longissimus dorsi tenderness was not. Tenderness in pork has been reported to be moderately hereditable ($0.20 \leq h \leq .40$) (Arganosa et al., 1969; and Jensen et al., 1967).

Sex is known to affect porcine and bovine tenderness especially as the animal matures. Recent work comparing acceptability of young bulls, steers, and heifers will be discussed later.

Treatments prior to slaughter also influence tenderness. A process characterized by the pre-slaughter injection of an enzyme tenderizer into the animal's vascular system has been patented and is in current commercial use (U.S. Patent No. 3,052,551) (Bratzler, 1971). The effect of antemortem stress upon tenderness and other quality factors has been studied. Webb et al. (1964) reported that steaks from non-stressed steers were significantly more tender than steaks from stressed steers when evaluated early in the aging period. After aging for 15 days, no significant difference in tenderness due to stress was observed (Webb et al., 1964). Antemortem stress has been related to the pale, soft and exudative (PSE) condition, characterized by rapid glycolysis and a low ultimate pH, and to the "dark cutter" phenomenon, characterized by a high ultimate pH. Lewis et al. (1967) showed the "dark cutter" reaction to be associated with increased tenderness in pork. Hedrick (1965) reviewed work on antemortem stress as related to meat palatability and reported the dark cutter condition to be associated with increased tenderness and the PSE condition with decreased tenderness. In work conducted at Michigan State University (personal communication, Dr. R. A. Merkel, 1971), increased tenderness was associated with increased severity of the PSE condition in pork. The conflicting data may be due to differences between studies in sample cooking methods or processing treatments; hence, the effects of time and temperature on muscle tenderness may become influencing factors. Bendall et al. (1962) reported that a low pH and a high temperature cause the sarcoplasmic proteins to precipitate on the myofibril, reducing the water holding capacity. Laakkone et al. (1970) studied the effects of low temperature, long time cooking methods on water holding capacity and tenderness of bovine muscle. They stated

> "...the final temperature of the meat is extremely critical in affecting tenderness and weight loss. If the temperature is below the temperature at which collagen shrinks, the major decrease in tenderness does not occur. If the temperature is higher than the shrinkage temperature of collagen, the more severe coagulation will cause a higher weight loss and more tightly packed, less tender tissue will be formed. If the meat is heated to the collagen shrinkage temperature, there will be less weight loss, yet the major increase in tenderness will have occurred."

Paul et al. (1952) observed that muscle tenderness decreases with the onset of rigor and increases with aging after rigor is complete. The exact mechanism by which toughening occurs during rigor is not explained. Muscle shortening during rigor is thought to be related to the degree of toughening (Pearson, 1971). Deatherage and Harsham (1947) observed increases in beef tenderness with aging. Gould et al. (1965)

studied the effect of aging on pork tenderness. Tenderness (by shear force) was found to increase as pork chops were aged from 2 to 12 days after slaughter.

The relationship between connective tissue present in muscle and its tenderness is controversial. Szczesniak and Torgeson (1965) reviewed the conflicting reports. Although still uncertain, increased tenderness appears to be at least somewhat associated with decreased quantities of connective tissue. The ratio of the collagen component of connective tissue to the elastin component partially determines the degree to which connective tissue influences tenderness. Collagen converts to gelatin upon heating whereas elastin does not (Briskey and Kauffman, 1971). Goll et al. (1964b) studied structural changes in the connective tissue associated with animal age. These changes, associated with decreased solubility of connective tissue as the animal ages, also appear to influence the degree to which connective tissue affects muscle tenderness (Goll et al., 1964a, b; Cormier et al., 1971).

Intramuscular fat has long been associated with meat quality and tenderness. Many investigators, however, have found the relationship between marbling and tenderness to be non-significant or small. Harrington and Pearson (1962) found marbling significantly correlated with increased tenderness in pork. Marbling and tenderness in pork muscle were reported to be positively correlated by Batcher and Dawson (1960); however, in a later study (Batcher et al., 1962), marbling and tenderness were found to be related in only a few cases. Henry et al. (1963) reported a small but significant correlation between marbling and tenderness in pork muscle. Referring to studies of various researchers, Bray (1966) suggested that a stronger relationship exists between marbling and juiciness than between marbling and tenderness or flavor of pork chops. In beef, there is considerable evidence indicating that marbling and tenderness are not statistically related (Walter et al., 1965; Goll et al., 1965; Romans et al., 1965; and Breidenstein et al., 1968). McBee, Jr. and Wiles (1967) reported a positive linear relationship between tenderness and marbling although the increases associated with marbling, again, were found to be non-significant. In contrast to these findings, Covington et al. (1970) reported that "moderately" marbled steaks were significantly more tender than steaks with a "small" marbling score. Moody et al. (1970) studied the effect of marbling texture on the palatability of beef rib. Beef with finer-textured marbling was observed to be significantly more tender (by shear force) than beef with coarser-textured marbling although this relationship was not significant for sensory tenderness. This relationship was observed earlier by Goll et al. (1965) who reported increased tenderness in samples with finer-textured and more evenly distributed marbling. Reddy et al. (1970) attempted to relate marbling distribution and vascular distribution to beef muscle tenderness. Contrary to the Goll et al. (1965) study, no significant relationship between marbling distribution and tenderness was observed. Likewise, the number and distribution of blood vessels appeared unrelated to tenderness (Reddy et al., 1970).

Tenderness and postmortem muscle contraction state have been investigated. Locker (1960) suggested that decreased tenderness is associated with contracted muscle. Similarly, Herring et al. (1965) reported that, "when muscles shortened, there were corresponding decreases in sarcomere length, increases in fiber diameter, and decreases in tenderness." Later, Herring et al. (1967) reported the relationship of tenderness with fiber diameter to be linear and with sarcomere length, curvilinear. Howard and Judge (1968) found shorter sarcomere lengths associated with decreased tenderness but only in the medial position of the muscle. In contrast to these studies, Covington et al. (1970) observed no significant relationship between fiber diameter and tenderness in A, AB, and B maturity group cattle. In work with beef strains selected for tenderness and leanness, Field et al. (1970) found sarcomere length and fiber diameter not significantly different between the "lean" or the "tender" lines although fiber diameter tended to be larger in the "lean" line. The "tender" line was significantly more tender, by panel and Warner-Bratzler shear, than the "lean" line. Dikeman et al. (1971) reported low and non-significant correlations between sarcomere length and panel tenderness ($r = 0.26$) and shear force ($r = -.30$).

Conflicting data have been reported concerning protein solubility and tenderness. Hegarty et al. (1963) found fibrillar protein solubility and tenderness (by shear force and panel) to be highly and positively correlated. Dikeman et al. (1971) reported data which indicated the relationship between certain soluble protein fractions and tenderness was a negative one.

The type and amount of free amino acids present in muscle has been associated with tenderness. Field and Chang (1969) reported an increase in individual and total free amino acids with increasing tenderness in beef muscle. The trend, however, was not significant.

Meat is not a homogeneous material. Tenderness is known to vary between different muscles of the animal and within a particular muscle. Weir (1953) reported that samples from either the posterior or anterior regions of the longissimus dorsi in pork to be more tender than samples from the central location. Alsmeyer _et al_. (1965a, b) assessed tenderness of the dorsal (nearest the backbone), medial and lateral positions of the longissimus dorsi of pork and beef. In pork, samples from the dorsal position were less tender than those from the medial or lateral locations (Alsmeyer _et al_., 1965a, b) whereas samples from the dorsal location in beef muscle were more tender than those from the medial or lateral positions (Alsmeyer _et al_., 1965b). Similar findings with beef were reported by Walter _et al_. (1965), McBee, Jr. and Wiles (1967), Hedrick _et al_. (1968) and Covington _et al_. (1970). In contrast, Romans _et al_. (1965) found no significant correlation between core position and tenderness by shear force, and Howard and Judge (1968) reported the lateral position to measure more tender than the medial (nearer the backbone) position (by ALLO-Kramer shear).

Feasibility of Marketing Young Bulls

Retailers could better satisfy their consumer's wants and needs if a reliable means were available for predicting the cooked meat tenderness of the fresh meat products they market. Reliance on U.S.D.A. grades for carcass quality information provides the retailer with an inadequate index of individual carcass tenderness (Sperring *et al.*, 1959). Work by Cover *et al.* (1958) and Cover and Hostetler (1960) indicated that the tenderness variation within grades accounts for the low correlation between grade and tenderness. Alsmeyer *et al.* (1966) found beef tenderness to increase with carcass grade although grade accounted for only 6.9% of the variance in panel tenderness measures. Hinnergardt and Tuomy (1970) discussed the need for a non-destructive measure of raw meat tenderness which closely relates to cooked meat tenderness. Such a measure incorporated into the present U.S.D.A. grading system would make this evaluation more meaningful. Cover *et al.* (1958) discussed the need for improved U.S.D.A. standards of carcass quality.

Bulls are graded by separate standards from heifers and steers under the present U.S.D.A. grading system (U.S.D.A. SRAC&M99). There is some discussion concerning the feasibility of including young bulls in the steer and heifer grading category. The reluctance to revise the standards for this purpose is based on the premise that bull beef is of inferior palatability to steer and heifer beef. Some recent studies have indicated that bull beef is not altogether unacceptable to consumers. Field *et al.* (1964) reported lower consumer scores for bull steaks although chuck roasts from bulls were rated higher than chuck roasts from steers because of less intramuscular fat. Bailey *et al.* (1966) found a small, consistent, but not always significant difference in the tenderness of bulls and steers, steer beef being the more tender. The effect of age on tenderness of bulls and of steers and heifers was studied by Field *et al.* (1966). At 300 to 399 days, no significant differences were noted. Bulls were slightly less tender (by shear force) than steers or heifers when evaluated at the 400-499 age range. At 500-599 and 600-699 days, bulls were found to be significantly less tender ($P < .01$) than steers or heifers of the same age (Field _et al._, 1966). Hedrick _et al._ (1969) reported that tenderness scores were comparable for bulls, steers, and heifers slaughtered at less than 16 months of age. Steaks from older bulls (> 16 months of age), however, were observed to be less tender than steers or heifers of similar age (Hedrick _et al._, 1969). Champagne _et al._ (1969) compared carcass characteristics of bulls and steers which were castrated at four ages. Tenderness as measured by shear and panel was not significantly different for bulls or steers among all castration categories. Arthaud _et al._ (1969) found steers to be more tender than bulls. In addition, bulls exhibited significantly greater variations in tenderness than did steers (Arthaud _et al._, 1969). Similar results were reported by Reagan _et al._ (1971). Steer carcasses produced steaks that were significantly more tender than those from bull carcasses. Greater variability in palatability attributes was noted in steaks from bull carcasses in this study also. If a better means of separating the more tender bull carcasses from the less tender were available, the results of these studies indicate that bull beef would satisfactorily compare with beef from steers and heifers in palatability characteristics.

From a production standpoint, the advantages of marketing bulls rather than steers has long been observed. Field _et al._ (1964) reported a faster daily gain, larger loin eyes per cwt of carcass, and an increased percent in retail cuts from chuck, rib, loin, and round in young bulls than for young steers undergoing the same treatment. The cost of castration is eliminated by marketing the intact male animal. In addition, selection of young bulls for breeding stock could be postponed until some demonstration of growth potential had been observed. Some problems may be encountered due to the more agressive nature of bulls such as increased feedlot injuries and greater damage to holding facilities.

If better avenues for marketing bull beef are to become accessible, a reliable method of evaluating raw meat tenderness may be needed to insure that only carcasses of a standard degree of tenderness are selected for the fresh meat market. The success of researchers' endeavors to develop a better means of evaluating tenderness could have important economic implications for the future of the industry.

Methods of Assessing Muscle Tenderness

Numerous attempts to evaluate the tenderness attribute of muscle are reported in the literature. Extensive reviews of methods for measuring meat tenderness have been presented by Shultz (1957), Pearson (1963), and Szczesniak and Torgeson (1965). The methods discussed in this review are divided into non-mechanical and mechanical method categories.

Non-Mechanical Methods

Chemical and Histological Methods: The relative success of attempts to relate various chemical and histological analyses of muscle to tenderness was discussed earlier (Factors Affecting Muscle Tenderness). Free amino acid composition and quantity, protein solubility, water holding capacity, sarcomere length, fiber diameter, and type and amount of connective tissue are among those factors studied. Szczesniak and Torgeson (1965) give a more complete review of the chemical and histological attempts to evaluate muscle tenderness.

Sensory Panels: Because of the similarities to the actual consumer circumstance, sensory panels are often used to assess tenderness of meat. Pearson (1963) discussed the use of large scale consumer panels, small scale untrained panels, and trained panels for assessing tenderness. The triangle test was recommended for selection and training of panelists. Sensory tenderness scoring methods generally recommended were the hedonic scale and chew count methods.

Mechanical Methods

Pearson (1963) reviewed many of the mechanical methods developed to assess tenderness.

Lehman's Device: In 1907, Lehman reported on two devices designed for measuring tenderness. One instrument measured breaking strength and the other measured shear force. The latter device functioned by adding weights to a weighing pan until the shear severed the meat.

Warner-Bratzler Shear: The development of a shearing device for measuring meat tenderness was reported by Warner in 1928. Black, Warner, and Wilson, in 1931, tested the device using beef from different grades. Since Bratzler modified and improved the device, in 1932, it has been known as the Warner-Bratzler shear. Bratzler described the apparatus as follows:

> "The standardized, or revised, machine uses a shearing blade 0.04 inches in thickness. The opening in the blade is made by circumscribing an equilateral triangle about a circle one inch in diameter. The cutting or shearing edge of the opening is rounded or dulled to the radius of a circle of 0.02 inch. As most of the machines are motor driven, a shearing speed of 9 inches per minute is used. While the amount of force necessary to shear the sample is recorded on a dead hand spring dynamometer, I can see no reason why any similar recording device in pounds cannot be used."

(Bratzler, 1949). Correlations between Warner-Bratzler shear force and sensory scores generally fall between 0.60 to 0.85. Carpenter et al. (1965) evaluated tenderness of raw meat using the Warner-Bratzler shear, the denture tenderometer and the wedge tenderometer. Little association was reported between sensory tenderness and any of these methods using the raw sample. Since its development, the Warner-Bratzler shear has been one of the most widely used objective methods of evaluating meat tenderness.

The Cutting Gage: Tressler, Birdseye and Murray, in 1932, reported on the development of a device measuring the pressure required to puncture or cut meat. A blunt penetrating instrument was attached to a Schrader tirepressure gage. A 3 x 3 x 1 inch sample of meat was used for the puncture determinations.

The Penetrometer: Also in 1932, Tressler, Birdseye and Murray tested a penetrometer device which they concluded to be more useful than the cutting gage. A needle, 1 3/8 inches long, 0.15 inches in diameter, and rounded at the point to a radius of 0.07 inches, driven by a 225 gram weight, penetrated a meat sample for 15 seconds. The penetration distance was recorded in millimeters on a dial. Penetrometer results and sensory scores have not been closely related.

Child-Satorius Shear: In 1938, Satorius and Child used a shear device, similar to the Warner-Bratzler instrument, to measure tenderness. Pounds of force were recorded as shearing bars were pulled across a dull blade with a triangular opening through which the sample was placed.

The Volodkevich Tenderness Device: The Volodkevich device, described by Volodkevich in 1938, has been used extensively in Germany and other European countries. The instrument consists of two metal wedges containing artificial teeth, one wedge being stationary and the other movable, and a chart device recording the continuous pressure on the meat sample. The slope of the curve and the area under the curve have been related to tenderness.

Winkler Device: Winkler, in 1939, worked with a device similar to that of Volodkevich. Tenderness was related to the force expressed as work per unit of sample.

Motorized Christel Texturemeter: This instrument described by Miyada and Tappel in 1955 is a modification of the Christel Texturemeter. Total work and maximum shear force were recorded as shearing prongs were forced through a cylindrical sample of meat. This device has not been widely used.

The Motorized Food Grinder: A motorized food grinder was also used by Miyada and Tappel in 1955 to assess tenderness. Power consumption in watts plotted as a function of time gave the total energy expended for grinding the meat sample. Increased power consumption should be associated with less tender meat.

Recording Strain-Gage Denture Tenderometer: In 1955 and 1956, Proctor, Davison, Malecki, Welch and Brody attempted to simulate the motions of chewing with this device. Two dentures, one stationary and the other movable, were fastened to an articulator which simulated the cheeks, lips, and tongue. The force of the vertical and lateral chewing motions was recorded to give a force penetration diagram.

Kramer Shear Press: In 1951, Kramer, Amalid, Guyer and Rogers reported the development of a shear press device used for measuring tenderness. Using hydraulic pressure, a series of metal plates are forced through the sample held in a metal box. A force-time curve is produced to determine maximum force and total work. The device has undergone improvements and modifications since 1951. Replacing the Standard Shear-Compression cell and shearing blades of an ALLO-Kramer Shear-Press with penetrometer needles, Hinnergardt and Tuomy (1970) obtained significant correlations between penetration force on the raw meat sample and penetration force for the cooked sample and trained panel tenderness scores. Good correlations between the shear press and the Warner-Bratzler shear and panel tenderness scores have been reported. This device has been widely used in studies for measuring meat tenderness.

Orifice Method: Sperring, Platt and Hiner in 1958 used a modified Carver press to evaluate tenderness of meat. Pressure applied to a meat sample placed in a cylinder causes the meat to extrude from an orifice. The pressure at which the meat first appears through the orifice is related to tenderness. The method has been reported to lack accuracy.

Slice Tenderness Evaluator: This device, described by Alsmeyer, Kulwich and Hiner in 1962, produces a force-penetration curve by puncturing, then shearing off the sample slice of meat. Alsmeyer *et al.* (1966) modified the instrument and reported that both the original model and the modified model correlated significantly with panel tenderness.

The Armour Tenderometer: Hansen (personal communication, Dr. Leo J. Hansen, 1970) developed a non-destructive probe-type tenderometer suitable for assessing tenderness at 24 hours postmortem in a packer's cooler. The device is described in the operating instructions by the following:

> "This instrument consists of a probe assembly and a read-out box. The probe assembly contains ten penetration needles mounted on a manifold which is in turn attached to an electronic strain gauge. The probe assembly also contains a handle for holding it, and an inverted U shaped member to serve as a penetration stop indicator. The strain gauge on the probe assembly is connected to the electronic read-out box by means of a cable."

During the developmental stages, different types of probes were tested (shear blade, ball, needle and small blunt probes) using an Instron testing machine. The needle was found to give the best repeatability with Warner-Bratzler scores for tenderness. Further testing revealed that a 10 needle probe had the lowest standard error due to internal differences in muscle tenderness.

To evaluate tenderness, the tenderometer is inserted into the rib-eye muscle of carcasses chilled to 0°-4°C (32°-40°F) (generally 24 hours postmortem). Below 0°C (32°F), ice crystals may cause readings to be erroneously high. Above 4°C (40°F), intramuscular fat may not be completely solidified resulting in erroneously low readings. Care must be taken to avoid penetration of the connective tissue sheath on the muscle which would cause the reading to be high. The probe is held perpendicular to the surface and pushed straight into the rib-eye muscle until the needles have penetrated to a depth of two inches (when penetration stops touch the surface of the muscle). Resistance to insertion is indicated as pounds of force on the strain gauge recorder. Research at Armour and earlier work at North Dakota State University showed that tenderness of the longissimus dorsi muscle is indicative of carcass tenderness. Beef carcasses are normally cut across the longissimus dorsi at the 12th and 13th rib position, making a tenderometer measure at this position optimal from the standpoint of practicality and as an estimator of carcass tenderness.

Armour researchers reported a correlation of 0.56 between tenderometer carcass readings and Warner-Bratzler shear force on the cooked sample and correlations of 0.77 (U.S.D.A. Choice grade beef) and 0.70 (U.S.D.A. Good grade beef) between tenderometer readings and panel tenderness scores.

The following scale is used commercially to interpret tenderometer readings:

Choice Grade Beef $<$ 18 pounds of resistance - moved directly to store
18 to 23 pounds of resistance - aged for 14 to 18 days
$>$ 23 pounds of resistance - ground or otherwise processed.

Should this device prove a reliable measure of cooked tenderness of carcass cuts, it should see broad commercial application and possible use as a determinant of federal grades.

EXPERIMENTAL PROCEDURES

The performance of the tenderometer (probe type serial number 62445, indicator serial number 1002; Armour and Company, Oak Brook, Illinois) was compared as an indicator of tenderness of beef and pork with the Warner-Bratzler shear, the ALLO-Kramer shear-press, and taste panel methods of measuring tenderness. The effect of the PSE (pale, soft and exudative) condition on pork tenderness was studied. Differences in beef tenderness readings due to differences in tenderometer operator technique, due to the sex of the animals (bulls and steers), and due to other carcass attributes were tested.

Data were collected from forty-five Michigan State University Experiment Station hogs, twenty-three steers and twenty bulls from a commercial feedlot, and eighteen bulls from a herd of cattle selectively bred for tenderness and/or leanness over a period of twelve years at Michigan State University. The hogs were of varying breeds, had been fed the same ration, and were slaughtered at approximately 6 months of age -- between 190 to 220 pounds live weight. The feedlot bulls and steers were of similar background in age, breeding and feedlot treatment. The bulls ranged from 15 to 24 months in age and the steers were assumed to be of similar age although the exact ages for this group were not known. The bulls selected for tenderness and/or leanness were slaughtered at approximately 12 months of age. Separate experimental procedures are presented for each of the animal groups. Measurements on the raw carcass and on a cooked portion of the longissimus dorsi muscle were collected to observe some of the factors affecting tenderness.

Pork

Cold carcass weight was recorded in pounds for each of the forty-five hogs. A roast was taken from the right loin, beginning at the 10th rib and measuring seven inches toward the posterior end of the loin. The tenderometer was adapted for use on the smaller pork loin-eye muscle by removing four needles, two from either end of the probe. Tenderometer readings (pounds of resistance) were taken on the 10th rib facing of the roast and into the remaining loin (seven inches posterior to the 10th rib cut). Visual scores estimating the degree to which the roast exhibited the PSE condition were recorded. Based on an appraisal of marbling, color, and firmness, the roasts were ranked on a 0-15 point scale (0-5, PSE; 6-10, Intermediate; 11-15, Normal). The roasts were cooked in a 149°C (300°F) convection oven to an internal temperature of 74-75°C (165-167°F). The roasts were held overnight at refrigerator temperature; the following morning, the longissimus dorsi was removed. After trimming away the browned edges, the muscle was divided according to the following scheme:

	5/8"	1" slices				
BLADE END <--	*	1	2	3	4	--> LOIN END

A 5/8 inch slice (*) was wrapped in foil, refrigerated, and later trimmed to a weight of 30 grams and evaluated for tenderness using an ALLO-Kramer shear press with standard shear compression cell and a TR-1 Recorder (Food Technology Corporation). Two readings recorded as pounds per gram were taken per sample. Three 1/2 inch diameter cores were taken from the dorsal (nearest the backbone), medial, and lateral position of chops 1 through 4 (see schematic). Using the Warner-Bratzler shear, three readings in pounds of shear force were recorded for each core. The sheared cores from each chop were wrapped in foil. Later, 30 gram, if possible, samples were weighed and subjected to evaluation by ALLO-Kramer shear press. Again, two readings were taken per sample.

After core removal, the remaining portion of chops 1 through 4 were divided into five samples for sensory tenderness evaluation. Twenty untrained panelists scored the samples according to a 9-point hedonic scale (9 = Extremely tender, 1 = Extremely tough).

Young Bulls and Steers

The following carcass measures were obtained in the packer's cooler from steers approximately 56 hours postmortem and from bulls approximately 30 hours postmortem.

1. Cold and/or hot carcass weights in pounds.
2. Right and left rib eye areas in square inches.
3. External fat over the rib eye in inches (right side).
4. Estimate of % kidney, heart and pelvic fat.
5. Tenderometer readings in pounds (two operators, testing alternate left and right sides).

6. Maturity level estimates.

7. Marbling scores (12th-13th rib cut; to the nearest 1/3 of a division).

8. U.S.D.A. Grade (quality grade estimate - based on steer standards).

9. Texture of marbling scores (5 = very coarse, 3 = intermediate, 1 = very fine).

10. Texture of lean scores (5 = very coarse, 3 = intermediate, 1 = very fine).

11. Color scores (5 = dark, 3 = normal, 1 = pale).

Average rib eye areas, carcass yield grades, and the quality grades for bulls were calculated from measurements and scores of carcass characteristics. Marbling scores, texture scores, and color scores were adjusted to a 15-point numerical scale for analytical purposes.

Three-rib roasts (10, 11, 12th ribs) were removed from the right sides and stored overnight in a cooler at the Meat Laboratory, Michigan State University. Before trimming and wrapping for freezer storage, additional tenderometer measures were obtained (again, at the 12-13th surface by a third operator and at the 9-10th cut by one of the original two operators). Marbling scores at the 9-10th rib cut were recorded. After removal of the chine bone, the roasts were double bagged in cryovac bags (the outer bag evacuated and clipped) and placed in a -7°C (-20°F) blast freezer until they were to be prepared for further evaluation (over a period of 2 to 14 weeks).

Tenderness of a cooked muscle was evaluated on the roasts after freezer storage. The roasts were allowed to thaw three days at cooler temperature (2-4°C, 36-40°F) before cooking in a convection oven at 149°C

(300°F) to an internal temperature of 66-68°C (151-154°F). Following overnight refrigerator storage, the longissimus dorsi was removed and the browned edges trimmed. The muscle was divided for analysis as shown below:

1/2" 3/4" slices

BLADE END <-- * 1 2 3 --> LOIN END

A 1/2 inch slice (*) was wrapped in foil and refrigerated. Later, two 25 to 30 gram samples were obtained from this slice and evaluated for tenderness using the ALLO-Kramer shear press in the manner described for pork. Warner-Bratzler shear values were recorded by steak (1, 2 and 3) and by core position (dorsal, medial and lateral) within the rib eye muscle. The 1/2" diameter sheared cores were saved for shear press analysis as was done with pork.

The remaining portion of steaks 1, 2 and 3 (after core removal) were divided into seven samples each for presentation to a taste panel. Twenty-one untrained panelists scored the samples for tenderness using the 9-point hedonic scale described earlier.

Bulls Selected for Tenderness and Leanness

Preliminary work with the tenderometer was carried out on eighteen young bulls slaughtered at the Meat Laboratory, Michigan State University. These animals were being evaluated for tenderness and lean meat yield as a part of a breeding improvement study (selection progress for tenderness and leanness) being conducted by the Department of Animal Husbandry, Michigan State University. Tenderometer readings were taken 48 hours postmortem on the right and left sides at the 12-13th rib cut by one operator. Seven days later, two steaks were removed from the rib and two additional tenderometer readings were taken by a second operator at this position. Warner-Bratzler shear values and taste panel scores for tenderness of steaks cooked in deep fat (138°C, 280°F) to an internal temperature of 63°C (145°F) were obtained for comparison with tenderometer tenderness measures on these animals.

Statistical Methods

A major portion of the data analyses for this study was calculated using Agricultural Experiment Station STAT routines programmed for the CDC 3600 computer, Michigan State University Computer Laboratory. Basic statistics including means, sums, sums of squared deviations from the means, and simple correlations between all variables, were calculated for all experimental groups using the MDSTAT (Basic statistics involving missing data) routine. Calculations of partial correlation coefficients (the association between two variables when the effect of another selected variable is held constant) were made when it was felt that this analysis would yield pertinent information. Partial correlation coefficients for some of the data were hand calculated using the following formula from Snedecor and Cochran (1967):

$$r_{12.3} = \frac{r_{12} - r_{13}\, r_{23}}{\sqrt{(1-r_{13}{}^2)(1-r_{23}{}^2)}}$$

where $r_{12 \cdot 3}$ = partial correlation coefficient

1 and 2 = components of the correlation coefficient being tested

3 = parameter held constant

An analysis of variance was made of Warner-Bratzler shear values on cores from three positions across the rib eye muscle (pooled data, bulls and steers). This analysis was hand calculated using the procedure for single classification analysis of variance as described by Sokol and Rohlf (1969). The STAT routine; UNEQ1, unequal frequency, single classification analysis of variance, was used to determine if differences existed between the bull and steer groups in the measurements of the various characteristics.

Pooled data from the young bulls and steers were subjected to least squares analysis (STAT routine, LSDEL, least squares with automatic stepwise deletion of variables from a least squares equation). A prediction equation for Warner-Bratzler shear value was obtained from a total of forty samples for which there was no missing data. The criterion for deletion from the equation was the significance of the partial F statistic. A partial F significance of .10 was specified as the requirement for deletion in this analysis.

RESULTS AND DISCUSSION

Preliminary Work with the Tenderometer

Simple correlation coefficients between measures of tenderness on eighteen bulls from a herd selectively bred for tenderness and/or leanness are presented in Table 1. Data from this table indicate that the tenderometer readings of the two operators (on two muscle portions, over a seven day period) were significantly related to each other. Readings taken on the 12-13th rib cut (two days postmortem, operator 1) were more closely associated with tenderness as measured by the Warner-Bratzler and taste panel methods than were the alternate set of tenderometer readings. Warner-Bratzler shear and taste panel scores for tenderness

Table 1. Simple correlation coefficients between measures of tenderness on young bulls selected for tenderness and/or leanness.

	Tenderometer				Warner-Bratzler shear
	Operator 1		Operator 2		
	Left	Right	Left 1	Left 2	
Tenderometer					
Left side[a], Operator 1					
Right side[a], Operator 1	0.77**				
Left side 1[b], Operator 2	0.64**	0.53*			
Left side 2[b], Operator 2	0.38	0.58*	0.67**		
Warner-Bratzler shear	0.47*	0.53*	0.02	0.28	
Taste panel	-.50*	-.50*	-.03	-.28	-.76**

[a]12-13 rib cut, 2 days postmortem.
[b]Two steaks removed, 9 days postmortem.
* $P < .05$
** $P < .01$

exhibited a close relationship ($r = -.76^{**}$). Although the percentage of the variance in shear force or panel scores associated with corresponding variance in tenderometer readings ($r^2 \approx .25$) was not very high, the data indicated that the tenderometer was of value in selecting for tenderness of beef. Thus further study was indicated.

Pork Group

The modified 6-needle probe tenderometer was of questionable value in predicting pork tenderness. The simple correlation coefficients between measures of tenderness, presented in Table 2, indicate that although the tenderometer readings from two positions on the loin were highly related ($r = 0.79^{**}$), no significant association was exhibited between these readings and measures of tenderness on the cooked sample (Warner-Bratzler shear, ALLO-Kramer shear press, and taste panel). The positive

Table 2. Simple correlation coefficients between measures of tenderness on pork loin roasts.

	Tenderometer		Warner-Bratzler shear	ALLO-Kramer shear press	
	(10th rib cut)	(loin end)		(Slice)	(Cores)
Tenderometer					
(on 10th rib cut)					
(on loin end)	0.79**				
Warner-Bratzler shear	-.02	-.18			
ALLO-Kramer shear press					
(slice)	-.10	-.15	0.73**		
(cores)	0.00	-.11	0.85**	0.82**	
Taste panel	-.01	0.10	-.89**	-.76**	-.89**

* P < .05
**P < .01

relationship between the mechanical methods of measuring tenderness of the cooked sample were highly significant ($P < .01$). The Warner-Bratzler shear and the ALLO-Kramer shear press (on slices and cores) demonstrated a close association with sensory tenderness evaluations (r = -.89**, -.76** and -.89**, respectively). These data indicate that the use of the Warner-Bratzler or ALLO-Kramer devices to measure tenderness of pork loin roasts appears to be strongly justified especially where size of available sample is small or taste panel evaluation is not feasible.

The lack of association between tenderometer scores for tenderness on the raw pork sample and tenderness evaluations on the cooked sample could result in part from alterations of the tenderometer's sensitivity due to needle number reduction. The developers of the device reported optimum sensitivity with a 10-needle probe when measuring beef tenderness (personal communication, Dr. Leo J. Hansen. 1970). Because the pork loin eye area is normally much smaller than the area of a beef rib eye, four needles were removed from the probe, in this study, to allow muscle penetration without interference from the surrounding bone or connective tissue. This modification may have affected the tenderometer's sensitivity to tenderness.

The severity of the PSE (pale, soft and exudative) condition of the muscle may have influenced the tenderometer readings. While taking tenderometer readings on the pork loins, it was noted that some "softer" muscles were unable to maintain their normal shape, thus, in effect, "sinking" into the bone/connective tissue sheath when held in the vertical position for probing. An accurate measure on these softer muscles was difficult to obtain. Sometimes the bone/connective tissue sheath "stopped" the probe before the full two inch insertion into the sunken muscle could be obtained. Also, the "sinking" behavior could have affected certain physical characteristics such as muscle density, contraction state, fiber diameter, or sarcomere length. These changes might influence the tenderometer's assessment of tenderness. An association between tenderness and contraction state, fiber diameter and sarcomere length has been reported (Locker, 1960; Herring et al., 1965).

Data from Table 3 show that lower PSE scores (increased PSE severity) were significantly associated with lower Warner-Bratzler shear values (increased tenderness). The same tendency was shown with taste panel scores although the association was not significant at the .05 level. This relationship between tenderness (by shear and panel) and the PSE

Table 3. Simple correlation coefficients between carcass traits and measures of tenderness on pork loin roasts.

Measures of tenderness	Tenderometer (10th rib cut)	Tenderometer (loin end)	Warner-Bratzler shear	ALLO-Kramer shear press (Slice)	ALLO-Kramer shear press (Cores)	Taste Panel
PSE score	-.28	-.38*	0.38*	0.15	0.09	-.30
Cold carcass weight	-.10	-.11	0.06	0.08	0.07	0.00

* P < .05
**P < .01

condition agrees with work at Michigan State University (personal communication, Dr. R. A. Merkel, 1971). The opposite effect with PSE and tenderness was indicated by tenderometer data; however, the tenderometer demonstrated a rather poor ability to measure pork tenderness in this study. Because of the problems encountered when taking a tenderometer reading on pork, the resulting evaluation of tenderness would be highly questionable. The Warner-Bratzler, ALLO-Kramer and panel methods were felt to be the more reliable ones for use on pork loin based on the realtionships shown in Table 2.

When the effect of PSE score was held constant, the ability of the tenderometer to predict Warner-Bratzler shear or taste panel tenderness evaluations apparently improved slightly (partial correlation coefficients, PSE score held constant) although changes in the magnitude of the correlations were small.

It appears from these data that the PSE condition may influence the accuracy of the tenderometer's evaluation of pork muscle tenderness --probably due to the abnormal behavior of the muscle when held in the vertical position for probing.

Cold carcass weight was not significantly associated with any of the measures of tenderness. No relationship between this factor and tenderness would be expected for these data since the hogs analyzed fell into a narrow weight range (slaughtered between 190-220 lb; cold carcass weight ranged from 124-193.4 lb, SD 11.3 lb).

Beef Group

The simple correlation coefficients presented in Table 4 show that all tenderometer readings on beef were associated at the .01 level of significance. Apparently, any differences due to using three operators at two positions did not critically alter the tenderometer's ability to

Table 4. Simple correlation coefficients between measures of tenderness on beef rib roasts.

	Tenderometer				Warner-Bratzler shear	ALLO-Kramer shear press	
	12-13 rib			9-10 rib			
	Operator 1[a]	Operator 2[a]	Operator 3[b]	Operator 2[b]		(Slices)	(Cores)
Tenderometer							
(12-13 rib[a] Operator 1)							
(12-13 rib[a] Operator 2)	0.70**						
(12-13 rib[b] Operator 3)	0.64**	0.47**					
(9-10 rib[b] Operator 2)	0.61**	0.49**	0.58**				
Warner-Bratzler shear	0.51**	0.47**	0.54**	0.40*			
ALLO-Kramer shear press							
(Slices)	0.42**	0.39*	0.46**	0.27	0.91**		
(Cores)	0.45**	0.42**	0.48**	0.34*	0.93**	0.90**	
Taste panel	-.51**	-.50**	-.61**	-.36*	-.89**	-.93**	-.87**

[a]approximately 30-56 hours postmortem.
[b]approximately 52-72 hours postmortem.
* P < .05
**P < .01

estimate tenderness. Generally, tenderometer readings were significantly associated with the mechanical and subjective measures of tenderness on the cooked beef sample. Correlation coefficients between tenderometer measures and the Warner-Bratzler shear ranged from 0.40* to 0.54**. Correlation coefficients between ALLO-Kramer shear press readings and tenderometer readings ranged from 0.27 to 0.48**. The type of sample (slices or cores) used for ALLO-Kramer shear press analysis apparently had little effect on the device's estimate of tenderness. The tenderometer and taste panel methods correlated over a range of -.36* to -.61**. It appears that for the beef group studied (young bulls and steers of similar background) the tenderometer exhibited some predictive value for tenderness determinations.

As was noted in the pork study, the mechanical measures on the cooked sample were highly correlated (Warner-Bratzler shear vs. ALLO-Kramer shear press; slices and cores r = 0.91** and 0.93**, respectively). These mechanical measures were highly successful in predicting taste panel tenderness (r = -.89**, -.93**, -.87** for Warner-Bratzler shear, ALLO-Kramer shear press slices and cores, respectively). As indicated by these data, mechanically obtained values of shear resistance on cooked muscle were generally better criteria for assessing tenderness than tenderometer readings on raw muscle.

Tables 5 and 6 contain the simple correlation coefficients between the measures of tenderness when the beef group was divided into bull and steer categories. A significant association between the raw sample

Table 5. Simple correlation coefficients between measures of tenderness on rib roasts from twenty young bulls.[1]

	Tenderometer 12-13 rib Operator 1[a]	Tenderometer 12-13 rib Operator 2[a]	Tenderometer 12-13 rib Operator 3[b]	Tenderometer 9-10 rib Operator 2[b]	Warner-Bratzler-shear	ALLO-Kramer shear press (Slices)	ALLO-Kramer shear press (Cores)
Tenderometer							
(12-13 rib[a] Operator 1)							
(12-13 rib[a] Operator 2)	0.51*						
(12-13 rib[b] Operator 3)	0.42	0.12					
(9-10 rib[b] Operator 2)	0.55**	0.32	0.32				
Warner-Bratzler shear	0.58**	0.42	0.36	0.01			
ALLO-Kramer shear press							
(slices)	0.46*	0.36	0.22	-.19	0.88**		
(cores)	0.58**	0.43	0.32	0.02	0.90**	0.86**	
Taste panel	-.59**	-.49*	-.36	0.04	-.88**	-.90**	-.82**

[a]approximately 30-56 hours postmortem.
[b]approximately 52-72 hours postmortem.
[1]Tenderometer vs shears and panel, n = 19.
* $P < .05$
** $P < .01$

Table 6. Simple correlation coefficients between measures of tenderness on rib roasts from young steers.[1]

	Tenderometer				Warner-Bratzler shear	ALLO-Kramer shear press	
	12-13 rib			9-10 rib			
	Operator 1[a]	Operator 2[a]	Operator 3[b]	Operator 2[b]		(Slices)	(Cores)
Tenderometer							
(12-13 rib[a] Operator 1)							
(12-13 rib[a] Operator 2)	0.73**						
(12-13 rib[b] Operator 3)	0.67**	0.62**					
(9-10 rib[b] Operator 2)	0.45*	0.44*	0.50*				
Warner-Bratzler shear	0.02	0.18	0.05	-.09			
ALLO-Kramer shear press							
(slices)	-.14	-.09	0.04	-.20	0.53*		
(cores)	-.27	-.08	0.00	-.23	0.67**	0.66**	
Taste panel	-.08	-.17	-.51*	0.07	-.31	-.68**	-.48*

[a]approximately 30-56 hours postmortem.
[b]approximately 52-72 hours postmortem.
[1]n = 20 for all comparisons except tenderometer, operators 1 vs 2 at the 12-13 rib position where n = 23.
* $P < .05$
**$P < .01$

tenderometer readings (comparing operators and locations) on steers was observed whereas this relationship was generally not significant for measures on the bull category. Between raw sample measures and cooked sample measures, correlations were generally very low for the steer category. Raw measures at the 12-13 rib position (30-56 hours postmortem) and cooked sample measures on the bulls were related to a degree that was significant or approached significance. The relationship between mechanical methods on the cooked sample and between these measures and the subjective analysis was generally significant for both the bull and steer categories; however, it is interesting to note that the correlations tended to be higher for the bulls than for the steers (bulls, between mechanical measures, r = -.86** to -.90** and between mechanical and subjective measures, r = -.82** to -.90**; steers, between mechanical measures, r = 0.53* to 0.67** and between mechanical and subjective measures, r = -.31 to -.68**). These differences between simple correlation coefficients for bulls and for steers would be somewhat indicative of the greater variability in tenderness of the bull sample. Variance in tenderness; by Warner-Bratzler, ALLO-Kramer and panel methods; was greater in the bull group. It would be expected then that correlations between the different methods of measuring tenderness would improve with greater sample variation.

The influence of various carcass characteristics on the ability of the tenderometer to predict tenderness was examined. Partial correlation coefficients were calculated to reveal changes in the magnitude of correlations between the tenderometer and the Warner-Bratzler shear and taste panel evaluations of tenderness when the effect of some carcass trait was held constant. These data are shown in Table 7.

Hot carcass weight apparently had little or no influence on tenderometer measures. Since the animals used in this study fell into a rather narrow weight range (500-726 lb, SD 57.6 lb), this parameter would not be expected to influence tenderness to any great degree. Likewise, little change in the tenderometer vs Warner-Bratzler or taste panel measures was noted when marbling scores at the 10th rib cut, texture of the lean, or color scores were held constant. Removing the effects of marbling, at the 12-13 rib cut, and of marbling texture appear to slightly enhance the tenderometer's predictability for tenderness. This type of effect was reasonable since higher degrees of marbling apparently tend to increase tenderometer readings (indicating toughness) although marbling was shown in this study to be associated with increased tenderness.

To determine if the bull and steer groups differed in tenderness and other carcass characteristics an analysis of variance of the bull and steer data was calculated. The means, standard deviations and significance of the variance are presented in Table 8. From these data it appears that the two groups did not differ significantly in hot carcass weights or texture parameters (of marbling and of lean). All other carcass measures analyzed were significantly different for the two groups. The means indicated that the bulls had larger rib eye areas,

Table 7. Partial correlation coefficients between tenderometer readings and Warner-Bratzler shear and taste panel measures on beef when certain carcass traits are held constant.

	Simple correlation coefficient	Carcass traits held constant: Hot carcass weight	Rib eye area	Yield grade	Marbling: 12-13 rib cut	Marbling: 9-10 rib cut	Texture: of marbling	Texture: of lean	Color
Warner-Bratzler shear vs tenderometer operator/position[a]									
1	0.51**	0.49**	0.47**	0.37*	0.59**	0.45**	0.58**	0.53**	0.54**
2	0.47**	0.50**	0.41**	0.40*	0.62**	0.48**	0.53**	0.46**	0.49**
3	0.54**	0.53**	0.36*	0.36*	0.48**	0.46**	0.60**	0.56**	0.50**
4	0.40*	0.40*	0.25	0.14	0.45**	0.40*	0.45**	0.40*	0.33*
Taste panel vs tenderometer operator/position[a]									
1	-.51**	-.50**	-.47**	-.38*	-.62**	-.46**	-.57**	-.50**	-.52**
2	-.50**	-.52**	-.45**	-.43**	-.66**	-.55**	-.54**	-.52**	-.51**
3	-.61**	-.60**	-.58**	-.48**	-.59**	-.57**	-.66**	-.60**	-.58**
4	-.36*	-.36*	-.24	-.12	-.42**	-.36*	-.40*	-.37*	-.29

[a]1. Operator 1, 12-13 rib cut, 30-56 hours postmortem.
2. Operator 2, 12-13 rib cut, 30-56 hours postmortem.
3. Operator 3, 12-13 rib cut, 52-72 hours postmortem.
4. Operator 2, 9-10 rib cut, 52-72 hours postmortem.

* $P < .05$

**$P < .01$

Table 8. Analysis of variance of some carcass traits between young bulls and young steers.

		Bulls[a]		Steers[b]		Significance * P < .05 ** P < .01
		Means	(SD)	Means	(SD)	
1.	Hot carcass weight	614.0	(59.7)	610.4	(57.0)	N.S.
2.	Rib eye area	13.78	(1.20)	11.83	(0.63)	**
3.	External fat over rib eye	.31	(0.14)	.63	(0.14)	**
4.	Kidney, heart, pelvic fat	2.52	(0.34)	3.53	(0.37)	**
5.	Yield grade	1.74	(0.55)	3.30	(0.52)	**
6.	Marbling (12-13 rib cut)	11.9	(3.6)	17.6	(4.0)	**
7.	(9-10 rib cut)	9.9	(4.4)	15.4	(2.1)	*
8.	Texture (of marbling)	8.2	(1.8)	8.7	(2.0)	N.S.
9.	(of lean)	7.8	(1.6)	7.9	(1.5)	N.S.
10.	Color	9.9	(1.6)	7.9	(1.4)	**
	Tenderometer readings[c]					
11.	1	21.52	(2.99)	18.46	(3.15)	**
12.	2	20.15	(2.52)	17.76	(2.53)	**
13.	3	19.60	(3.02)	16.12	(2.78)	**
14.	4	16.35	(2.00)	13.82	(1.76)	**
15.	Warner-Bratzler shear	8.61	(1.41)	6.19	(0.61)	**
	ALLO-Kramer shear press					
16.	(slices)	60.42	(12.98)	41.78	(5.75)	**
17.	(cores)	62.65	(13.89)	44.63	(5.29)	**
18.	Taste panel	5.62	(1.10)	7.31	(0.57)	**

[a]All measures on bulls, n = 20.

[b]On steers, n = 23 for measures 1-6 and 8-12 and n = 20 for measures 7 and 13-18.

[c]1. Operator 1, 12-13 rib cut, 30-56 hours postmortem.
2. Operator 2, 12-13 rib cut, 30-56 hours postmortem.
3. Operator 3, 12-13 rib cut, 52-72 hours postmortem.
4. Operator 2, 9-10 rib cut, 52-72 hours postmortem.

less fat, a lower yield grade, less marbling, were of darker color and were less tender than the steers. A greater variation in tenderness was noted within the bull group, significant at the .01 level, than was found in the steer group. The two groups differed in U.S.D.A. grade assignment as follows:

	Prime	Choice	Good	Standard
Bulls	0	5	13	2
Steers	2	18	3	0

Maturity scores and U.S.D.A. grades were not included in the tenderness analysis. Maturity scores were essentially the same for the entire beef group and should have exerted no significant influence on the tenderness attribute. The U.S.D.A. grades were assigned to the nearest one-third of a grade based on subjective evaluations of marbling, maturity and conformation. The influence of marbling was included in the analysis; as stated, the samples varied little in maturity ratings. Conformation is reported to have little association with tenderness (Pearson, 1966). Although the somewhat arbitrarily assigned grades were deleted from the computational data, it was felt that the components of the U.S.D.A. grade that were pertinent to tenderness (or that were held constant) were included in the analysis.

The effect of various carcass characteristics on the tenderness attribute in beef were studied. Simple correlation coefficients between tenderness measures and various carcass traits are presented in Table 9. As would be expected because of the rather narrow range of carcass weight of the beef samples, hot carcass weight exhibited little association with

Table 9. Simple correlation coefficients between carcass traits and measures of tenderness on beef rib roasts.[1]

	Hot carcass weight	Rib eye area	Yield grade	Marbling 12-13 rib cut	Marbling 9-10 rib cut	Texture of marbling	Texture of lean	Color
Tenderometer								
(12-13 rib[a] Operator 1)	-.17	0.23	-.38*	-.08	-.28	0.19	0.09	0.07
(12-13 rib[a] Operator 2)	0.03	0.27	-.28	0.02	-.16	0.15	-.08	0.08
(12-13 rib[b] Operator 3)	-.14	0.25	-.44**	-.29	-.32*	0.14	0.13	0.24
(9-10 rib[b] Operator 2)	-.02	0.46**	-.45**	-.08	-.15	0.15	-.05	0.26
Warner-Bratzler shear	-.19	0.43**	-.69**	-.62**	-.64**	-.24	-.12	0.45**
ALLO-Kramer shear-press								
(Slices)	-.16	0.35*	-.62**	-.68**	-.69**	-.28	0.06	0.41*
(Cores)	-.20	0.44**	-.65**	-.64**	-.63**	-.30	-.06	0.44**
Taste panel	0.16	-.35*	0.62**	0.68**	0.70**	0.19	-.12	-.37*

[a]approximately 30-56 hours postmortem.
[b]approximately 52-72 hours postmortem.
[1]n = 40 for all comparisons except those with tenderometer operator 1 and 2 at the 12-13 rib position where n = 43.
* $P < .05$
** $P < .01$

the tenderness attribute; no correlations were significant. As measured on the cooked beef sample, tenderness was significantly associated with smaller rib eye areas. The correlations with raw meat measures (tenderometer) were lower and generally not significant. The calculated yield grade factor generally exhibited a highly significant negative association with tenderness of beef. Marbling scores at both positions were generally not significantly correlated with the tenderometer's estimate of tenderness but highly significantly related to tenderness by all measures of this attribute on the cooked sample. These data indicate that both animal fatness, as indicated by yield grade, and intramuscular fat are positively associated with tenderness.

It is interesting to note that when analyzed by groups, increased marbling was associated with increased tenderometer readings, (decreased tenderness) although the opposite effect was indicated by the other measures of steer group tenderness. (See Table 11). This contradiction was not observed for the bull group (Table 10). To further investigate those relationships, partial correlation coefficients (by group) between the tenderometer measure and the Warner-Bratzler shear measure, marbling held constant, were calculated. It appeared that most of the change in tenderometer and Warner-Bratzler shear correlations attributable to marbling effects arose from the steer data where the degree of marbling was of significantly greater magnitude. As previously noted, this was a reasonable or expected effect of marbling on tenderometer values. Therefore, adjustment for marbling in the selection of tender carcasses

Table 10. Simple correlation coefficients between carcass traits and measures of tenderness on young bulls.[1]

	Hot carcass weight	Rib eye area	Yield grade	Marbling 12-13 rib cut	Marbling 9-10 rib cut	Texture of marbling	Texture of lean	Color
Tenderometer								
(12-13 rib[a] Operator 1)	-.53*	-.36	-.10	-.20	-.34	-.06	-.01	-.01
(12-13 rib[a] Operator 2)	-.07	-.19	-.16	0.08	-.06	0.03	-.24	-.03
(12-13 rib[b] Operator 3)	-.27	-.47*	-.11	-.04	-.06	0.01	-.04	0.18
(9-10 rib[b] Operator 2)	-.23	-.12	0.16	0.38	0.22	0.20	-.09	0.08
Warner-Bratzler shear	-.23	-.24	-.01	-.28	-.32	-.10	-.08	0.02
ALLO-Kramer shear press								
(Slices)	-.29	-.32	-.03	-.42	-.48*	-.20	0.20	0.10
(Cores)	-.28	-.04	-.20	-.32	-.35	-.20	-.02	0.17
Taste panel	0.35	0.42	0.02	0.40	0.50*	0.06	-.17	-.06

[a]approximately 30-56 hours postmortem.
[b]approximately 52-72 hours postmortem.
[1]n = 20.
*$P < .05$

Table 11. Simple correlation coefficients between carcass traits and measures of tenderness on young steers.[1]

	Hot carcass weight	Rib eye area	Yield grade	Marbling 12-13 rib cut	Marbling 9-10 rib cut	Texture of marbling	Texture of lean	Color
Tenderometer								
(12-13 rib[a] Operator 1)	0.06	0.13	0.08	0.63**	0.58**	0.55**	0.24	-.48*
(12-13 rib[a] Operator 2)	0.20	0.12	0.16	0.64**	0.49*	0.39	0.08	-.41*
(12-13 rib[b] Operator 3)	0.53*	0.30	-.06	0.25	0.20	0.55**	0.41	-.44*
(9-10 rib[b] Operator 2)	0.37	0.55**	-.03	0.62**	0.67**	0.42	0.03	-.39
Warner-Bratzler shear	-.25	-.04	-.57**	-.26	-.43	-.18	-.24	0.03
ALLO-Kramer shear press								
(Slices)	0.11	0.01	-.26	-.49*	-.44*	-.18	0.01	-.14
(Cores)	-.07	0.02	-.48*	-.61**	-.60**	-.37	-.11	-.02
Taste panel	-.24	-.18	0.18	0.50*	0.43	0.06	-.33	0.29

[a]approximately 30-56 hours postmortem.
[b]approximately 52-72 hours postmortem.
[1]n = 20 for all comparisons except those with tenderometer operator 1 and 2 at the 12-13 rib position where n = 23.
* $P < .05$
** $P < .01$

by tenderometer is strongly indicated. By removing yield grade and rib eye area, slight reductions in the tenderometer's predictiveness were observed. An explanation for this effect (if real) was not apparent. It should be noted that none of the carcass traits presented in Table 7 appear to exert any great degree of influence on the performance of the tenderometer.

Low, non-significant correlations between the texture measures (of marbling and of lean) and tenderness were observed (Table 9). Also from Table 9, it appears that a darker color (higher color score) was associated with decreased tenderness as indicated by the Warner-Bratzler shear (higher shear force) and by taste panel (lower hedonic rating). This relationship is consistent with data from Table 8 which indicated that the darker colored muscle from bulls was also less tender than the samples from the steer group. The reason for the differences in color was not apparent.

To test for tenderness differences within the longissimus dorsi, an analysis of variance in tenderness of cores from three positions across the longissimus was calculated. It appeared from the analysis that, in this study, no differences in tenderness (by Warner-Bratzler shear) were exhibited due to core position within the muscle. Lateral, medial, and dorsal positions were tested (dorsal being nearest the backbone).

A prediction equation for tenderness by Warner-Bratzler shear was obtained by a least squares analysis (deletion, r_{α_S} .10). Of the variables tested, those deleted from the equation were (in order of deletion) rib eye area, percent kidney, heart and pelvic fat, hot carcass weight, color, external fat, and tenderometer score (13th rib, operator 2). The remaining variables (texture of the lean, marbling and tenderometer scores at the 13th rib) are presented in the prediction equation:

$$\text{Warner-Bratzler shear force} = 7.62 - [(-.20)(\text{marbling score}) + (-.22)(\text{texture of lean}) + (0.23)(\text{tenderometer})]$$

For a narrow range of size, hot carcass weight and maturity, marbling and tenderometer scores at the 13th rib and texture of the lean appear to be useful for predicting Warner-Bratzler shear measures of tenderness on beef. The multiple correlation coefficient for this equation indicated that approximately 64% ($R^2 = .64$) of the variation in Warner-Bratzler shear force could be predicted by the combination of carcass evaluations shown in the above equation.

The standard partial regression coefficients (b' or beta weights) for parameters in this equation indicated that marbling and tenderometer scores at the 13th rib were the most important parameters (b' = -.60 and 0.48, respectively). A lower standard partial regression coefficient for the texture parameter was obtained (b' = -.22). Thus it was indicated that for a group of beef carcasses with similar weight and in the young or intermediate maturity range, marbling and tenderometer evaluation could be used to significant advantage in selecting carcasses for the tenderness attribute. The reliability of the evaluation of beef tenderness based on subjective evaluation of raw carcass traits was significantly improved by including the objective values obtained with the tenderometer.

SUMMARY

Results of this study indicated that the tenderometer may be of significant value in predicting tenderness from measures on the raw beef carcass. For the beef sample selected in this study (young bulls and steers of similar maturity, weight and background) the tenderometer evaluation, in combination with subjective marbling and texture evaluations, was found to account for approximately 64% of the variation in tenderness as measured by Warner-Bratzler shear on the cooked sample. Apparently, higher degrees of marbling may cause the tenderometer reading to be erroneously high indicating toughness when marbling, in this study, was otherwise shown to be associated with increased tenderness. An adjustment in tenderometer readings on highly marbled carcasses to account for this effect would be recommended.

In evaluating the cooked beef sample, the Warner-Bratzler shear and the ALLO-Kramer shear press measures were highly correlated with each other and with sensory scores for tenderness. Generally, the results of this study indicated that these mechanical measures of the cooked sample had a higher predictive value for determining sensory tenderness than did the tenderometer (raw sample evaluation). ALLO-Kramer shear press values on either slice or core sample types correlated well with the other measures of tenderness on the cooked sample. The nature of the Warner-Bratzler and ALLO-Kramer shear press methods (destructive to sample, need cooked sample, time consuming) limit their use primarily to research programs. The possibility for broad commercial and/or federal application of the tenderometer exists because of the speed with which the evaluation may be obtained (24 hours postmortem), the simplicity of the method, and the non-destructive nature of the evaluation. Thus, the use of the tenderometer might be justified when the inherent disadvantages of the other, more reliable methods (Warner-Bratzler, ALLO-Kramer and panel methods) makes their use prohibitive.

The ability of a modified tenderometer to measure tenderness of the pork loins selected for use in this study was highly questioned. The very poor association between the modified tenderometer readings and the other measures of tenderness was felt to result from a composite of factors. Removing four needles from the probe to permit insertion into the small pork loin eye muscle may have altered the sensitivity of the device. The "sinking" behavior of softer muscles, when held vertically for probing, hindered the acquisition of the tenderness reading by proper procedures. This problem suggested that tenderometer readings might be erroneously influenced by the development of the PSE (pale, soft and exudative) condition in the muscle.

As in the beef study, analysis of the cooked sample using the Warner-Bratzler and ALLO-Kramer devices were highly correlated with each other and with panel tenderness. For the hogs used in this study (similar weight and background) these methods exhibited a strong ability to predict tenderness.

The effects of the PSE condition and of cold carcass weight on the tenderness of pork loin were examined. Cold carcass weight, as expected considering the narrow weight range of the carcasses, apparently exerted

little or no influence on the tenderness attribute. Increased PSE development and increased tenderness were associated at low but positive levels as measured by Warner-Bratzler shear and panel methods (lower PSE scores; lower shear values and higher panel ratings). By tenderometer measures, the opposite relationship was found between the PSE condition and tenderness. However, the unreliability of the modified tenderometer as a measure of pork tenderness, as exhibited in this study, especially considering the problems encountered in measuring the softer, PSE-type muscles, suggests that these data have little meaning. Thus, a low but positive association between the development of the PSE condition and increased tenderness was assumed.

Results of an analysis of the bull and steer groups indicated that the bulls had larger rib eye areas, had less fat, less marbling, lower yield grades (thus increased cutability), a darker color and were less tender than the steers. The variability in tenderness was significantly greater within the bull group than within the steer group. The relationship between various carcass traits and tenderness on the pooled beef sample was examined. The indicators of fatness, higher yield grade and higher marbling scores, were significantly correlated with increased tenderness. Larger rib eye area and darker muscle color were associated with toughness.

Cross-sectional tenderness variation within the beef muscle was examined by taking cores from three positions, dorsal (nearest the backbone), medial and lateral, across the longissimus dorsi. No significant variation in tenderness between these three positions was observed.

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APPENDICES

APPENDIX I

U MDSTAT MEASURING MEAT TENDERNESS PORK DATA *

ANIMAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
01P28	1395		076	090	0577	0613	0704	0652	0636	0363	0360	0362	0423	0347	0385	74	74	75	72	74
02P29	1530		075	095					0732	0447	0303	0375	0467	0397	0432					72
03P27	1377		101	116	0776	0752	0774	0724	0756	0420	0367	0394	0533	0393	0463	64	48	64	60	59
04P25	1372		069	100	0878	0846	0760	0758	0810	0403	0430	0416	0487	0383	0435	66	54	64	70	64
05P05	1455	11	085	105	1003	0864	0833	0794	0874	0483	0563	0523	0690	0563	0626	58	48	48	46	50
06P06	1545	04	120	159	0586	0547	0558	0525	0554	0353	0380	0366	0517	0377	0447	78	74	72	72	74
07P07	1455	01	112	115	0620	0618	0552	0551	0585	0437	0473	0455	0513	0447	0480	74	74	72	66	72
08P08	1460	02	100	175	0628	0625	0634	0600	0622	0500	0417	0458	0487	0413	0450	72	66	62	74	68
09P09	1495	05	075	100	0703	0806	0917	1037	0866	0387	0477	0432	0690	0520	0605	62	58	56	36	53
10P15	1510	01	076	140	0605	0731	0667	0580	0646	0540	0440	0490	0600	0530	0565	72	72	58	62	66
11P16	1430	02	127	175	0897	0900	0878	0778	0863	0493	0553	0523	0690	0593	0642	62	54	50	56	56
12P17	1385	12	083	118	0739	0792	0905	0889	0831	0497	0350	0424	0593	0493	0543	70	62	56	42	58
13P18	1480	08	086	115	0840	0875	0958	0853	0882		0608	0608	0667	0567	0617	54	52	50	52	52
14P17	1490	07	072	075	0911	0939	0919	0940	0927		0517	0517	0690	0586	0638	62	54	56	38	52
15P27	1600	11	065	070	0677	0715	0664	0628	0671	0507	0463	0485	0527	0460	0494	58	68	60	66	63
16P19	1400	10	065	086	0559	0592	0522	0500	0543	0427	0450	0438	0523	0420	0472	66	64	68	68	66
17P26	1500	02	075	116	0599	0472	0588	0537	0549	0373	0480	0427	0533	0413	0473	64	70	60	58	63
18P25	1535	04	074	105	0683	0772	0708	0641	0701	0523	0473	0498	0597	0493	0545	68	68	62	68	66
19P15	1505	04	066	076	0614	0558	0578	0543	0573	0303	0420	0362	0414	0379	0396	68	78	76	72	74
20P16	1400	09	075	120	0535	0562	0572	0588	0564	0460	0407	0434	0467	0367	0417	68	76	68	72	71
21P35	1350	11	076	090	0794	0790	0795	0621	0750	0400	0667	0533	0509	0457	0483	62	56	68	58	61
22P25	1490	14	096	118	0895	0814	0825	0725	0815	0367	0533	0450	0550	0433	0492	60	48	66	48	56
23P06	1300	11	090	121	0908	0814	0836	0716	0818		0603	0603	0598	0482	0540	62	44	56	48	52
24P27	1540	04	087	109	0615	0630	0631	0678	0638	0408	0392	0400	0508	0408	0458	78	60	74	68	70
25P08	1480	09	094	110	0560	0589	0523	0609	0570	0350	0350	0350	0408	0333	0370	78	60	70	76	71
26P05	1370	05	094	114	0875	0821	0673	0657	0756	0458	0575	0516	0583	0475	0529	58	52	55	70	59
27P07	1240	02	120	165	0812	0821	0722	0690	0761	0450	0517	0484	0642	0500	0571	64	50	52	56	56
28P09	1375	09	105	165	0543	0595	0546	0532	0554	0333	0275	0304	0425	0308	0366	68	56	68	82	68
29P26	1545	06	090	100	0871	0873	0859	0793	0849	0500	0567	0534	0733	0617	0675	44	48	32	44	42
30P28	1575	05	100	140	0663	0636	0623	0558	0620	0433	0333	0383	0450	0333	0392	54	64	60	80	64

APPENDIX I (CONTINUED)

ANIMAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
31P25	1510	07	079	095	0669	0634	0562	0556	0605	0350	0417	0384	0433	0358	0396	80	68	72	64	71
32P19	1410	12	069	102	0709	0632	0526	0536	0601	0400	0367	0384	0417	0350	0384	76	82	78	66	76
33P26	1395	07	070	097	0669	0543	0585	0544	0585	0367	0358	0362	0375	0350	0362	74	72	74	68	72
34P18	1460	09	109	129	0620	0608	0607	0566	0600	0317	0325	0321	0425	0325	0375	70	80	80	64	74
35P15	1400	12	077	083	1002	1041	1062	1028	1033	0450	0567	0508	0767	0633	0700	48	46	34	28	39
36P17	1335	06	113	120	0630	0684	0605	0649	0642	0350	0350	0350	0458	0392	0425	70	70	78	68	72
37P27	1325	05	069	105	0690	0764	0661	0607	0680	0475	0475	0475	0575	0450	0512	56	64	68	50	60
38P39	1365	08	089	101	0726	0803	0820	0663	0753	0383	0583	0483	0517	0517	0517	56	48	66	58	57
39P35	1310	13	099	130	1089	1023	1028	0992	1033	0533	0633	0583	0750	0583	0666	42	32	48	36	40
40P36	1295	13	080	095	0921	0905	0860	0849	0884	0558	0458	0508	0625	0475	0550	70	58	66	56	62
41P37	1415	10	066	070	0760	0713	0705	0733	0728	0400	0425	0412	0592	0492	0542	70	48	74	60	63
42P29	1380	03	078	083	0821	0855	0863	0905	0861	0442	0625	0534	0608	0550	0579	60	48	54	56	54
43P25	1935	08	090	115	0957	1040	0992	0926	0979	0533	0550	0542	0642	0525	0584	58	48	54	52	53
44P26	1560	10	084	085	0921	0902	0866	0757	0862	0617	0542	0580	0558	0583	0570	56	52	52	56	54
45P27	1545	08	070	074	0919	0928	0918	0869	0908	0775	0600	0688	0650	0667	0658	44	56	50	52	50

* SEE APPENDIX I PORK DATA - COLUMN IDENTIFICATION

APPENDIX I

PORK DATA - COLUMN IDENTIFICATION

1. Cold carcass weight. One decimal place (139.5).
2. PSE (pale, soft and exudative) score. No decimal.
3. Tenderometer reading at 10th rib. One decimal place (7.6).
4. Tenderometer reading at loin end. One decimal place (9.0).
5. Warner-Bratzler shear, chop position 1. Two decimal places (5.77).
6. Warner-Bratzler shear, chop position 2. Two decimal places (6.13).
7. Warner-Bratzler shear, chop position 3. Two decimal places (7.04).
8. Warner-Bratzler shear, chop position 4. Two decimal places (6.52).
9. Warner-Bratzler shear, chop average. Two decimal places (6.36).
10. ALLO-Kramer Shear-Press, slice, trial 1. One decimal place (36.3).
11. ALLO-Kramer Shear-Press, slice, trial 2. One decimal place (36.0).
12. ALLO-Kramer Shear-Press, slice, average. One decimal place (36.2).
13. ALLO-Kramer Shear-Press, cores, trial 1. One decimal place (42.3).
14. ALLO-Kramer Shear-Press, cores, trial 2. One decimal place (34.7).
15. ALLO-Kramer Shear-Press, cores, average. One decimal place (38.5).
16. Taste panel, chop position 1. One decimal place (7.4).
17. Taste panel, chop position 2. One decimal place (7.4).
18. Taste panel, chop position 3. One decimal place (7.5).
19. Taste panel, chop position 4. One decimal place (7.2).
20. Taste panel, chop average. One decimal place (7.4).

APPENDIX IIA

~~U MDSTAT MEASURING MEAT TENDERNESS BEEF DATA~~

U MDSTAT MEASURING MEAT TENDERNESS BEEF DATA STEERS *

ANIMAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
01SM2	596	1318	1082	1200	4	32	26	19	14	07	05	08	195	185	160	145	0624	0659	0682	0655	0652	0723	0590	1
02SM21	626	1178	1183	1180	6	35	33	14	14	08	06	08	150	165	140	125	0608	0791	0637	0679	0613	0649	0773	1
03SM1	585	1155	1072	1114	6	38	34	17	13	06	06	07	175	170	165	135	0646	0738	0655	0680	0653	0662	0724	1
04SM4	643	1220	1153	1186	7	38	37	20	15	11	06	10	155	175	155	155	0597	0670	0671	0646	0668	0616	0654	1
05SM11	624	1184	1221	1202	5	38	30	17	15	11	11	05	230	210	225	145	0637	0702	0669	0669	0798	0613	0598	1
06SM3	556	1141	1047	1094	6	33	33	17	15	11	08	08	190	175	145	115	0622	0543	0623	0596	0604	0581	0603	1
07SM6	594	1237	1164	1200	7	35	34	15	14	08	09	10	140	145	125	110	0497	0543	0578	0539	0528	0495	0595	1
08SM8	522	1165	1177	1171	6	35	29	23	18	08	06	07	230	235	180	140	0644	0638	0568	0617	0685	0628	0537	1
09SM9	530	1127	1074	1100	5	32	29	16	13	10	09	10	195	185	160	120	0763	0741	0709	0738	0809	0673	0730	1
10SM10	678	1253	1228	1240	6	38	34	19	16	07	08	08	210	185	125	135	0696	0689	0634	0673	0601	0653	0766	1
11SM12	650	1103	1197	1150	7	38	38	21	16	10	09	06	185	185	160	140	0633	0682	0712	0676	0571	0727	0729	1
12SM14	665	1266	1198	1232	6	35	33	15	15	06	07	08	145	140	125	130	0607	0568	0583	0586	0486	0603	0668	1
13SM15	632	1237	1219	1228	9	37	40	19	16	10	08	07	200	175	175	150	0580	0527	0535	0547	0540	0577	0524	1
14SM16	578	1186	1101	1144	6	30	32	13	12	05	08	09	130	180	135	110	0633	0598	0679	0637	0660	0581	0670	1
15SM17	694	1102	1010	1056	8	40	45	18	16	08	08	07	165	180	135	130	0551	0515	0477	0514	0539	0576	0428	1
16SM20	610	1089	1130	1110	7	40	38	27	19	12	09	06	245	190	170	145	0572	0539	0520	0544	0508	0558	0565	1
17SM22	626	1338	1214	1276	8	42	32	26	21	11	08	08	210	215	165	180	0554	0654	0570	0593	0498	0646	0635	1
18SM5	512	1105	1182	1144	6	30	29	11		06	07	09	180	145										1
19SM13	560	1249	1238	1244	4	32	23	13		09	08	08	165	140										1
20SM7	530	1106	1179	1142	5	27	27	14		08	08	10	160	140										1
21SM18	700	1261	1300	1280	9	35	40	17	15	11	09	09	230	210	215	140	0500	0693	0593	0595	0493	0683	0609	1
22SM19	639	1222	1250	1236	7	38	35	19	16	10	11	07	175	165	190	155	0526	0545	0553	0541	0510	0570	0543	1
23SM23	690	1287	1261	1274	4	34	27	15	15	08	08	06	185	190	175	160	0717	0634	0611	0654	0610	0683	0670	1

* SEE APPENDIX IIA BEEF DATA STEERS - COLUMN IDENTIFICATION

APPENDIX IIA

BEEF DATA (STEERS) -- COLUMN IDENTIFICATION

1. Hot carcass weight. No decimal (596).
2. Rib eye area, left side. Two decimal places (13.18).
3. Rib eye area, right side. Two decimal places (10.82).
4. Rib eye area, average. Two decimal places (12.00).
5. External fat over rib eye. One decimal place (.4).
6. Percent kidney, heart and pelvic fat. One decimal place (3.2).
7. Yield grade. One decimal place (2.6).
8. Marbling score, 13th rib. No decimal (19).
9. Marbling score, 10th rib. No decimal (14).
10. Texture of marbling. No decimal (7).
11. Texture of lean. No decimal (5).
12. Color score. No decimal (8).
13. Tenderometer reading, operator 1, P, 13th rib.
    One decimal place (19.5).
14. Tenderometer reading, operator 2, B, 13th rib.
    One decimal place (18.5).
15. Tenderometer reading, operator 3, J, 13th rib.
    One decimal place (16.0).
16. Tenderometer reading, operator 2, B, 10th rib.
    One decimal place (14.5).
17. Warner-Bratzler shear, steak position 1. Two decimal places (6.24).
18. Warner-Bratzler shear, steak position 2. Two decimal places (6.59).
19. Warner-Bratzler shear, steak position 3. Two decimal places (6.82).
20. Warner-Bratzler shear, steak average. Two decimal places (6.55).

APPENDIX IIA (continued)

21. Warner-Bratzler shear, lateral core position.
    Two decimal places (6.52).

22. Warner-Bratzler shear, medial core position.
    Two decimal places (7.23).

23. Warner-Bratzler shear, dorsal core position.
    Two decimal places (5.90).

24. Card 1 of observation.

APPENDIX IIB

U MDSTAT MEASURING MEAT TENDERNESS BEEF DATA STEERS *

ANIMAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
01SM2	0458	0383	0420	0500	0350	0425	0479	0366	0422	0500	0408	0454	73	79	77	76	2
02SM21	0548	0512	0530	0596	0412	0504	0572	0462	0517	0515	0467	0491	73	73	67	71	2
03SM1	0436	0380	0408	0388	0380	0384	0412	0380	0396	0487	0385	0436	74	71	67	71	2
04SM4	0517	0383	0450	0533	0325	0429	0525	0354	0440	0471	0412	0442	74	77	71	74	2
05SM11	0683	0450	0566	0725	0450	0588	0704	0450	0577	0533	0432	0482	56	53	56	55	2
06SM3	0475	0333	0404	0350	0367	0358	0412	0350	0381	0510	0374	0442	71	73	80	75	2
07SM6	0458	0300	0379	0283	0408	0346	0370	0354	0362	0417	0286	0352	74	80	76	77	2
08SM8	0408	0325	0366	0342	0358	0350	0375	0342	0358	0469	0375	0422	77	76	79	77	2
09SM9	0525	0350	0438	0450	0425	0438	0488	0388	0438	0533	0495	0514	80	81	67	76	2
10SM10	0536	0392	0464	0500	0372	0436	0518	0382	0450	0482	0393	0438	69	80	71	73	2
11SM12	0452	0328	0390	0476	0340	0408	0464	0334	0399	0489	0429	0459	70	80	80	77	2
12SM14	0400	0476	0438	0500	0392	0496	0500	0434	0467	0531	0463	0497	76	77	71	75	2
13SM15	0300	0440	0370	0500	0373	0436	0400	0406	0403				79	77	74	77	2
14SM16	0508	0433	0470	0483	0425	0454	0496	0429	0462	0544		0544	73	66	64	68	2
15SM17	0408	0350	0379	0483	0342	0412	0446	0346	0396	0438	0338	0388	74	80	70	75	2
16SM20	0353	0383	0368	0453	0333	0393	0403	0358	0380	0394	0371	0382	80	77	76	78	2
17SM22	0310	0400	0355	0333	0347	0340	0322	0374	0348	0371		0371	81	79	83	81	2
18SM5																	2
19SM13																	2
20SM7																	2
21SM18	0500	0292	0396	0464	0273	0368	0482	0282	0382	0529	0324	0426	66	63	70	66	2
22SM19	0464	0223	0344	0417	0308	0362	0440	0266	0353	0350	0483	0416	74	74	71	73	2
23SM23	0573	0304	0438	0463	0357	0410	0518	0330	0424	0553	0494	0524	70	62	69	67	2

* SEE APPENDIX IIB BEEF DATA STEERS - COLUMN IDENTIFICATION

APPENDIX IIB

BEEF DATA (STEERS) -- COLUMN IDENTIFICATION

1. ALLO-Kramer Shear-Press, slice 1, trial 1. One decimal place (45.8).

2. ALLO-Kramer Shear-Press, slice 1, trial 2. One decimal place (38.3).

3. ALLO-Kramer Shear-Press, slice 1 average. One decimal place (42.0).

4. ALLO-Kramer Shear-Press, slice 2, trial 1. One decimal place (50.0).

5. ALLO-Kramer Shear-Press, slice 2, trial 2. One decimal place (35.5).

6. ALLO-Kramer Shear-Press, slice 2 average. One decimal place (42.5).

7. ALLO-Kramer Shear-Press, slices 1 and 2, 1st trials. One decimal place (47.9).

8. ALLO-Kramer Shear-Press, slices 1 and 2, 2nd trials. One decimal place (36.6).

9. ALLO-Kramer Shear-Press, slices 1 and 2 average. One decimal place (42.2).

10. ALLO-Kramer Shear-Press, cores, trial 1. One decimal place (50.0).

11. ALLO-Kramer Shear-Press, cores, trial 2. One decimal place (40.8).

12. ALLO-Kramer Shear-Press, cores average. One decimal place (45.4).

13. Taste panel, steak position 1. One decimal place (7.3).

14. Taste panel, steak position 2. One decimal place (7.9).

15. Taste panel, steak position 3. One decimal place (7.7).

16. Taste panel, steak average. One decimal place (7.6).

17. Card 2 of observation.

APPENDIX IIIA

U MDSTAT MEASURING MEAT TENDERNESS BEEF DATA BULLS *

ANIMAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
24B619	591	1348	1303	1326	2	22	15	09	05	08	11	12	200	190	165	130	0969	0935	0976	0960	1094	0885	0901	1
25B4 69	658	1460	1482	1471	3	28	16	15	09	11	05	09	220	210	210	155	0957	0934	1065	0985	0976	1066	0914	1
26B3 69	658	1587	1726	1656	2	22	06	08	06	05	08	09	190	175	150	135	0727	0859	0822	0803	0916	0738	0755	1
27BD249	665	1355	1373	1364	3	28	20	14	12	08	08	08	220	175	240	165	0941	0904	0907	0917	0887	0935	0931	1
28B5 69	644	1466	1485	1476	4	28	18	19	18	11	08	12	175	185	165	175	0767	0643	0666	0692	0801	0717	0558	1
29B349	655	1372	1487	1430	5	28	22	14	15	05	05	08	245	205	170	165	1077	0970	1010	1019	0964	1087	1007	1
30B917	726	1371	1487	1429	4	28	22	14	15	08	05	10	160	205	215	150	0751	0818	0803	0791	0966	0726	0681	1
31B5859	549	1251	1226	1238	2	22	16	13	11	11	08	08	230	185	200	160	0807	0794	0864	0822	0891	0583	0992	1
32B1 11	662	1381	1336	1358	4	28	22	15	13	08	08	08	170	220	160	150	0755	0718	0658	0710	0755	0691	0685	1
33B3Q	671	1479	1552	1516	4	28	18	13	12	08	08	08	215	230	160	150	0792	0842	0675	0770	0809	0838	0695	1
34BE319	620	1225	1351	1288	4	28	22	11	11	08	08	12	240	220	260	160	1072	1067	1103	1081	1092	1076	1073	1
35BB119	673	1247	1225	1236	6	30	32	11	12	08	06	08	220	215	180	175	0904	0898	0887	0896	0931	0979	0780	1
36B32P9	600	1473	1520	1496	4	25	15	11	12	08	08	11	185	150	190	160	0518	0513	0550	0527	0599	0443	0539	1
37B5P9	610	1246	1233	1240	2	21	18	11	07	08	08	12	220	195	210	165	0712	0651	0642	0668	0740	0733	0533	1
38B1639	585	1516	1305	1410	1	25	13	10	04	11	08	11	260	220	185	200	0876	0814	0976	0889	0679	1066	0922	1
39BR898	500	1313	1208	1260	1	20	10	07	03	08	08	11	260	260	210	165	0981	0975	1087	1014	1055	1032	0956	1
40BM139	525	1337	1136	1236	2	25	16	12	09	05	09	09	260	215	245	195	0849	0762	0938	0850	1041	0791	0718	1
41BP329	527	1354	1375	1364	2	20	10	05	04	08	08	12	210	185	205	150	0978	1047	1059	1028	1019	1033	1032	1
42BD39	563	1355	1139	1247	2	20	16	08	05	08	11	09	195	170	195	155	0862	0889	0893	0881	0892	0860	0891	1
43B25P9	606	1604	1423	1514	5	27	17	18	15	09	08	11	230	220	205	210	0924	0891	0927	0914	0939	0927	0875	1

* SEE APPENDIX IIIA BEEF DATA BULLS - COLUMN IDENTIFICATION

APPENDIX IIIA

BEEF DATA (BULLS) -- COLUMN IDENTIFICATION

1. Hot carcass weight. No decimal (596).
2. Rib eye area, left side. Two decimal places (13.18).
3. Rib eye area, right side. Two decimal places (10.82).
4. Rib eye area, average. Two decimal places (12.00).
5. External fat over rib eye. One decimal place (.4).
6. Percent kidney, heart and pelvic fat. One decimal place (3.2).
7. Yield grade. One decimal place (2.6).
8. Marbling score, 13th rib. No decimal (19).
9. Marbling score, 10th rib. No decimal (14).
10. Texture of marbling. No decimal (7).
11. Texture of lean. No decimal (5).
12. Color score. No decimal (8).
13. Tenderometer reading, operator 1, P, 13th rib. One decimal place (19.5).
14. Tenderometer reading, operator 2, B, 13th rib. One decimal place (18.5).
15. Tenderometer reading, operator 3, J, 13th rib. One decimal place (16.0).
16. Tenderometer reading, operator 2, B, 10th rib. One decimal place (14.5).
17. Warner-Bratzler shear, steak position 1. Two decimal places (6.24).
18. Warner-Bratzler shear, steak position 2. Two decimal places (6.59).
19. Warner-Bratzler shear, steak position 3. Two decimal places (6.82).
20. Warner-Bratzler shear, steak average. Two decimal places (6.55).

APPENDIX IIIA (continued)

21. Warner-Bratzler shear, lateral core position.
    Two decimal places (6.52).

22. Warner-Bratzler shear, medial core position.
    Two decimal places (7.23).

23. Warner-Bratzler shear, dorsal core position.
    Two decimal places (5.90).

24. Card 1 of observation.

APPENDIX IIIB

U MDSTAT MEASURING MEAT TENDERNESS BEEF DATA BULLS *

ANIMAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
24B619		0867	0867	0908	0725	0816	0908	0796	0842	0733	0617	0675	50	51	37	46	2
25B4 69	0708	0650	0679	0742	0608	0675	0725	0629	0677	0811	0619	0715	51	43	53	49	2
26B3 69	0558	0550	0554	0542	0508	0525	0550	0529	0540	0551	0763	0657	56	63	71	63	2
27BD249		0517	0517	0683	0550	0616	0683	0534	0566	0635	0570	0602	51	59	66	59	2
28B5 69	0433	0407	0420	0433	0360	0396	0433	0384	0408	0506	0472	0489	79	80	73	77	2
29B349		0650	0650	0800	0683	0742	0800	0666	0696	0750		0750	59	53	56	56	2
30B917	0542	0500	0521	0542	0408	0475	0542	0454	0498	0510	0497	0504	59	71	74	68	2
31B5859	0567	0467	0517	0542	0475	0508	0554	0471	0512	0529	0471	0500	53	60	54	57	2
32B1 11	0625	0508	0566	0566	0447	0506	0596	0478	0536	0502	0404	0453	56	66	60	61	2
33B3Q	0542	0567	0554	0575	0508	0542	0558	0538	0548	0639	0528	0584	61	57	49	56	2
34BE319	1017	0642	0830	0875	0708	0792	0946	0675	0811	0967	0826	0896	41	37	27	35	2
35BB119	0775	0517	0646	0617	0542	0580	0696	0530	0613	0660	0495	0578	54	51	53	53	2
36B32P9	0367	0276	0322	0442	0333	0388	0322	0304	0355	0443	0341	0392	80	84	83	82	2
37B5P9	0467	0350	0408	0517	0433	0475	0492	0392	0442	0445	0393	0419	66	67	56	63	2
38B1639	0850	0833	0842	0633	0667	0650	0742	0750	0746	0785		0785	47	54	51	51	2
39BR898	0808	0683	0746	0617	0692	0654	0712	0688	0700	0857	0757	0807	39	47	51	46	2
40BM139	0833	0725	0779	0525	0408	0466	0679	0566	0622	0629	0614	0622	64	51	49	55	2
41BP329	0775	0708	0742	0633	0700	0666	0704	0704	0704	0870	0668	0769	51	47	37	45	2
42BD39	0933	0517	0725	0675	0617	0646	0804	0567	0686	0667	0583	0625	51	44	54	50	2
43B25P9	0533	0558	0546	0683	0558	0620	0608	0558	0583	0788	0628	0708	56	59	40	52	2

* SEE APPENDIX IIIB BEEF DATA BULLS - COLUMN IDENTIFICATION

APPENDIX IIIB

BEEF DATA (BULLS) -- COLUMN IDENTIFICATION

1. ALLO-Kramer Shear-Press, slice 1, trial 1. One decimal place (45.8).
2. ALLO-Kramer Shear-Press, slice 1, trial 2. One decimal place (38.3).
3. ALLO-Kramer Shear-Press, slice 1 average. One decimal place (42.0).
4. ALLO-Kramer Shear-Press, slice 2, trial 1. One decimal place (50.0).
5. ALLO-Kramer Shear-Press, slice 2, trial 2. One decimal place (35.5).
6. ALLO-Kramer Shear-Press, slice 2 average. One decimal place (42.5).
7. ALLO-Kramer Shear-Press, slices 1 and 2, 1st trials. One decimal place (47.9).
8. ALLO-Kramer Shear-Press, slices 1 and 2, 2nd trials. One decimal place (36.6).
9. ALLO-Kramer Shear-Press, slices 1 and 2 average. One decimal place (42.2).
10. ALLO-Kramer Shear-Press, cores, trial 1. One decimal place (50.0).
11. ALLO-Kramer Shear-Press, cores, trial 2. One decimal place (40.8).
12. ALLO-Kramer Shear-Press, cores average. One decimal place (45.4).
13. Taste panel, steak position 1. One decimal place (7.3).
14. Taste panel, steak position 2. One decimal place (7.9).
15. Taste panel, steak position 3. One decimal place (7.7).
16. Taste panel, steak average. One decimal place (7.6).
17. Card 2 of observation.

APPENDIX IV

U MDSTAT — MEASURING MEAT TENDERNESS

BULLS SELECTED FOR TENDERNESS AND LEANNESS

ANIMAL	1	2	3	4	5	6
0141	22.5	22.5	20.2	17.0	6.25	7.18
0257	15.0	18.0	13.6	15.0	6.88	8.48
0325	18.5	20.0	18.0	20.0	6.87	6.16
0406	18.0	21.0	15.0	12.5	6.94	6.48
0520	24.5	24.5	22.0	21.6	6.44	8.12
0607	16.0	17.5	14.1	13.0	7.31	7.28
0713	17.0	17.5	15.1	15.7	5.44	8.59
0803	15.0	15.0	18.4	15.5	7.94	4.33
0904	16.0	19.5	14.9	18.1	6.19	8.32
1030	14.5	18.0	13.8	14.5	6.62	4.94
1144	19.0	21.0	18.8	16.4	7.31	7.16
1209	20.0	21.0	16.2	16.8	5.25	9.42
1338	25.0	22.5	17.1	15.5	4.31	9.78
1435	17.5		19.3	19.5	6.19	7.20
1526	17.5	22.5	18.4	20.1	5.19	9.03
1655	19.0	18.0	19.4	15.5	6.62	6.62
1748	17.5	15.5		14.6	6.75	7.24
1854	16.5	17.5	15.5	15.0	6.62	5.12

* SEE APPENDIX IV BULLS SELECTED FOR TENDERNESS - COLUMN IDENTIFICATION

APPENDIX IV

BULLS SELECTED FOR TENDERNESS AND LEANNESS

- COLUMN IDENTIFICATION

1. Tenderometer reading, operator 1, J, left side, 13th rib.
2. Tenderometer reading, operator 1, J, right side, 13th rib.
3. Tenderometer reading, operator 2, B, left side, trial 1.
4. Tenderometer reading, operator 2, B, left side, trial 2.
5. Taste panel score.
6. Warner-Bratzler shear value.

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