

THE EFFECT OF INTERNAL TEMPERATURE ON THE  
PALATABILITY OF BEEF COOKED IN DEEP FAT

by

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## INTRODUCTION

The effect of the degree of protein coagulation, as determined by internal temperature, on the palatability, particularly the juiciness and tenderness, of meat has been studied. The results are incomplete and in disagreement. Therefore, there is a need for more study in this area of meat research.

Visser (1957) cooked certain beef muscles in deep fat at 110°C. to internal temperatures of 55°, 70°, and 85°C. When the two lower temperatures were used, the maximum internal temperatures reached after the meat was taken from the fat, were too high for the meat to be representative of rare and medium doneness. It was her recommendation, therefore, that in further work lower internal temperatures be used or that the temperature of the fat be less than 110°C. It was determined in preliminary work for the present study that both internal temperatures of 45°, 65°, and 85°C. and a temperature of 100°C. for the fat would be desirable. One of the aims of this study was to obtain cooked meat that was representative of rare, medium, and well-done, with which to study the rate of heat penetration, cooking losses, and palatability.

A penetrometer has been used for measuring the consistency of whole raw and cooked meat, but there has been no published work in which the consistency of ground raw meat has been determined by the penetrometer. Another aim of this study was to discover if there was a correlation between penetrometer readings and characteristics of the cooked meat, such as tenderness, juiciness, and cooking losses.

## REVIEW OF LITERATURE

## Factors That Affect the Palatability of Beef

There are many factors that affect the flavor, aroma, juiciness, and particularly the tenderness of beef. Among these are the age, sex, and breed of the animal, the level of nutrition, the structure and composition of the muscle, and the position of the muscle in the carcass. Storage conditions of the carcass as well as the method and degree of cooking the meat also affect palatability. The effects are complicated to study because of the interrelationships among the various factors. The effect of the method of cooking is dependent on the structure of the muscle. Storage effects vary with the level of nutrition of the animal and the treatment before slaughter. Although many of these factors cannot be controlled, it is well to keep in mind the possible sources of variation in palatability when reviewing the factors that affect the palatability of beef.

Muscle Structure and Composition. Muscle Fiber. Szent-Györgyi (1951) and Maximow and Bloom (1952) have described the structure and composition of skeletal muscle. The muscle is composed of cylindrically-shaped fibers that consist of a protoplasmic mass and thin cross-striated fibrils that are held together by connective tissue. The fibers have longitudinal and definite cross striations, that are a periodic variation of the physical properties along the axis of the muscle. They are enclosed by the sarcolemma.

It has been stated that the fibrils appear as long parallel

threads that do not branch and are composed of bundles of myosin filaments (Maximow and Bloom, 1952). The fibril is divided into disc-like partitions or sarcomeres, that are separated by a thin Z-membrane. Within the sarcomere are isotropic and anisotropic bands and the M-membrane in the center. Szent-Györgyi (1951), however, pointed out that the fibrils do not appear in the intact muscle, and may be artifacts caused by physical or chemical treatment outside the body.

The fibers are bound to ether into primary, secondary, and tertiary bundles. Layers of interstitial connective tissue, the epimysium, at the periphery of the muscle bundles project into the spaces between muscle fiber bundles and become the perimysium. The endomysium between the separate muscle fibers inside primary muscle bundles consists of thin fibrous networks which form capsules for the fibers (Maximow and Bloom, 1952).

An investigation of the cross striations of myosin filaments, the major component of muscle fibrils, was reported by Hall et al. (1946). The filaments were found to have an indefinite length in the intact fibril, but were fragmented extensively during extraction in weak alkaline salt solutions. Evidence indicated that myosin filaments are contractile units. According to Szent-Györgyi (1951), all attempts to separate adenosine triphosphatase activity (ATPase) from myosin have been unsuccessful, proving that myosin is ATPase. It interacts with ATP to cause muscular contraction.

It was suggested by Bailey (1948) that troponin, an asymmetric protein component of the muscle fibril may be one of

the units from which the myosin filament is elaborated. Its amino acid composition is of the myosin type. Tropomyosin is an exceedingly viscous protein because of the aggregation of molecules. However, in dilute salt solutions it crystallizes in large bi-refrinent plates.

Several studies have been made on the relationship of muscle fiber diameter to the tenderness of the cooked beef muscle. Brady (1937) reported significant differences in the diameter of muscle fiber and size of the bundle between muscles of yearling steers and mature Holstein cows. There were also differences among muscles in the size of the bundle. Positive correlation coefficients were found for the size of bundle and the texture score, the size of bundle and the tenderness score, and the tenderness and texture scores; whereas the size of the bundle and shear stress gave a negative correlation coefficient. He concluded that the larger the muscle bundle, the finer the texture, and the more tender the meat.

Hiner and co-workers (1953) studied the relationship of tenderness in beef muscles to fiber diameter. The animals that they used varied from 10-week-old veal calves to nine-year-old cows. The diameters of the fixed fibers classified themselves into four general groups. The tenderloin had fibers of the smallest diameter, and the second group was composed of two chuck samples, the eighth rib, shortloin, and loin end. The third group in order of increasing magnitude was the round, and finally the neck and foreshank. With increasing age of the animal there was a consistent increase in the average muscle fiber

diameter. Coefficients of correlation for tenderness, as measured by resistance to shear, and the fiber diameter for each muscle were positive and very highly significant, and the relationship was shown to be curvilinear. Analysis of variance showed that the differences in fiber diameter and tenderness among the animals were very highly significant, but the interaction between the two was only significant.

**Connective Tissue.** The amount and character of connective tissue is one of the factors that influences the tenderness of meat. Hiner et al. (1955) found that both collagenous and elastic fibers were more numerous and larger in muscles that were used most, such as the serratus ventralis, deep digital flexor, semimembranosus, semitendinosus, and biceps femoris. In muscles where fatty deposits were evident, the collagenous fibers formed more of a loose network between bundles, whereas they appeared bunched in those with less fat.

In investigating some factors that affect the connective tissue content of beef muscle, Mitchell et al. (1928) determined that the eye-muscle of the rib possessed the lowest collagen content of any of the muscles studied, with the tenderloin only slightly higher in collagen. The round, porterhouse, and sirloin were next in order. The chuck rib and the navel contained consistently larger percentages of collagen nitrogen than the other cuts. The highest percentage of collagen was found in the fore-shank. Although the distribution of elastin among the different retail cuts differed from the collagen distribution, it was as consistently distributed among the muscles of various animals as



was collagen.

Miller and Kastelic (1956), in fractionating connective tissue, suggested that the amorphous ground substance, which is the matrix of connective tissue, may play a determining role in the architectural aspects and therefore the tenderness of meat.

**Fat.** The third major component of muscle is fat, and when it is dispersed throughout the muscle it is referred to as marbling. It is present, also, as a covering for the muscle.

Wierbicki et al. (1956) stated that intramuscular fat appeared to be a sex characteristic rather than a mark of tenderness per se. In twenty identically fed animals used by Huisaini et al. (1950) there was no correlation between tenderness at three or 15 days of aging and carcass grade or intramuscular fat. Similarly no correlation between the fat content and tenderness in muscles of the round of U. S. Commercial cows was reported by Paul et al. (1956). The greatest fat content was found in steaks from the biceps femoris muscle and the lowest amount was found in the adductor.

Gaddis et al. (1950) found that where there was a greater amount of intramuscular fat in the ribeye muscle, there was an increased amount of fat in the press fluid, which was correlated with higher palatability scores for quantity and quality of juice. The relationship was curvilinear up to about two percent fat content, beyond which there was little change.

It was pointed out by Cover et al. (1958) that there was little relation between the amount of fat on the carcass and the tenderness of meat. Separable fat on the 9-10-11 rib cut of

Santa Gertrudis and Bluebonnet steers seemed to have no measurable effect on the tenderness of loin steaks broiled to the well-done stage. There was, however, some correlation between the degree of marbling and tenderness. Some correlation coefficients for separable fat versus shear force and ether extract versus shear force were significant, but in both cases the highest coefficients of correlation accounted for a very small percentage of the variation in shear force values. They concluded that the general agreement between fatness and tenderness was quite low.

Position of the Muscle in the Carcass. Muscles from different parts of the carcass vary greatly in tenderness because of their relative amounts of muscle fiber, fat, and connective tissue and difference in muscular activity. Ramsbottom et al. (1945) found, in their study of the comparative tenderness of various beef muscles cooked in lard to  $76.7^{\circ}\text{C}.$ , that the muscles were fairly uniform from one end to another, but different muscles varied in collagenous and elastic connective tissue content, fat, and the size of the muscle bundle. They reported that the amount of connective tissue present significantly affected tenderness as shown by the fact that shear tests on predominantly collagenous and elastic tissue gave readings much higher than those of most muscles.

In an experiment with the semimembranosus and adductor muscles, Paul and Bratzler (1955b) discovered that steaks from the adductor, cooked in deep fat, were quite uniform in shear tenderness regardless of grade, treatment, or position in the

muscle; whereas those from the semimembranosus were affected by these factors. The tenderness of semimembranosus steaks from U. S. Good animals became more tender between six and nine days of storage, whereas those from U. S. Prime animals were less tender after eight days than after six days. Steaks from the center portion of the muscle were less tender than the first and second steaks from the anterior portion and more tender than the eighth and ninth steaks from the posterior portion.

Hiner and Hankins (1950) reported no significant difference in the tenderness of the three large muscles of the round, i.e., the semimembranosus, semitendinosus, and biceps femoris. Similar results were obtained by Griswold (1955). Hiner and Hankins (1950) found less difference in tenderness among muscles in samples representing veal or 500-pound steer calves than in those from older, more mature animals.

Strandine et al. (1949) reported a variation in pH, protein, fat, and moisture content in beef muscles from various positions in the carcass, but these factors did not correlate with tenderness values for the muscle. Both elastic and collagenous fibers varied from muscle to muscle with respect to size and quantity.

Biochemical Factors. Level of Nutrition. Jacobson and Denton (1956) studied the effects of the level of nutrition of Holstein bulls and heifers on palatability factors. The three levels of nutrition used were 160, 100, and 60 percent total digestible nutrients. The 160 percent group also received a daily mineral supplement. Roasts from the longissimus dorsi, psoas major, semimembranosus, and adductor muscles were cooked

from the hard-frozen state to an internal temperature of 69°C. The fat content of both raw and cooked meat increased with the level of nutrition, and the tenderness of the longissimus dorsi may have been improved with increased fat. There were no consistent effects of the level of nutrition on shear stress, aroma, and juiciness, but the flavor of beef from animals on the higher levels was preferred to that of the beef from the other animals. They concluded that, if cost permits, the palatability of roasts from some muscles may be improved by higher levels of nutrition, particularly in younger animals.

**Glycogen Content of the Muscle.** The amount of exercise which the animal has before slaughter determines the glycogen content of the tissues at the time of death. Bate-Smith (1948) stated that intermittent exercise builds up glycogen and seems to increase tenderness by preferentially increasing the muscle substance proper.

**Dissociation of Actomyosin.** According to Szent-Györgyi (1951), resting muscle is extensible because myosin is dissociated from actin. When the muscle dies, potassium ions and adenosine triphosphate are removed from myosin by diffusion and breakdown, respectively. Actin then combines with myosin to form actomyosin, which is quite inextensible and confers on the muscle the rigid condition of rigor mortis. Evidence was presented by Wierbicki et al. (1954) in their work with Hereford bulls and steers that suggested increases in tenderness with post mortem age may be related to the dissociation of actomyosin or similar protein changes, and redistribution of ions within the

muscle. These reactions result in increased hydration and tenderness. In a later study Wierbicki et al. (1956) reported that extractable nitrogen and potassium citrate-soluble nitrogen decreased during post mortem aging. This indicated that dissociation of actomyosin is not responsible for post mortem tenderization.

**Muscle Hemoglobin.** No relation of muscle hemoglobin to tenderness at three days of aging, but a very significant correlation with tenderness at 15 days was observed by Huisaini et al. (1950). They concluded that muscle plasma, as represented by muscle hemoglobin, is in part responsible for tenderness. Wierbicki et al. (1954) reached the same conclusion after finding that the total nitrogen extractable from muscle with a buffer was related to tenderness of the meat at 15 days.

**Diethylstilbestrol.** The effect of diethylstilbestrol treatment on bulls and steers was studied by Wierbicki et al. (1956). The meat was held at 36° to 38°F. during post-mortem aging. No great differences were noted between groups in tenderness of the shortloin at 13 days post-mortem, although the hormone treatment tended to produce slightly tougher meat at both three and 13 days after slaughter. Hydroxyproline values were slightly higher in the meat from the hormone-treated animals, and hormone-treated steers yielded meat that was less marbled than meat from untreated animals.

Rate of Heat Penetration and Internal Temperature. Morgan and Nelson (1926) stated that the factors which determine the rate of heat penetration during the cooking of meat are the

relative amount of bone and fat, firmness, and water content. All of these factors were considered more important than weight. In their study in which standing two-rib beef roasts were cooked in the oven to internal temperatures of 51°, 60°, and 70°C., they compared skewered to unskewered roasts. The skewers, copper plated with nickel, decreased cooking time 30 to 45 percent and the skewered roasts were more tender and juicy than the unskewered roasts. If the skewers were left in, the internal temperature of the roasts did not rise after removal from the oven. They also found a greater rise in the internal temperature of roasts without bone after removal from the oven than in the roasts with bone.

Cover (1941) compared skewered with unskewered roasts from the semimembranosus, triceps brachii, and longissimus dorsi muscles, cooked in a 125°C. oven to an internal temperature of 80°C. The skewers decreased the cooking time and losses, but in contrast to the results of the study reported by Morgan and Nelson (1926), increased the toughness of all three muscles. This undesirable effect on tenderness seemed to be greatest when the effect on cooking time was least. She concluded that the difference in cooking time influenced the tenderness in paired roasts more than did the oven temperature.

The paired-eating method was used to test the tenderness of standing-rib and round-bone chuck roasts, cooked to 80°C. in 125° and 225°C. ovens, Cover (1936). The majority of the judgments for both cuts were in favor of the constant low oven temperature. The difference was more decided in the case of the lowest grade carcasses, emphasizing the importance of low oven

temperature in cooking the lower grades of meat.

Cover (1943) also studied the effects of extremely low rates of heat penetration by using oven temperatures of 80° and 125°C. and endpoint temperatures of 59°, 63°, and 70°C. She stated that roasts were always tender when the rate of heat penetration was slow enough that 30 or more hours were required for roasts to lose their pink color. With less time roasts were not always tender. Muscle fibers in the well-done arm-bone chuck roasts that required 40 hours of cooking were so tender that they were described as "mealy" and were quite dry and flaky.

The effect of the rate of heat penetration on the tenderness of the semitendinosus and biceps femoris muscles cooked by two methods after 0, 5, 12, 24, 48-53, and 144-149 hours of cold storage after slaughter was studied by Paul et al. (1952). Roasts were cooked in the oven at 163°C. to an internal temperature of 63°C. and steaks were fried in deep fat at 150°C. to the same internal temperature. They stated that the slow rate of heat penetration during roasting induced the development of rigor in roasts cooked immediately after slaughter, and resulted in less tender meat. The rapid heat penetration during deep fat frying of the steaks coagulated the muscle substance before zero-storage steaks could go into rigor, and produced very tender meat.

When Visser (1957) cooked roasts in deep fat to internal temperatures of 55°, 70°, and 85°C., it was observed that roasts that had a slower rate of heat penetration were more "done" at the endpoint of cooking than the roasts that had a faster rate of heat penetration.

Fat plays an important role in the speed of heat penetration into meat and the direction of its influence depends upon the location of the fat. Thille et al. (1932) discovered in cooking three-rib roasts to an internal temperature of  $65^{\circ}\text{C}$ . at  $210^{\circ}\text{C}$ . that exterior fat speeds up the rate of heat penetration, but interior fat retards it. This was attributed to the change in heat conductivity of fat as it passes from the solid to liquid condition.

Siemers and Hanning (1953) reported increased juice loss and lower juiciness scores as the temperature of braising was increased. The rate of heat transfer was found to be slower in braised suet-covered samples than in those prepared entirely from lean.

In a study of the effects on coagulation of beef muscle, roasts from the longissimus dorsi muscle were cooked to  $58^{\circ}$ ,  $67^{\circ}$ , and  $75^{\circ}\text{C}$ . at  $150^{\circ}\text{C}$ . by Satorius and Child (1938). Press fluid and total moisture decreased with each increment in internal temperature, except between  $58^{\circ}$  and  $67^{\circ}\text{C}$ . The muscle fiber diameter decreased and tenderness increased with coagulation up to  $67^{\circ}\text{C}$ . The tenderness was decreased from  $67^{\circ}$  to  $75^{\circ}\text{C}$ .

It was reported by Child and Fogarty (1936) that the ratio of press fluid to dry matter was greater in meat from the semitendinosus muscle heated to  $58^{\circ}\text{C}$ . than in that heated to  $75^{\circ}\text{C}$ . Approximately 11 percent more press fluid was found in the muscle cooked to the lower temperature. In addition, chemical analysis showed that the moisture content of the press fluid varied directly with the internal temperature.



Method of Cooking. Broiling was compared to braising as a method of cooking steaks to the well-done stage, Cover and Smith (1956). Three-fourths-inch steaks from the short loin and bottom round from 62 steers were broiled at 392°F. and braised 45 minutes in steam after browning. All of the broiled steaks were more juicy than the braised steaks. Steaks from the biceps femoris muscle were more tender when braised than when broiled. There was little difference between the methods of cooking in the effect on the tenderness of steaks from the longissimus dorsi. Collagen retention was smaller in braised steaks from the biceps femoris than in broiled ones, which indicated that the moist heat method was more effective in degrading collagen of that muscle than was dry heat. Collagen content was associated with tenderness when the two cooking methods were compared, but these factors were not associated when two muscles were cooked by the same method.

Griswold (1955) compared 15 cooking methods to a standard braising method for cooking beef round of U. S. Commercial and U. S. Prime grades. She found that standard braising to 85°C. with prebrowning in suet at 200°C. for seven and one-half minutes on each side and braising in a covered pan in a 300°F. oven was preferred to braising under pressure. Application of enzymes before braising made the meat more tender, but less juicy than standard braising. Pounding, but not scoring, increased tenderness; and soaking in vinegar lowered the acceptability of the meat and failed to increase tenderness. Beef round roasted at 250°F. scored high in flavor and acceptability and had lower

shear values than meat cooked by any other method. Meat roasted at 300°F. was superior only in juiciness to that cooked at the lower temperature. Little difference was found in the reaction of the two grades of beef to the cooking methods.

Dry and moist heat methods of cooking muscles from the round of low grade beef were compared by Hood et al. (1955). The dry heat methods consisted of roasting in a shallow, uncovered pan at 300°F. for thick cuts and 350°F. for thin cuts, and broiling beneath a gas flame at 350°F. The moist heat methods were braising in a covered casserole without water and with no pre-browning, and braising at 300°F. after browning. In the latter method water was used and the meat was cooked to an internal temperature of 176°F. There were no significant differences in the juiciness scores for meat cooked by moist and dry heat methods, but cuts cooked by dry heat scored significantly higher in aroma and flavor and tended to be more tender than those cooked by moist heat. Surface-braised and oven-braised cuts were not significantly different in quality, but oven-braised meat had a higher percentage of drip loss and a shorter cooking time than surface-braised meats.

Paul et al. (1956) found that dry heat was superior to moist heat as a method of cooking U. S. Commercial grade cow beef. The flavor of dry heat-cooked steaks was superior to that of braised steaks, but there was not a difference between the aroma of the two. The juiciness of the dry heat-cooked steaks was superior in every case and the tenderness in 75 percent of the cases to the braised steaks.

Aging and Storage Conditions. Harrison et al. (1949)

studied the changes that take place during the aging of beef. Roasts from four muscles were aged up to 30 days and cooked in lard to 70°C. They stated that aroma and flavor scores reached a maximum at 10 days of aging and decreased after 30 days of aging. Tenderness, when all muscles were considered, increased with continued aging of the roasts, but the greatest increase occurred in the first 10 days.

Storage times and temperatures were compared by Griswold and Wharton (1941). They stored meat from two-year old Hereford steers for nine and 37 days at 34°F., and at 60°F. with and without ultraviolet radiation. Meat stored 37 days had a stronger aroma and flavor, but was less juicy than that stored nine days. However, the differences in tenderness of the meat stored for nine and 37 days were small. The odor and appearance of meat stored at 60°F. was more desirable when ultraviolet lights were used, but flavor and tenderness were similar for the ultraviolet-treated and untreated meat.

McCarthy and King (1942) studied the Tenderay process of storing beef for 48 hours at 60°F. with ultraviolet light. They compared this to standard storage for 30 days at 35°F. With the Tenderay process there was a more rapid rise in sulfhydryl content, a more rapid increase in soluble nitrogen compounds, a comparable rate of disappearance of Vitamin C, and a more rapid rise in hematin-type pigments in the press juice.

It was found by Paul et al. (1956) that increasing the length of storage time at 32° to 34°F. decreased aroma, flavor,

and juiciness of the round of Commercial grade cows. Tenderness increased up to seven days, but did not increase between seven and 21 days.

The relationship of storage conditions to tenderness was determined by Ramsbottom and Strandine (1949). Some steaks were frozen and stored at  $-20^{\circ}\text{F}$ . for two weeks and others were used immediately. They were cooked in lard at  $250^{\circ}\text{F}$ . to an internal temperature of  $170^{\circ}\text{F}$ . Objective and subjective measurements of tenderness showed that beef that was chilled in the carcass form was more tender than beef that was boned and then chilled to  $35^{\circ}\text{F}$ . Two hours after slaughter was the most tender period for beef until the twelfth day, when it was considerably more tender.

Paul and Bratzler (1955a) studied the differences between frozen and unfrozen beef, and the effect of storing muscles on and off the carcass at  $5^{\circ}$  to  $7^{\circ}\text{C}$ . for two to nine days. All steaks from the longissimus dorsi muscle were cooked in deep fat to  $63^{\circ}\text{C}$ . In every case more tender steaks resulted from longer storage and any type of handling interfered with the tenderizing process. For example, muscles stored off the carcass were less tender than those stored on the carcass. Additional cold storage or freezing of steaks after three days of aging on the carcass increased the tenderness. Steaks cooked without thawing were less tender than those thawed before cooking. Cold storage on the carcass for seven to nine days after slaughter tended to minimize animal variations.

## Methods of Measuring the Palatability of Beef

Measurement of aroma and flavor are primarily limited to the subjective judgment of members of sensory taste panels. There are, however, objective means for testing tenderness and juiciness in addition to the taste panel evaluations. In many studies objective and subjective methods for measuring tenderness and juiciness have been shown to be significantly related, but some workers have not found this to be true.

Sensory Methods. Dawson and Harris (1951) reviewed the literature pertaining to sensory methods for measuring food quality. These methods are based on the judges' senses of taste, smell, sight, and feel in evaluating food quality. According to the literature that they reviewed, the number of judges on a taste panel varied from three to 50, but the majority of them had four to 12 members. Factors involved in choosing panel members were age, sex, availability, tasting experience, experience with the particular food under consideration, taste and smell sensitivity, flavor memory, and psychological factors. It was pointed out that meat judges need experience that covers a complete range of quality.

The time of day, sample size, uniform temperature of samples, and coding of samples were said to be important in determining the results of sensory tests. Also Dawson and Harris (1951) noted that the tasting rooms were reported to be arranged for independent judging, and temperature, lighting, and ventilation were carefully controlled.

The following factors were listed by Dawson and Harris (1951) as those that determine the accuracy of sensory tests: number and kind of characteristics involved, uniformity of material, quality of food, standardization of terminology used to describe quality, number of samples and replications, use of reference standards, and amount of information given the panel.

Satorius and Child (1938) studied the reliability of judges' scores for roasts from the longissimus dorsi, adductor, and triiceps brachii muscles cooked to an internal temperature of 58°C. at 150°C. They stated that factors of palatability as measured by the members of the taste panel are interrelated. Interdependence was found between flavor and aroma, quantity and quality of juice, flavor-aroma and juiciness (quantity and quality), texture and tenderness, flavor-aroma and tenderness, and tenderness and juiciness. No such relationship existed between press fluid and shear stress. There was a high correlation between tenderness scores and shear stress values, but not between juiciness scores and press fluid yields. It was concluded that juiciness, as evaluated subjectively, is influenced by flavor and aroma, which stimulate the flow of saliva.

Mechanical Methods for Measuring Tenderness. A number of machines have been invented that objectively estimate a quality of meat called tenderness. Winkler (1939) described a recording apparatus with blunt jaws that cut through a cross section of the sample. Movement of the jaws was recorded on a revolving drum. Comparative values for work required to cut the sample could be obtained by measuring areas beneath the curves and

applying corrections for variation in thickness of the sample.

The Warner-Bratzler shearing apparatus is most commonly used in meat research. Hurwicz and Tischer (1954) reported that the maximum shear force, as the criterion of tenderness by means of the Warner-Bratzler shear, displayed a pooled coefficient of variation of 7.41 percent; and the slope of the shear force versus the time curve was the best criterion of tenderness with the apparatus, because of the smallest coefficient of variation, 4.79 percent. They recommended that the machine be redesigned in an attempt to lower the experimental error inherent to it.

Paul and Bratzler (1955b) found close agreement in tenderness trends between shear values from one-half and one-inch cores of steaks cooked in deep fat. They suggested that a core of either size may be used to measure shear tenderness.

In many studies, significant negative correlation coefficients have been found for Warner-Bratzler shear stress values and subjective tenderness scores. These data were significantly correlated in a study in which Brady (1937) used the triceps brachii, longissimus dorsi, adductor, and semitendinosus muscles from yearling steers and mature cows.

Mackintosh et al. (1936) stated that where beef from cattle of varying ages was considered as one group, the coefficient of correlation between the tenderness scores of the palatability committee and shear values of the cooked sample was significant. They also concluded that the Warner-Bratzler shearing apparatus was, at that time, the most accurate method of determining tenderness. They believed that the fact that a significant

correlation existed between shear values and percent of collagen nitrogen and between percent of collagen nitrogen and palatability scores for tenderness indicated that all three methods measure some factor related to tenderness, and probably the same thing.

When 25 beef muscles were cooked in lard to  $76.7^{\circ}\text{C}$ . by Ramsbottom et al. (1945) there was a high correlation between shear values and the organoleptic rating for tenderness. Histological ratings for certain muscles, however, were widely divergent from shear values.

Deatherage and Garnatz (1952) reported correlations which were non-significant for shear values and panel tenderness scores for 32 pairs of matched shortloins. In their study all out-of-line shear readings attributable to artery or connective tissue were discarded. In contrast to the conclusion of Mackintosh et al. (1936) they stated that the Warner-Bratzler machine and the palatability panel measured some quality of meat in a reproducible manner, but that it was not the same property. The sensory panel method was preferred for investigations of tenderness as a consumer quality attribute.

Cover and Smith (1956) found highly significant correlations between tenderness scores and shear force values for steaks from both the longissimus dorsi and biceps femoris muscles, whether the broiling or braising method of cookery was used. However, Paul and co-workers (1956), when comparing the same cookery methods for muscles of the round, did not find a significant correlation between shear force and tenderness scores.

Kramer (1957) reported a new type of shear press which



employs a hydraulically driven piston that forces the test cell through the sample box. Resistance of the item, measured by compression of a proving ring dynamometer, is indicated on a gage. Since the test cell is directly attached to the proving ring, eliminating a major source of frictional error, the force developed by resistance of a food to shearing or compression is transferred to the measuring system.

McCarthy and King (1942) reported the use of a specially devised penetrometer for measuring tenderness. The instrument was not described and results were not given.

Mechanical Methods for Measuring Juiciness. Gaddis et al. (1950) stated that a great deal of the disagreement in the literature with respect to the relationship between scores for quantity of juice and amount of press fluid must be attributable to differences in interpretation of juiciness. In their study of ribeye muscle cooked to 60°C., there was not a significant correlation between the amount of press fluid expressed at 9,800 p.s.i.g. and the scores for quantity of juice.

In many studies of meat the Carver-Laboratory press has been used for obtaining an objective measurement of juiciness. The pressometer is a similar machine which has been used frequently. Press fluid has been defined as the fluid consisting of moisture, soluble material, and a colloidal fraction pressed from muscle by the pressometer (Child and Moyer, 1938).

Child and Fogarty (1936) found a significant negative correlation between the percentage of press fluid, as measured by the pressometer, and total cooking losses in the semitendinosus

muscle cooked to 75°C. No such relationship existed when the muscle was cooked to 58°C.

The pressometer was used by Child and Moyer (1938) to determine sampling variation in amounts of press fluid. Pressure of 250 pounds per square inch was applied for 10 minutes to samples from the semitendinosus muscle of beef animals and several cuts of pork. The quantity of press fluid from comparable slices of beef and of pork taken at equal distances from each side of the center of the roast did not vary significantly. Neither was there a significant difference between halves of roasts. Successive slices from the center to outside of the roast gave significantly smaller amounts of press fluid. There were significant negative correlations between cooking losses and the amounts of press fluid in pork, but not in beef.

#### Factors That Affect Cooking Losses and Shrinkage

When meat is cooked there is a decrease in volume, as a result of shrinkage of the fibers; and a loss in weight, brought about by the escape of volatile constituents, as well as fat and other drip losses. A number of factors influence the magnitude of these losses. Thille et al. (1932) found that total cooking loss in weight from fat roasts was greater than that from lean roasts. The age of the animal may be a factor because Jacobson and Fenton (1956) found that drip losses tended to decrease with increasing age of the animal. However, they found no relationship between the level of nutrition and cooking losses.

Paul and Bratzler (1955b) found that a major variation in

cooking losses was attributable to differences among muscles. The steaks from the adductor had higher losses than those from the semimembranosus, and losses tended to increase with increased cooking time.

Aging and Frozen Storage. Paul and Child (1937) found significantly greater total losses, including thawing and cooking losses, in frozen than in unfrozen beef. Losses were greater when frozen meat was thawed at 175°C. than when thawed at 24°C., because beef thawed at the lower temperature gained weight instead of losing it by evaporation.

Paul and Bratzler (1955a) reported greater cooking losses in steaks that had been frozen than in those which had not, when the steaks were cooked in deep fat to 63°C. Frozen steaks cooked without thawing had the highest losses. Losses varied between the ends of the muscle, the posterior end having greater losses than the anterior end.

Wierbicki et al. (1957) studied drip losses from fresh and frozen meat thawed at 40°C. They observed that drip losses on frozen aged meat were much less than on frozen unaged meat. Although drip losses on unaged meat were greater for frozen than for fresh meat, the reverse was true for aged meat. Losses decreased with aging both for frozen and unfrozen meat.

Effect of Temperature. Morgan and Nelson (1926) stated that shrinkage of meat is governed by the length of exposure to oven heat. They noted a relatively small decrease in shrinkage when the searing oven temperature of 250°C. was lowered after 15 minutes to 175°C.

The semitendinosus muscle was cooked to an internal temperature of 58°C. at oven temperatures of 125°, 150°, 175°, and 200°C., Child and Satorius (1938). They found that cooking losses were increased with increased exterior temperature because of losses from evaporation. Cooking losses were greater at 200°C. and at 150°C. following searing than at 150°C. constant temperature. High exterior temperature and searing caused increased cooking losses in rare meat, but not in well-done meat.

Internal temperatures of 58°, 67°, and 75°C. were used as endpoints for cooking roasts from the longissimus dorsi, adductor, triceps brachii, and semitendinosus muscles in another study by Satorius and Child (1938). With increasing degree of coagulation of the semitendinosus muscle total losses were increased with each increment of temperature.

Siemers and Hanning (1953) reported that increasing the temperature of braising and the length of cooking time significantly increased the juice loss from small samples of braised beef. Juiciness scores decreased with increasing juice loss caused by longer cooking.

Method of Cooking. In a study by Siemers and Hanning (1953) roasts that were covered with suet before braising had lower juice losses than roasts that were not treated in this manner, but the judges could not detect the differences in juiciness between the standard samples and the suet-covered samples.

Paul et al. (1956) found that roasts from beef round braised to 80°C. had 29 percent greater cooking losses than roasts cooked by dry heat to 71°C. The greater losses may have

been attributable to longer cooking time and higher internal temperature rather than to the method of cooking. The correlation coefficients between raw surface area and percentage of shrinkage were not significant.

It was reported by Hood et al. (1955) that the percent of cooking loss attributable to drippings was greater when muscles of the beef round were cooked by braising than when they were roasted or broiled. The same internal temperature, 176°F., was used as the endpoint in both methods. The weight losses were influenced by the thickness of the cut. They found that oven-braised meats had a higher percent of loss in drippings than the surface-braised meats.

Morgan and Nelson (1926) found a two percent greater loss of volatilized matter, largely water, in open pan roasting than when a covered pan was used. This volatile loss was about one-third of the total shrinkage in weight.

The Presence of Electrolytes. Wierbicki et al. (1957) studied the effect of adding citric acid and chlorides of sodium, potassium, calcium, and magnesium on the water holding capacity (shrinkage) of meat. They discovered that these chlorides, when added to meat prior to heating to 70°C., increased the water holding capacity of meat proteins except when very high concentrations were used. The juice expressed on heating was less for calcium and magnesium chlorides than for sodium and potassium chlorides. The shrinkage was increased by the addition of citric acid prior to heating. Combinations of sodium and magnesium chlorides showed the greatest effect in promoting

water holding capacity of cooked meat.

#### EXPERIMENTAL PROCEDURE

The long hindquarters (round, tenderloin, and loin, cut from the chuck between the fourth and fifth ribs) of three U. S. Good grade steers were purchased from a Kansas City packing company and shipped to the Kansas State College Animal Husbandry Meats Laboratory six to eight days after slaughter. The carcass was dissected into the paired muscles and their respectively coded roasts listed in Table 1. In addition to the code letter, l or r was used to designate the left and right sides of the carcass.

Table 1. Coded roasts of the muscles used.

Muscle	: Roast code
Psoas major	A, B
Adductor	C, D
Rectus femoris	E, F
Vastus lateralis	G, H
Semitendinosus	J, K, L
Longissimus dorsi (loin)	M, N, O
Semimembranosus (posterior)	P, Q
Semimembranosus (anterior)	R, S
Longissimus dorsi (rib)	T, U, V

As the muscles were dissected and trimmed of most of the visible fat, samples were removed for histological and chemical studies on the raw meat. When the muscles were labeled and sampled, the anterior or proximal end of the muscles from the right side of the animal were placed to the right of the cutter,

and the anterior or proximal end of the muscles from the left side were placed to the left of the cutter. Histological samples were taken from the surface facing the cutter. A physiological salt solution and formalin were used for preserving these samples. The chemical samples were ground and frozen in glass bottles. The analyses of the latter two samples are part of a larger study and the results are not included in this thesis. Pictures of the muscles from one animal are shown in Plates I through VIII. The roasts, labeled with code letter, side letter, and internal cooking temperature, were wrapped individually in 0.0015 gauge aluminum foil. The meat was immediately frozen in an upright household freezer on plates containing coils and maintained at  $-20^{\circ}\text{F.}$ , and the meat was held at that temperature prior to defrosting. All roasts were cooked within 12 weeks after freezing.

#### Statistical Design

For the roasts from the longissimus dorsi (loin and rib sections) and the semitendinosus muscles, an incomplete block design, that consisted of the left and right cuts of a muscle, was used to determine the internal temperature in degrees centigrade. The corresponding muscles from the left and right sides of one animal were one replication. These muscles from each of the three animals, with the three temperatures, representing rare, medium-, and well-done are listed in Table 2.

For the six muscles shown in Table 3 a randomized complete block design was used to determine the internal temperature of

EXPLANATION OF PLATE I

Top of plate:

Psoas major muscle, right side from Animal XIII.

Bottom of plate:

Psoas major muscle from the left side of Animal XIII, divided into roasts A1 (anterior end) and B1 (posterior end), and penetrometer sample.



PLATE I



EXPLANATION OF PLATE II

Top of plate:

Adductor muscle, right side from Animal XIII.

Bottom of plate:

Adductor muscle from left side of Animal XIII, divided into roasts C1 (proximal end) and D1 (distal end), and penetrometer sample.

PLATE II



EXPLANATION OF PLATE III

Top of plate:

Rectus femoris muscle, right side from Animal XIII.

Bottom of plate:

Rectus femoris muscle from the left side of Animal XIII,  
divided into roasts E1 (proximal end) and F1 (distal end),  
and penetrometer sample.

PLATE III



EXPLANATION OF PLATE IV

Left side of plate:

Vastus lateralis muscle from the left side of Animal XIII, divided into roasts G1 (proximal end) and H1 (distal end), and penetrometer sample.

Right side of plate:

Vastus lateralis muscle, right side from Animal XIII.

PLATE IV



EXPLANATION OF PLATE V

Top of plate:

Semitendinosus muscle, right side from Animal XIII.

Bottom of plate:

Semitendinosus muscle from the left side of Animal XIII,  
divided into roasts J1 (proximal end), L1 (distal end),  
and K1 (center), and penetrometer samples.



PLATE V



EXPLANATION OF PLATE VI

Top of plate:

Loin section of the longissimus dorsi muscle, right side from Animal XIII.

Bottom of plate:

Loin section of the longissimus dorsi muscle from left side of Animal XIII, divided into roasts M1 (anterior end), O1 (posterior end), and N1 (center), penetrometer samples, and samples for chemical analyses.

PLATE VI



EXPLANATION OF PLATE VII

Top of plate:

Seminembranosus muscle, right side from Animal XIII.

Bottom of plate:

Seminembranosus muscle from left side of Animal XIII, divided into roasts P1 (posterior side, proximal end), Q1 (posterior side, distal end), R1 (anterior side, proximal end), and S1 (anterior side, distal end), penetrometer samples, and samples for chemical analyses.

PLATE VII



EXPLANATION OF PLATE VIII

Top of plate:

Rib section of the longissimus dorsi muscle, right side from Animal XIII.

Bottom of plate:

Rib section of the longissimus dorsi muscle from left side of Animal XIII, divided into roasts T1 (anterior end), V1 (posterior end), and U1 (center), penetrometer samples, and samples for chemical analyses.

PLATE VIII



Table 2. Internal temperatures, representing the end point of cooking for roasts from three muscles.

Muscle	: Animal : number	: Roasts and internal : temperature, °C.					
		<u>Jl</u>	<u>Jr</u>	<u>Kl</u>	<u>Kr</u>	<u>Ll</u>	<u>Lr</u>
Semitendinosus							
	IX	45	65	85	65	45	85
	XI	45	45	65	65	85	85
	XIII	45	85	85	45	65	65
Longissimus dorsi (loin section)							
	IX	85	65	45	85	45	65
	XI	65	45	85	85	45	65
	XIII	65	45	45	65	85	85
Longissimus dorsi (rib section)							
	IX	65	85	45	65	45	85
	XI	45	65	65	85	85	45
	XIII	45	85	65	45	65	85

the roasts. The posterior and anterior parts of the semimembranosus were considered as two muscles.

#### Method of Cooking and Data Obtained

The roasts that were to be cooked in one cooking period were defrosted for approximately 48 hours at 43°F. in a household refrigerator. One replication of roasts was cooked in a single cooking period and in random order. The weight of the thawed roast and weight of the meat thermometer were recorded and the thermometer was placed with the bulb in the center of the thickest portion of the roast. Roasts were cooked in household electric deep-fat fryers in a medium of hydrogenated vegetable fat, maintained at 100° ± 4°C. The time required for each 5°C. rise in the internal temperature of the meat was recorded



Table 3. Internal temperatures, representing the end point of cooking for roasts from six muscles.

Muscle	: Animal : : number :	Roasts and internal temperatures, °C.			
Psoas major		<u>Al</u>	<u>Ar</u>	<u>B1</u>	<u>Br</u>
	IX	65	45	65	45
	XI	65	45	45	65
	XIII	65	45	65	45
Adductor		<u>C1</u>	<u>Cr</u>	<u>D1</u>	<u>Dr</u>
	IX	65	45	45	65
	XI	45	65	45	65
	XIII	65	45	45	65
Rectus femoris		<u>E1</u>	<u>Er</u>	<u>F1</u>	<u>Fr</u>
	IX	45	65	45	65
	XI	45	65	65	45
	XIII	65	45	45	65
Vastus lateralis		<u>G1</u>	<u>Gr</u>	<u>H1</u>	<u>Hr</u>
	IX	65	45	65	45
	XI	65	45	45	65
	XIII	45	65	65	45
Semimembranosus (posterior)		<u>P1</u>	<u>Pr</u>	<u>Q1</u>	<u>Qr</u>
	IX	45	65	45	65
	XI	65	45	65	45
	XIII	45	65	65	45
Semimembranosus (anterior)		<u>R1</u>	<u>Rr</u>	<u>S1</u>	<u>Sr</u>
	IX	65	45	45	65
	XI	65	45	65	45
	XIII	65	65	45	45

to the nearest five seconds.

The internal end temperatures 45°, 65°, and 85°C. were chosen with the desire to approximate the final internal temperatures of 55°, 70°, and 85°C., which represent rare, medium-, and

well-done, respectively. This procedure was necessary because it was observed in preliminary work that when the meat was cooked to the lower internal temperatures, the temperature continued to rise after roasts were removed from the fat. The roasts were drained and allowed to reach the maximum temperature, which was recorded, before weighing. From this final weight and the initial weight of the thawed meat the total cooking losses were calculated. Cooking time, in minutes per pound, was determined.

Samples for histological studies were taken from all roasts, and chemical samples were taken from the longissimus dorsi and semimembranosus roasts only. Shear cores, one-inch in diameter, were cut parallel to the fiber axis through the center of the roasts. These cores were sheared crosswise on the Warner-Bratzler shearing apparatus, which measures the force in pounds that is required to cut through the one-inch core. Five shear readings were recorded and averaged for each core.

Samples of meat for tasting by the palatability panel were sliced on a household rotary blade slicer. Each judge received a slice from approximately the same position in every roast. Scores from one, extremely poor, to ten, extremely good, were given each sample for aroma, flavor, juiciness, and tenderness by the judges. Tenderness scores were based on the number of chews that were necessary to completely masticate a bite of certain size.

Also, the judges rated the samples in order of their preference for juiciness and tenderness, and scores were assigned to the juiciness and tenderness preference ratings. A rating of one received a score of one, etc. When two or more samples

received the same rating, the sum of the scores that they represented, two, three, and four, were divided equally among them. Thus, three samples sharing a preference rating of second place would each be assigned a score of three. All judges' scores and scores assigned to preference ratings were averaged for each roast.

The remainder of the roast was ground in a Universal No. 3 food grinder and stored in closed glass jars in the refrigerator overnight. These ground samples were used for determining press fluid yields the following day. Twenty-five grams of the ground meat were placed in a 2.25-inch metal cylinder between four layers of filter paper in a circle of cheesecloth. A leather disc and metal plunger were fitted on top of the meat sample and the entire assembly in a shallow stainless steel pan with pouring lip, was placed on a Carver Laboratory Press. Pressure was applied according to the following schedule:

<u>Time in minutes</u>	<u>Pressure in pounds</u>
1.0	5,000
2.0	7,500
3.0	10,000
5.0	10,000
7.5	12,500
10.0	15,000
11.0	16,000
15.0	16,000

The pressure refers to the total pressure on the 1.25-inch ram of the metal cylinder. After the pressure was released, any juice clinging to parts of the cylinder was scraped into the pan with a small rubber policeman and the entire sample was transferred to a centrifuge tube with the same implement. After

standing overnight in the refrigerator the amounts of total press fluid, serum, and fat were read to the nearest one-tenth milliliter in the graduated tube. Duplicate determinations were made on each sample.

A Precision Penetrometer was used to measure the consistency of the ground, raw meat. The samples were hand packed in round aluminum moisture cups, two and one-half inches in diameter and three-fourths-inch in height and placed in the refrigerator for 30 minutes before testing. The cups were filled with meat so that there were no air spaces and no definite weight of meat was used. The one-quarter-scale cone of the penetrometer was allowed to penetrate the surface of the meat for five seconds and the depth of penetration was read in tenths of millimeters. Readings were taken from six positions in the sample. One reading was taken in the center and the other five were taken half-way between the center and the edge around the cup.

### Statistical Analysis

Analyses of variance were run to determine any differences, attributable to internal temperature, in cooking losses, cooking time, shear values, press fluid yields, aroma, flavor, tenderness, juiciness, and preferences for juiciness and tenderness for roasts from the longissimus dorsi (loin and rib sections) and the semitendinosus muscles. The means of these factors for each internal temperature were arrayed and Fischer's least significant difference was computed to analyze them when they were significant. The t-test was used to determine differences in the

same factors for the psoas major, adductor, vastus lateralis, rectus femoris, and semimembranosus muscles.

Correlation coefficients for roasts from each muscle cooked to each internal temperature were computed for tenderness scores versus penetrometer readings, tenderness scores versus shear values, juiciness scores versus press fluid yields, juiciness scores versus penetrometer readings, cooking losses versus juiciness scores, cooking losses versus press fluid yields, and cooking losses versus penetrometer readings. Also, correlation coefficients for these factors were calculated with roasts from all muscles cooked to a given temperature considered as one group.

## RESULTS AND DISCUSSION

### Appearance of the Meat

All roasts, whether cooked to 45°, 65°, or 85°C., were similar in external appearance. The surfaces had the greyish-brown color of cooked meat, but were not browned in the way that is characteristic of roasts cooked in the oven. The center of the roasts cooked to 45°C. was a bright pink and exuded a red juice. The pink color gradually faded to a greyish-brown around the edge. The center of the roasts cooked to 65°C. was a light pink that faded to greyish-brown about half way through the roast, whereas the interior of the roasts cooked to 85°C. was a uniform grey-brown color.

### Measurements for Juiciness

Cooking Time and Cooking Losses. The amount of cooking loss,

which is affected by the length of cooking time, is related to juiciness of the cooked meat. As meat is cooked the amount of water that is bound is comparatively small, according to Siemers and Hanning (1953); therefore, the largest portion of the water remains in the free state. When large amounts of water are lost through evaporation and dripping during cooking, less remains to contribute to the juiciness of the meat.

The average cooking times, in minutes per pound, average cooking losses, and the significance of the effect of internal temperature on these factors are shown in Table 4. T-tests were used to determine significant differences when roasts were cooked to two internal temperatures and analyses of variance and least significant difference were used for three internal temperatures. As the internal temperature of the roasts was increased, average cooking time, in minutes per pound, increased significantly for the roasts from all muscles, and was accompanied by a significant increase in average cooking losses from all roasts except those from the adductor and semimembranosus (posterior) muscles. The cooking time, in minutes per pound, ranged from 19 to 63 minutes. Roasts cooked to  $45^{\circ}\text{C}$ . required from 19 to 26 minutes per pound; those cooked to  $65^{\circ}\text{C}$ . required 30 to 40 minutes per pound; and those cooked to  $85^{\circ}\text{C}$ . required 50 to 63 minutes per pound. There was a greater difference between the time required for cooking the roasts to  $65^{\circ}$  and  $85^{\circ}\text{C}$ . than between  $45^{\circ}$  and  $65^{\circ}\text{C}$ ., which indicated that protein coagulation was taking place at the higher temperatures.

The average weight of the roasts, shown in Table 4, from

Table 4. Average weight, cooking time, total cooking losses, and average of mean press press fluid yields, palatability scores for juiciness, and scores assigned to judges' preference ratings for juiciness.<sup>1</sup>

Muscle	Int. temp. : °C.	Wt. of roast : lbs.	Ckg. time : min./lb.	Ckg. losses : %	Press fluid : ml/25 g.	Juiciness: Juiciness	
						score : 10-1	score : pref.
Psoas major	45	1.1	20.3***	17.4***	10.0***	8.9***	2.4
	65	1.1	33.2	23.2	8.9	8.0	2.6
Adductor	45	1.2	26.3***	21.5	8.8	8.3**	2.0***
	65	1.1	34.4	25.4	8.4	6.9	3.0
Rectus femoris	45	1.5	25.8**	24.4**	9.1*	8.1**	2.2
	65	1.4	38.2	31.3	8.1	7.0	2.6
Vastus lateralis	45	1.8	21.0***	20.8***	9.4***	8.6***	1.9***
	65	1.6	32.2	29.4	8.0	5.8	3.1
Semimembranosus (posterior)	45	1.6	22.2***	20.2	9.4*	8.7	2.2*
	65	1.5	31.7	24.6	8.4	7.4	2.7
Semimembranosus (anterior)	45	1.9	21.8***	22.8***	9.3*	8.0***	2.1
	65	1.9	29.8	30.7	8.5	6.7	2.7
Semitendinosus	45	1.1	26.0*	17.4*	9.5	8.3*	2.5*
	65	1.3	36.6*	25.1*	8.8*	7.0	3.4
	85	1.2	62.6	35.3	6.4	6.6	3.9
			l <sub>sd</sub> =8.0	l <sub>sd</sub> =2.4	l <sub>sd</sub> =0.9	l <sub>sd</sub> =0.6	l <sub>sd</sub> =0.6

Table 4. (concl.)

Muscle	Int. temp. : °C.	wt. of roast : lbs.	of time : min./lb.	Ckg. losses : %	Press : fluid ml/25 g.	Julciness : score	Julciness : score
Longissimus dorsi (loin)	45	1.3	19.2*	17.6*	9.2*	9.2*	3.0
	65	1.2	29.8*	26.8*	8.1*	7.6*	3.1
	85	1.1	50.1	35.2	6.3	6.2	4.3
			lsd=5.5	lsd=2.3	lsd=0.8	lsd=1.3	lsd=1.3
Longissimus dorsi (rib)	45	1.3	24.9*	23.0	9.0	9.0*	2.8
	65	1.2	35.1*	28.5*	7.6*	7.4*	3.3*
	85	1.4	51.4	35.5*	7.0	6.2*	4.4
			lsd=7.4	lsd=5.9	lsd=1.6	lsd=1.1	lsd=0.8

1. The possible preference ratings ranged from 1 to 6. Lower numbers indicate higher preference.

- \* - significant at the .05 level
- \*\* - significant at the .01 level
- \*\*\* - significant at the .001 level
- lsd - least significant difference at the .05 level



different muscles varied from 1.1 to 1.9 pounds. In general, cooking time, in minutes per pound, was not related to the weight, but was more dependent on the shape of the roasts. The long, flat roasts cooked more quickly than the thick, blocky ones. This will be discussed further under rate of heat penetration.

The range in average cooking losses was from 17.4 to 24.4 percent for roasts cooked to 45°C., from 23.3 to 31.3 percent for those cooked to 65°C., and from 35.2 to 35.5 percent for those cooked to 85°C. The only differences between cooking losses attributable to internal temperature that were not significant were those for the adductor and semimembranosus (posterior) muscles cooked to 45° and 65°C.

Press Fluid Yields. Since press fluid is the amount of juice remaining in the meat after it is cooked, it is to be expected that roasts cooked for a longer period of time would have smaller amounts of press fluid. In the present study significant differences between amounts of press fluid yielded by roasts cooked to two or three internal temperatures were found for the psoas major, rectus femoris, vastus lateralis, semitendinosus, semimembranosus, and the longissimus dorsi (loin and rib) muscles. Differences in press fluid yields that were attributable to the internal temperature of roasts from the adductor muscle were not significant, Table 4. Roasts from the vastus lateralis cooked to 45°C. yielded significantly ( $P < .001$ ) more press fluid than those cooked to 65°C. For all other muscles the differences in press fluid from roasts cooked to 45° and 65°C. or 65° and 85°C. were significant at the five percent

level. The amount of press fluid yielded by all roasts decreased slightly with increased internal temperature.

All of the correlation coefficients for cooking losses and press fluid yields were negative except those for roasts from the adductor and longissimus dorsi (rib) muscles cooked to 45°C. and those from the semitendinosus cooked to 65° and 85°C., Table 5. However, the only significant coefficients were for the roasts from the rectus femoris cooked to 65°C. and for the vastus lateralis cooked to 45° and 65°C. The number of degrees of freedom was very small; therefore, an extremely high correlation coefficient was need for significance. The psoas major muscle cooked to 45°C. had a high negative correlation coefficient for cooking losses versus press fluid yields even though it was not significant. When all of the muscles cooked to each internal temperature were considered together, the correlation coefficient, -0.417, was significant at the one percent level for roasts cooked to 45°C., and -0.547, significant at the one-tenth percent level for roasts cooked to 65°C.

Juiciness Scores. The differences between mean palatability scores for juiciness and scores assigned to judges' preference ratings for juiciness attributable to internal temperature are listed in Table 4. All differences between palatability scores were significant with the exception of roasts from the semimembranosus (posterior) muscle and between roasts from the semitendinosus muscle cooked to 65° and 85°C. The juiciness scores decreased and the assigned preference scores for juiciness increased with increasing internal temperature. The higher

Table 5. Correlation coefficients for cooking losses and press fluid yields, cooking losses and juiciness scores, press fluid yields and juiciness scores, and shear values and tenderness scores.

Factor	: 45°C.	: 65°C.	: 85°C.
<b>Cooking losses and press fluid</b>			
Psoas major	-.760	-.134	
Adductor	.487	-.494	
Rectus femoris	-.634	-.911 *	
Vastus lateralis	-.914 *	-.967 ***	
Semimembranosus (posterior)	-.471	-.427	
Semimembranosus (anterior)	-.258	-.462	
Semitendinosus	-.066	.483	.202
Longissimus dorsi (loin)	-.611	-.520	-.609
Longissimus dorsi (rib)	.433	-.045	-.577
<b>Cooking losses and juiciness scores</b>			
Psoas major	-.744	-.491	
Adductor	-.588	-.172	
Rectus femoris	-.363	-.061	
Vastus lateralis	-.497	-.045	
Semimembranosus (posterior)	-.730	-.023	
Semimembranosus (anterior)	-.855 *	-.754	
Semitendinosus	-.048	.583	.430
Longissimus dorsi (loin)	.523	.283	.261
Longissimus dorsi (rib)	.582	-.474	.115
<b>Press fluid and juiciness scores</b>			
Psoas major	.765	-.288	
Adductor	-.895 *	.633	
Rectus femoris	-.230	.246	
Vastus lateralis	.629	.058	
Semimembranosus (posterior)	.718	.000	
Semimembranosus (anterior)	.275	.360	
Semitendinosus	.104	.417	-.443
Longissimus dorsi (loin)	.391	.469	-.247
Longissimus dorsi (rib)	.598	.351	.722
<b>Shear values and tenderness scores</b>			
Psoas major	-.858 *	-.332	
Adductor	.169	-.794	
Rectus femoris	-.036	-.359	
Vastus lateralis	.639	.825 *	
Semimembranosus (posterior)	-.497	-.540	
Semimembranosus (anterior)	-.715	-.512	
Semitendinosus	-.381	-.203	-.730
Longissimus dorsi (loin)	-.700	.091	-.511
Longissimus dorsi (rib)	-.667	-.047	-.779

preference scores indicated lower preferences. The differences between preference ratings attributable to internal temperature were significant for roasts from the adductor, vastus lateralis, and semimembranosus muscles, between  $45^{\circ}$  and  $65^{\circ}$ C. for the semitendinosus,  $65^{\circ}$  and  $85^{\circ}$ C. for the longissimus dorsi (rib), and  $45^{\circ}$  and  $85^{\circ}$ C. for the longissimus dorsi (loin).

As mentioned previously, the juiciness scores and press fluid yields decreased and cooking losses increased with each increment of increase in internal temperature; thus negative correlation coefficients for juiciness scores and cooking losses and positive coefficients for press fluid yields and juiciness scores would be expected. In the Review of Literature it was pointed out that many workers found this to be true, whereas others did not. In this study there were 14 negative and seven positive correlation coefficients for cooking losses and juiciness scores, and several of the negative coefficients were quite low, Table 5. All coefficients for juiciness scores and cooking losses for roasts cooked to  $85^{\circ}$ C. were positive. The only significant correlation coefficient was for roasts from the semimembranosus (anterior) muscle cooked to  $45^{\circ}$ C. If there had been a larger number of animals to allow for more degrees of freedom, a larger number of significant coefficients probably would have been found. For example, the correlation coefficient for roasts from the psoas major cooked to  $45^{\circ}$ C. (-.744) and that for roasts from the semimembranosus (posterior) cooked to  $45^{\circ}$ C. and the semimembranosus (anterior) cooked to  $65^{\circ}$ C. (-.754) may have been significant. When correlation coefficients for cooking

losses and juiciness scores for all muscles cooked to a given internal temperature were calculated, the coefficients,  $-0.342$  and  $-0.318$ , were significant at the two percent level for roasts cooked to  $45^{\circ}$  and  $65^{\circ}\text{C.}$ , respectively.

The correlation coefficients for press fluid yields and juiciness scores were positive for roasts from all muscles except the adductor and rectus femoris cooked to  $45^{\circ}\text{C.}$  and the semitendinosus and longissimus dorsi (loin) cooked to  $85^{\circ}\text{C.}$ , Table 5. It is interesting to note that the only significant correlation coefficient, that for roasts from the adductor muscle cooked to  $45^{\circ}\text{C.}$ , was negative, which indicated an inverse relationship between the two factors. When roasts from all muscles cooked to a given temperature were grouped together, correlation coefficients for juiciness scores versus press fluid yields were  $+0.200$ ,  $+0.167$ , and  $+0.427$  for roasts cooked to  $45^{\circ}$ ,  $65^{\circ}$ , and  $85^{\circ}\text{C.}$ , respectively. These coefficients were non-significant at all temperatures.

#### Measurements for Tenderness

Tenderness Scores. The tenderness of cooked meat depends upon the degree of balance between the toughening effect of heat on meat protein as a result of coagulation and the softening effect of partial hydrolysis of collagenous tissue. It is to be expected that the more tender cuts of meat would be toughened by longer cooking, whereas cuts of meat with relatively large amounts of connective tissue would be made more tender by longer cooking. However, in this study the average tenderness scores for roasts

were approximately the same regardless of internal temperature, Table 6. The only statistically significant difference between tenderness scores that was attributable to internal temperature was for roasts from the semitendinosus muscle cooked to 45° and 65°C. The roasts cooked to 45°C. had an average tenderness score that was 0.4 of a point higher than those cooked to 65°C. When cooked to 85°C. the roasts were similar in tenderness to those cooked to 45°C., having a score only 0.1 of a point lower. In contrast roasts from the longissimus dorsi (loin) increased slightly in tenderness between 45° and 65°C. and decreased in tenderness between 65° and 85°C. These differences were not significant.

Preference scores for tenderness are presented in Table 6. The differences in preference scores for tenderness attributable to internal temperature that were significant were for roasts from the vastus lateralis and longissimus dorsi (rib) muscles cooked to 45° and 65°C., and from the semitendinosus muscle cooked to 65° and 85°C. The only significant differences among tenderness scores that were attributable to internal temperature were between scores for roasts from the semitendinosus that were cooked to 45° and 65°C. The average scores assigned to the judges' preference ratings for tenderness for roasts from the longissimus dorsi (loin) muscle cooked to 45° and 65°C. were the same. The roasts from the semitendinosus muscle cooked to 85°C. had slightly higher preference ratings than those cooked to 65°C. This is in agreement with the tenderness scores. For roasts from all other muscles the preference ratings for tenderness decreased

Table 6. Average of the mean palatability scores for aroma, flavor, tenderness, scores assigned to judges' preference ratings for tenderness, and mean shear values. Maximum possible palatability score, 10.

Muscle <sup>1</sup>	Int. temp. °C.	Aroma	Flavor	Tenderness score	Tenderness pref.	Shear values
Psoas major	45	7.6**	7.3	9.1	2.4	11.0*
	65	8.1**	8.2	9.0	2.5	14.0*
Adductor	45	7.1	7.2	7.6	2.4	17.9
	65	7.6	7.5	7.4	2.5	21.2
Rectus femoris	45	7.6*	7.8	7.7	2.2	17.4
	65	8.2*	7.7	8.1	2.5	20.6
Vastus lateralis	45	7.7	7.7	7.8	2.4*	20.4
	65	8.1	8.0	7.8	2.6*	19.6
Semimembranosus (posterior)	45	7.4*	7.5*	7.5	2.2	21.8
	65	7.9*	8.2*	7.1	2.7	23.6
Semimembranosus (anterior)	45	7.7	7.5	7.2	2.3	17.3
	65	7.8	7.6	6.9	2.8	22.0**
Semitendinosus	45	7.3	7.6	8.0*	2.8	31.3
	65	7.7]*	7.7	7.6*	3.8*	21.9
	85	8.2]	8.0	7.9	3.1*	21.9
		lsd=0.6		lsd=0.4	lsd=0.7	lsd=11.5
Longissimus dorsi (loin)	45	7.7	7.5	8.1	3.4	13.0
	65	7.6	7.7	8.2	3.4	13.6
	85	7.8	7.7	7.9	3.6	14.7
Longissimus dorsi (rib)	45	7.6]	7.7	8.6	2.6	13.4
	65	7.8]*	8.1*	8.1	3.7*	14.7
	85	8.2]	8.0	7.8	4.2	16.3
		lsd=0.5	lsd=0.4		lsd=1.1	

1.

Significant differences were determined by t-tests for the psoas major, adductor, rectus femoris, vastus lateralis, and semimembranosus (posterior and anterior) muscles.

\* - significant at the .05 level

\*\* - significant at the .01 level

\*\*\* - significant at the .001 level

lsd - least significant difference at the .05 level

slightly with increasing internal temperature.

Shear Values. The mean shear values and significance of the effect of internal temperature for roasts from all muscles are shown in Table 6. T-tests showed significant differences in shear values between roasts from the psoas major cooked to 45° and 65°C. and between roasts from the semimembranosus (anterior) cooked to 45° and 65°C. Analyses of variance revealed no significant differences among the shear values for roasts from any of the three muscles that were cooked to 45°, 65°, and 85°C. Shear values increased slightly with increasing internal temperature with the exception of roasts from the semitendinosus, which had the highest shear values when cooked to 45°C., and shear values that were 9.4 pounds lower when cooked to 65°C. and 85°C. than when cooked to 45°C. These differences were non-significant.

Roasts from the psoas major muscle were the most tender, as measured by shear values, with roasts from the longissimus dorsi (loin and rib) being slightly less tender. The remainder of the muscles in decreasing order of tenderness were: the rectus femoris, adductor, vastus lateralis, semimembranosus (anterior and posterior), and the semitendinosus. Roasts from the psoas major had average shear readings of 11.0 and 14.0 when cooked to 45° and 65°C., respectively, whereas roasts from the semitendinosus had average shear readings of 31.3 and 19.6 for the same internal temperatures.

Correlation coefficients for shear values versus tenderness scores are shown in Table 5. All but four of the coefficients were negative as would be expected, since higher shear values



are indicative of less tender meat. Three of the four positive coefficients were quite low, but the coefficient for roasts from the vastus lateralis cooked to 65°C. was .825 and was significant at the five percent level. The only other significant correlation coefficient for shear values and tenderness scores was that for roasts from the psoas major cooked to 45°C. Coefficients for roasts from all muscles cooked to a given internal temperature grouped together were -0.362, highly significant, and -0.573, very highly significant, for roasts cooked to 45° and 65°C., respectively. The coefficient for all roasts cooked to 85°C. was -.390 and non-significant.

#### Aroma and Flavor

Analyses of variance and t-tests were used to determine significant differences in aroma scores that were attributable to internal temperature. When the mean aroma scores for roasts cooked to three internal temperatures were arrayed for three muscles and analyzed by least significant difference, only the difference between scores for roasts from the semitendinosus and longissimus dorsi (rib) cooked to 45° and 85°C. were significant, Table 6. The differences between roasts cooked to 45° and 65°C. were significant at the five percent level for the rectus femoris and semimembranosus (posterior) muscles, and significant at the one percent level for the psoas major muscle.

When least significant differences were calculated, the difference in mean flavor scores attributable to internal temperature was significant between 45° and 65°C. for roasts from the

longissimus dorsi (rib) muscle, Table 7. T-tests showed that the only significant difference in flavor between 45° and 65°C., for roasts cooked only to those temperatures, was for roasts from the semimembranosus (posterior). Wherever there were significant flavor differences there were also significant differences in aroma, but the reverse was not always true. The difference between mean flavor scores for roasts from the longissimus dorsi (rib) cooked to 45° and 65°C. was 0.4 of a point, and that for the semimembranosus (posterior) cooked to the same temperatures was 0.7 of a point. Even though these differences were statistically significant, they probably are not large enough to be of practical value.

#### Rate of Heat Penetration

The heat penetration curves are presented in Figs. 1 through 9. In most of the curves there is a slight leveling off beginning around 55°C. This is a result of the endothermic process of protein coagulation, which begins at 60°C. or below. When roasts were cooked to 85°C. there was another slight plateau in the rise in internal temperature between 75° and 85°C. Lowe (1955) stated that when meat was cooked at low oven temperatures, 80° to 120°C., the internal temperature was often stationary for several minutes, indicating that considerable coagulation was taking place at that temperature.

There were no noticeable differences in the heat penetration curves between roasts from corresponding muscles of the left and right sides of the animal, nor between the anterior and posterior

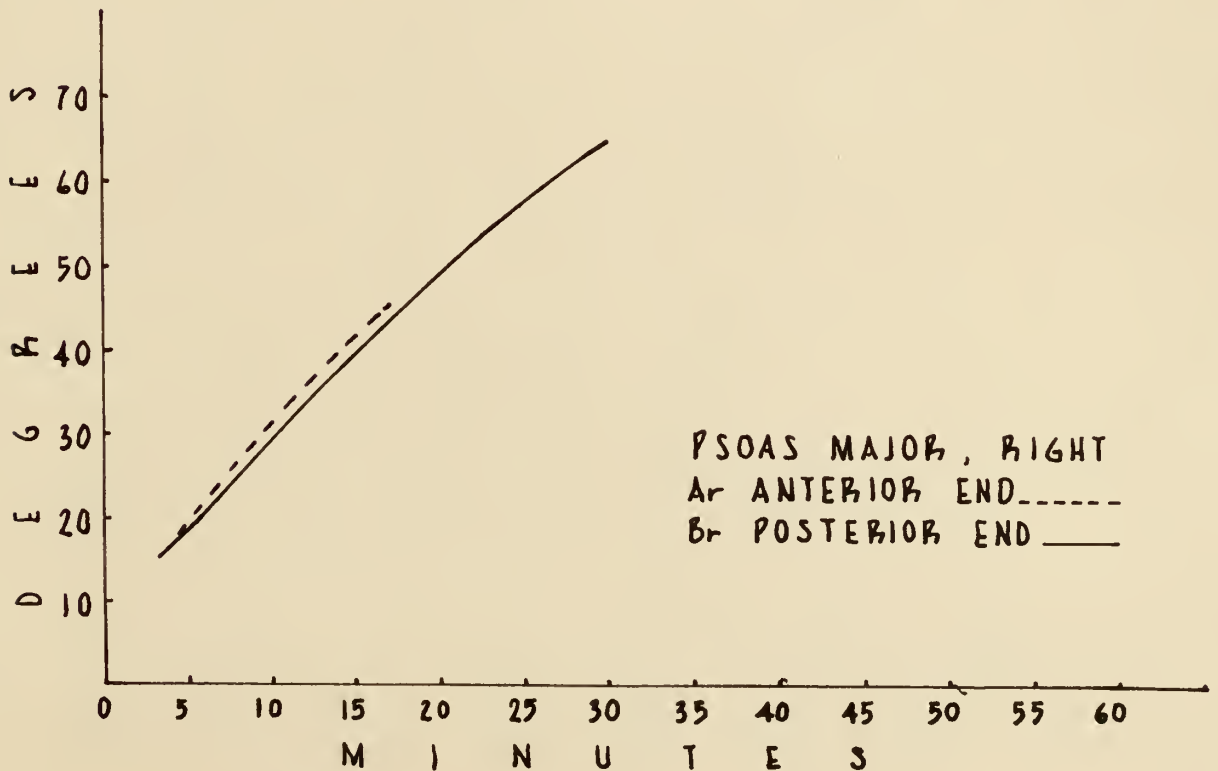
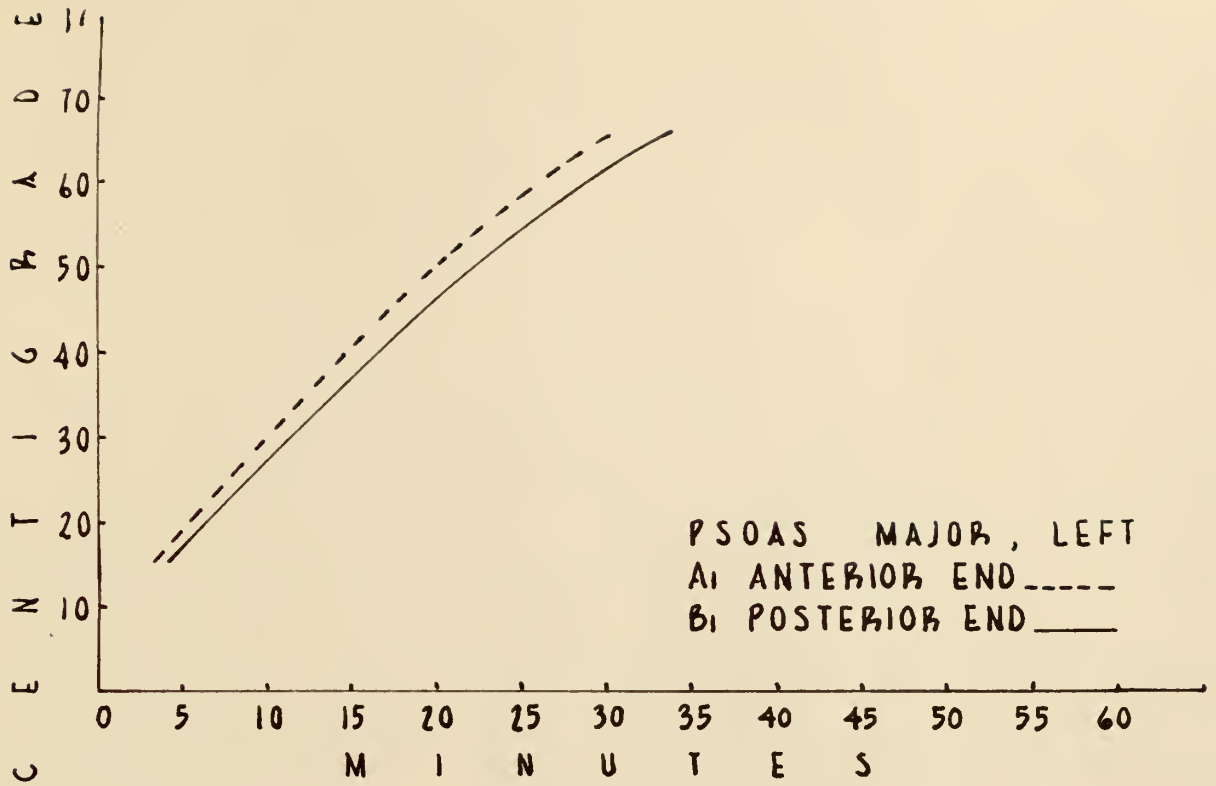


Fig. 1. Average heat penetration curves for the psoas major muscle.

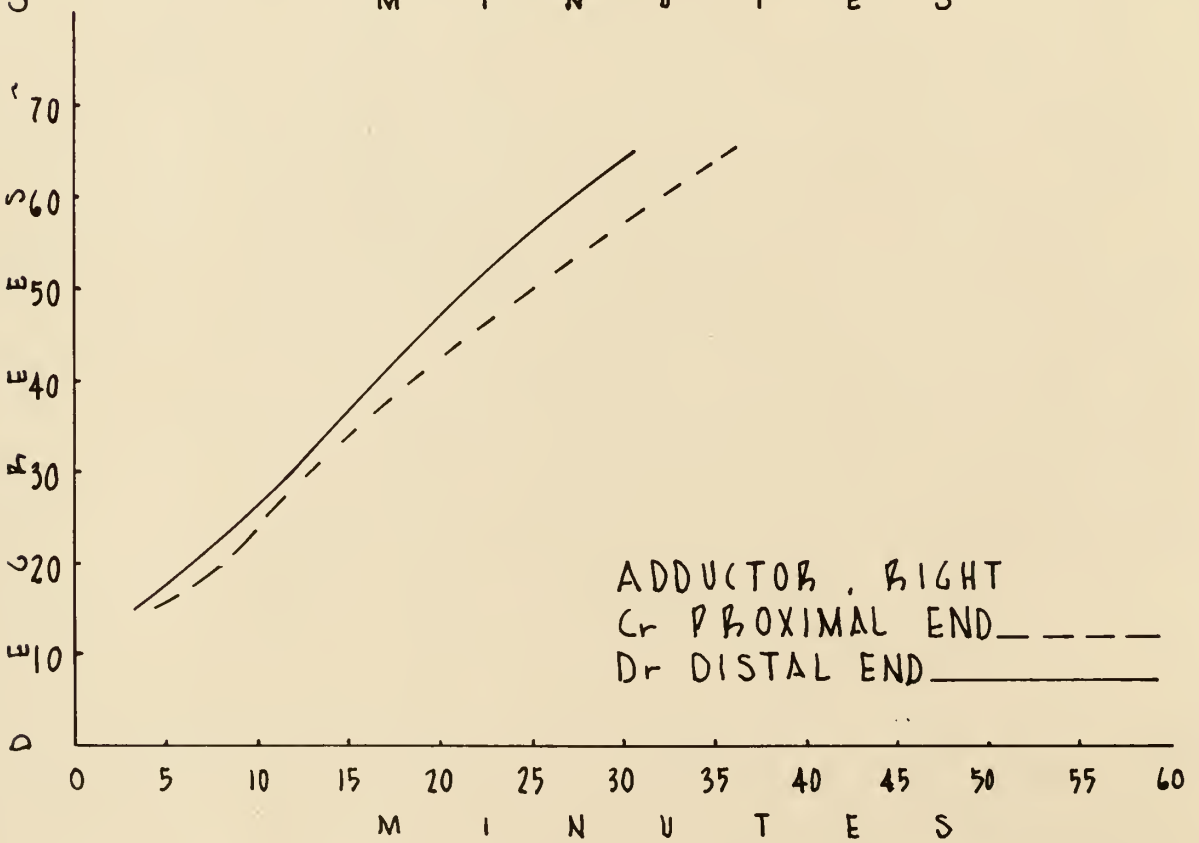
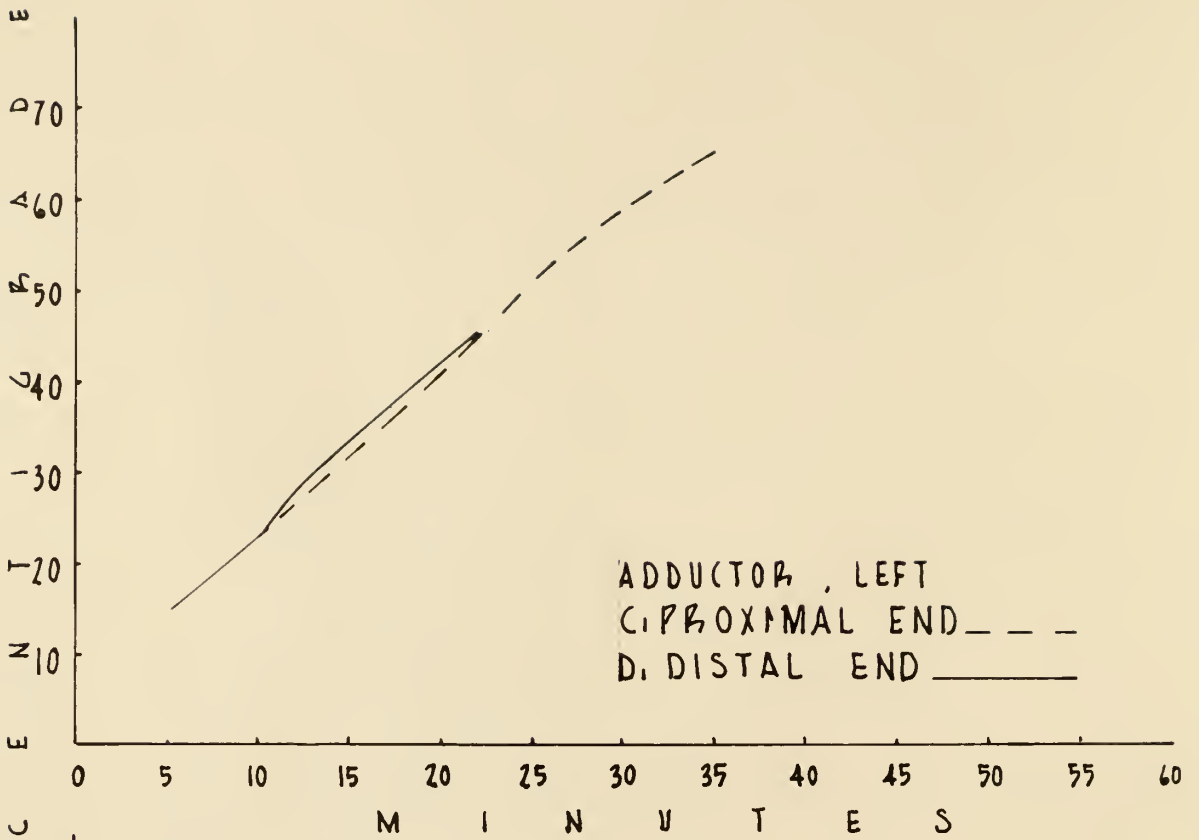


Fig. 2. Average heat penetration curves for the adductor muscle.

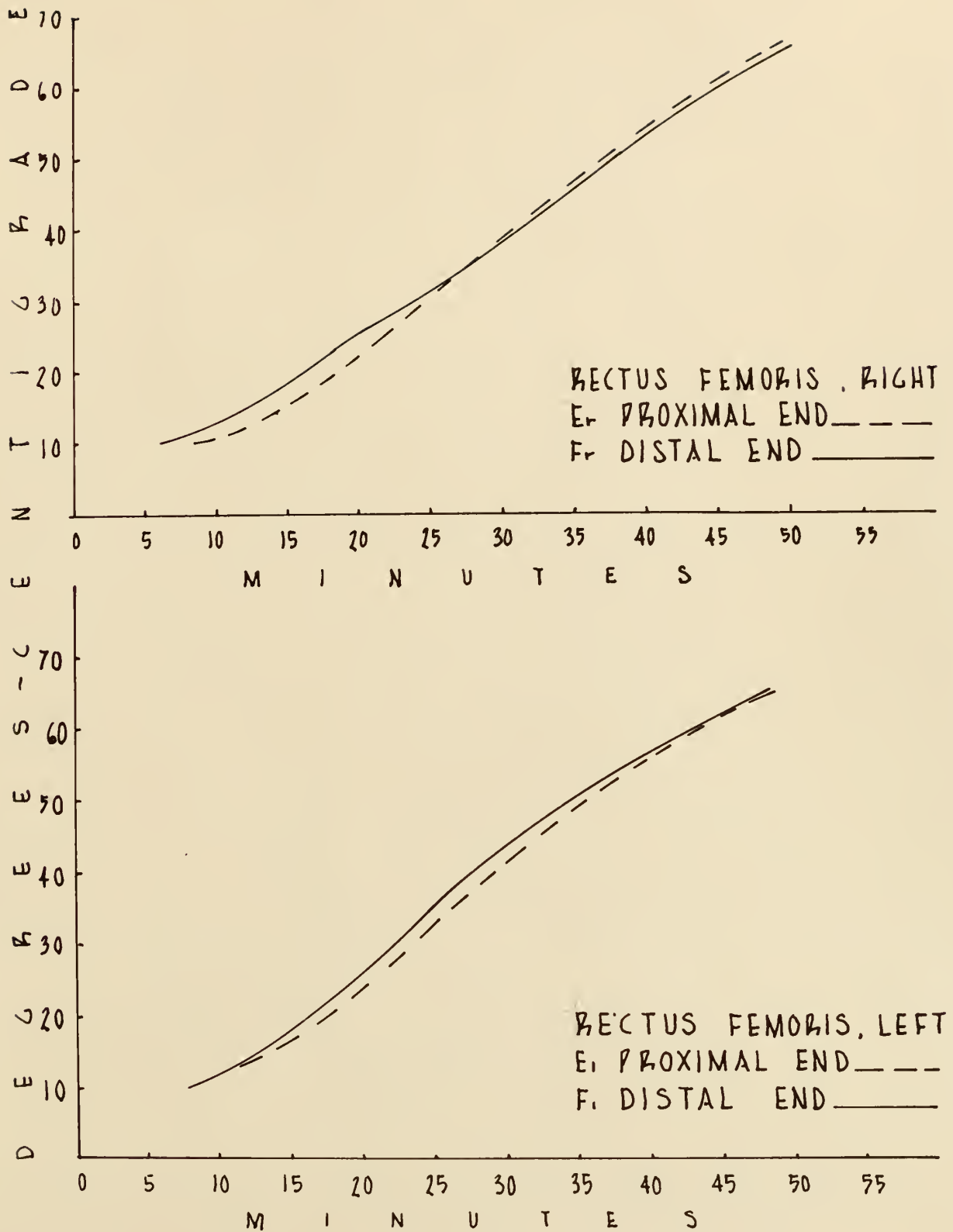


Fig. 3. Average heat penetration curves for the rectus femoris muscle.

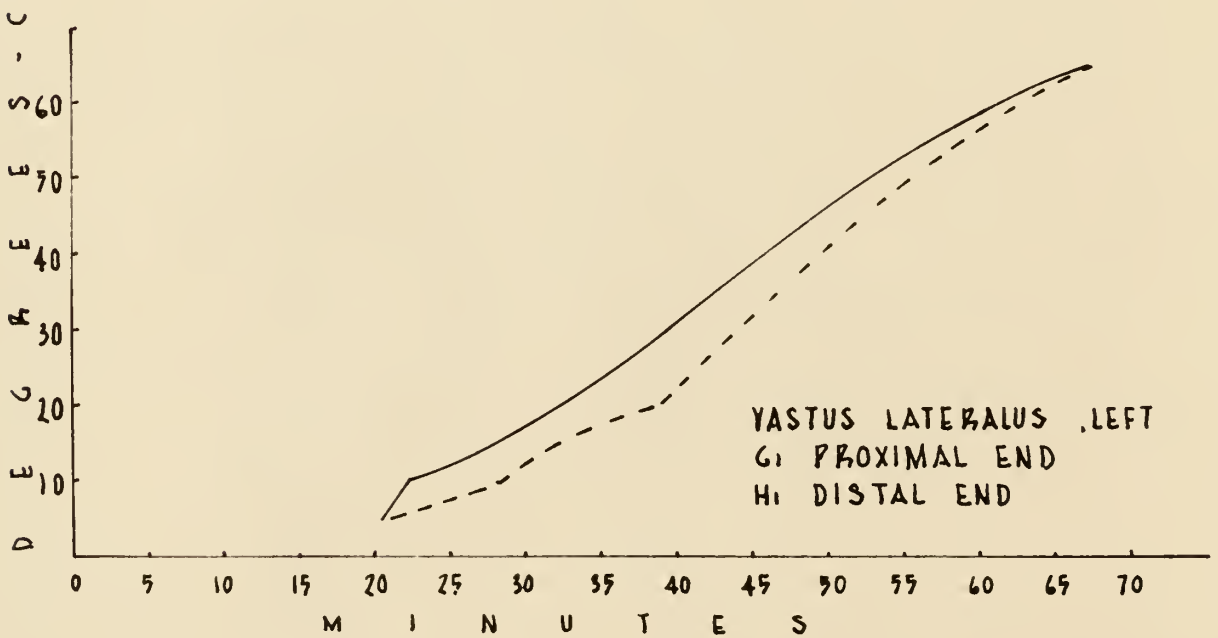
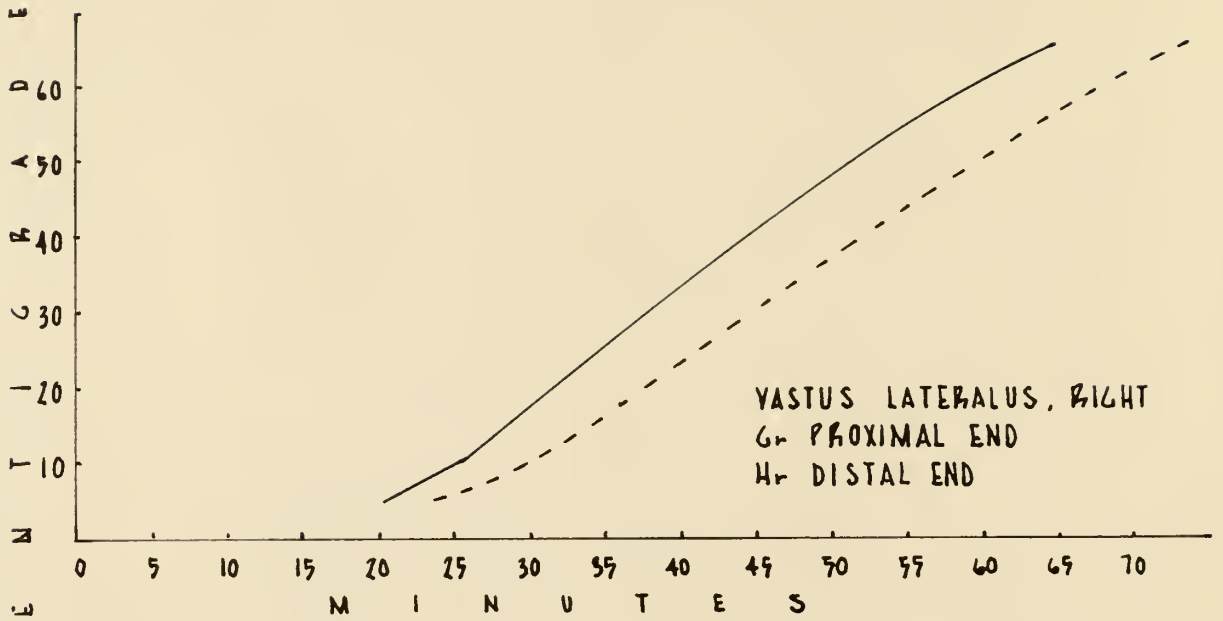


Fig. 4. Average heat penetration curves for the vastus lateralis muscle.

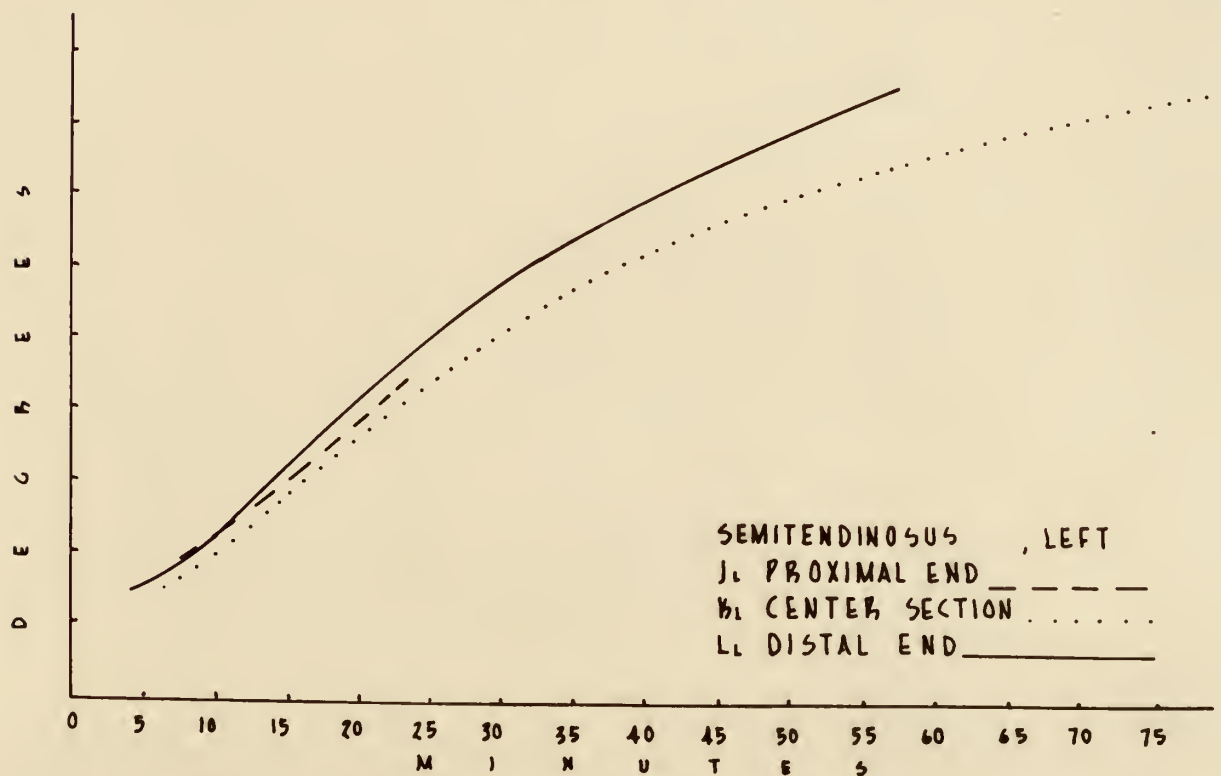
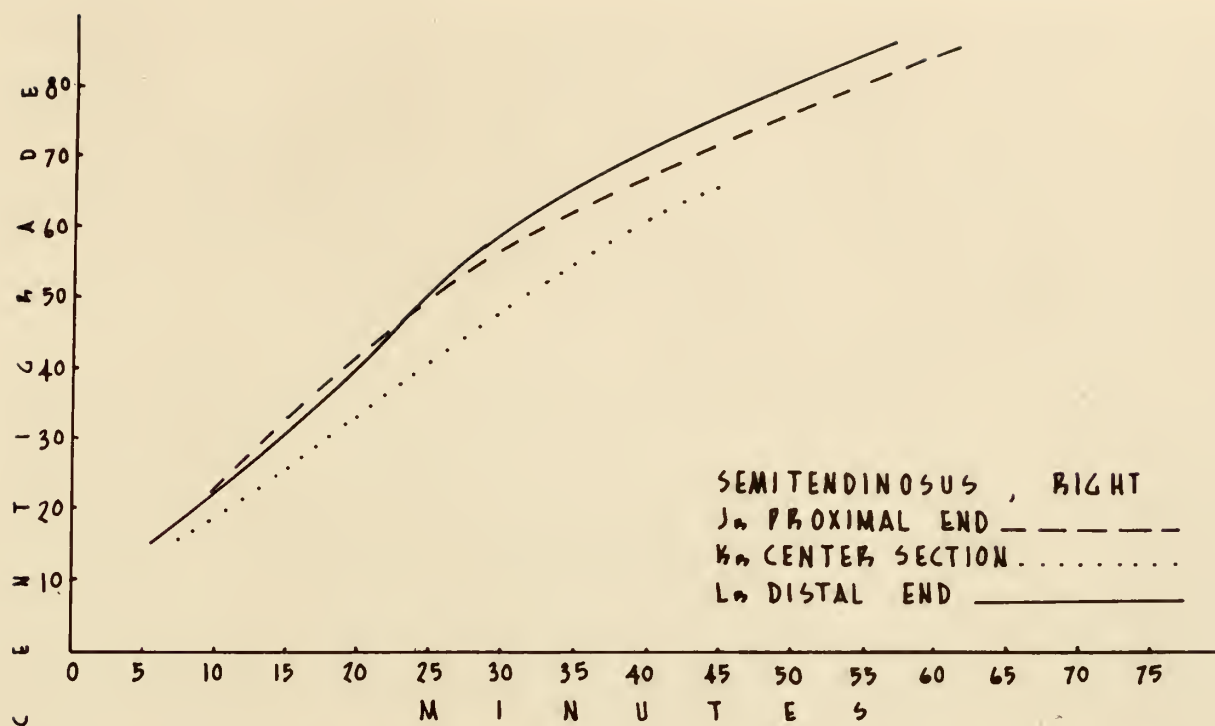


Fig. 5. Average heat penetration curves for the semitendinosus muscle.

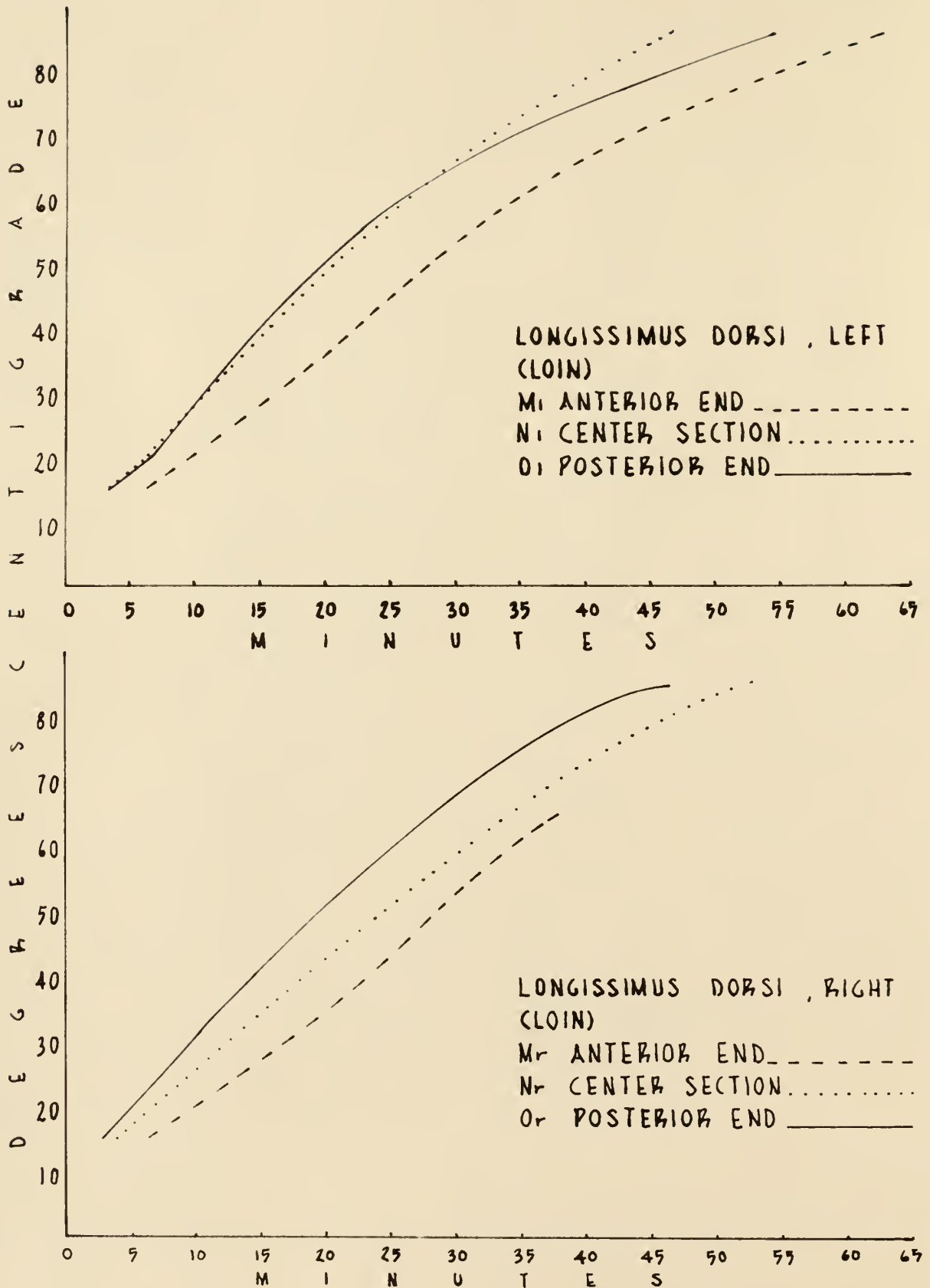


Fig. 6. Average heat penetration curves for the longissimus dorsi (loin) muscle.



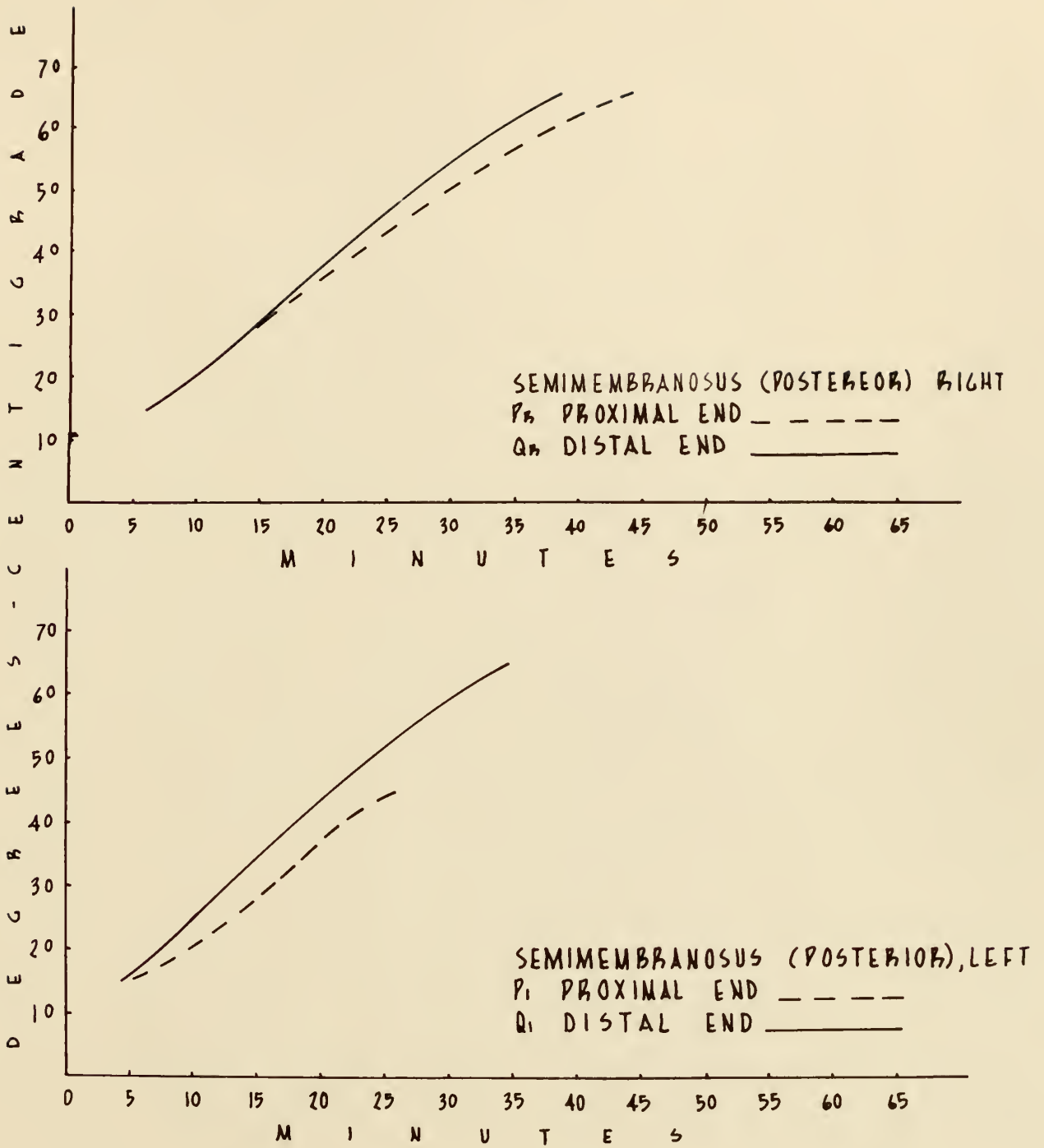


Fig. 7. Average heat penetration curves for the semimembranosus (posterior) muscle.

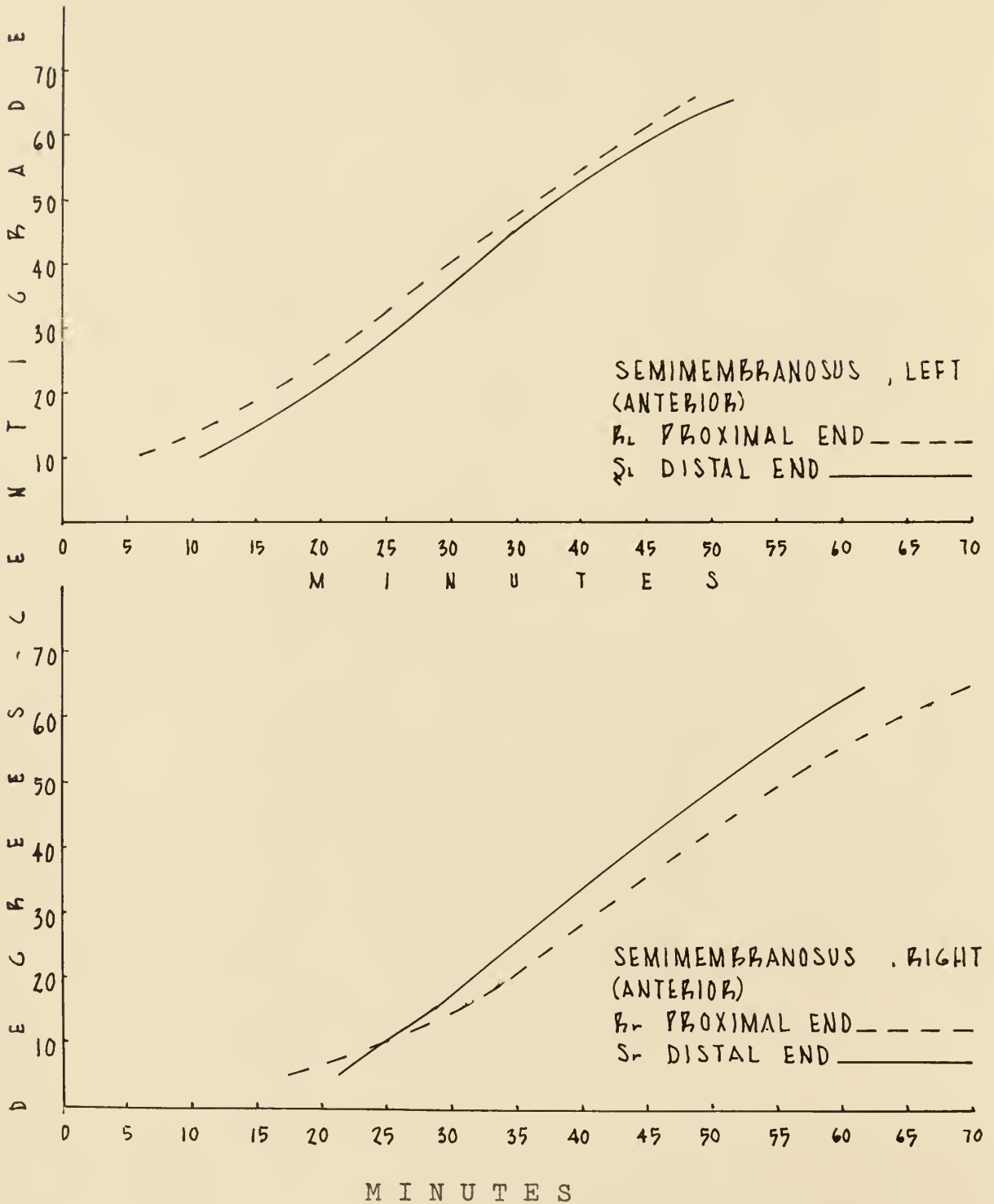


Fig. 8. Average heat penetration curves for the semimembranosus (anterior) muscle.

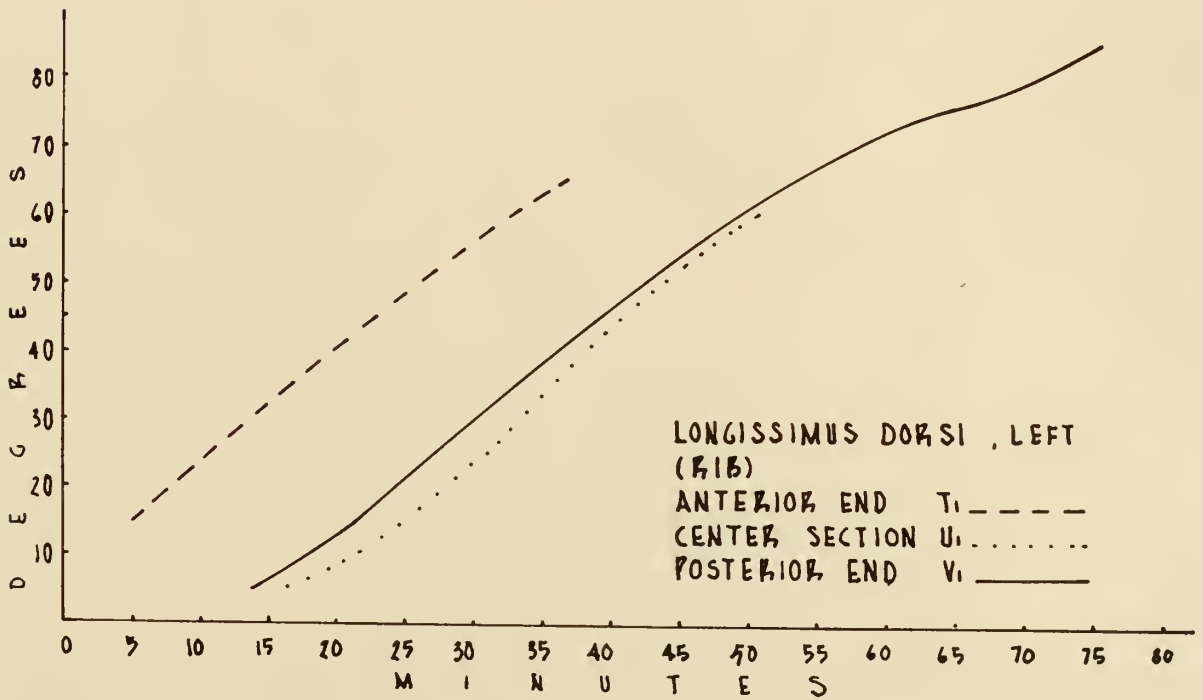
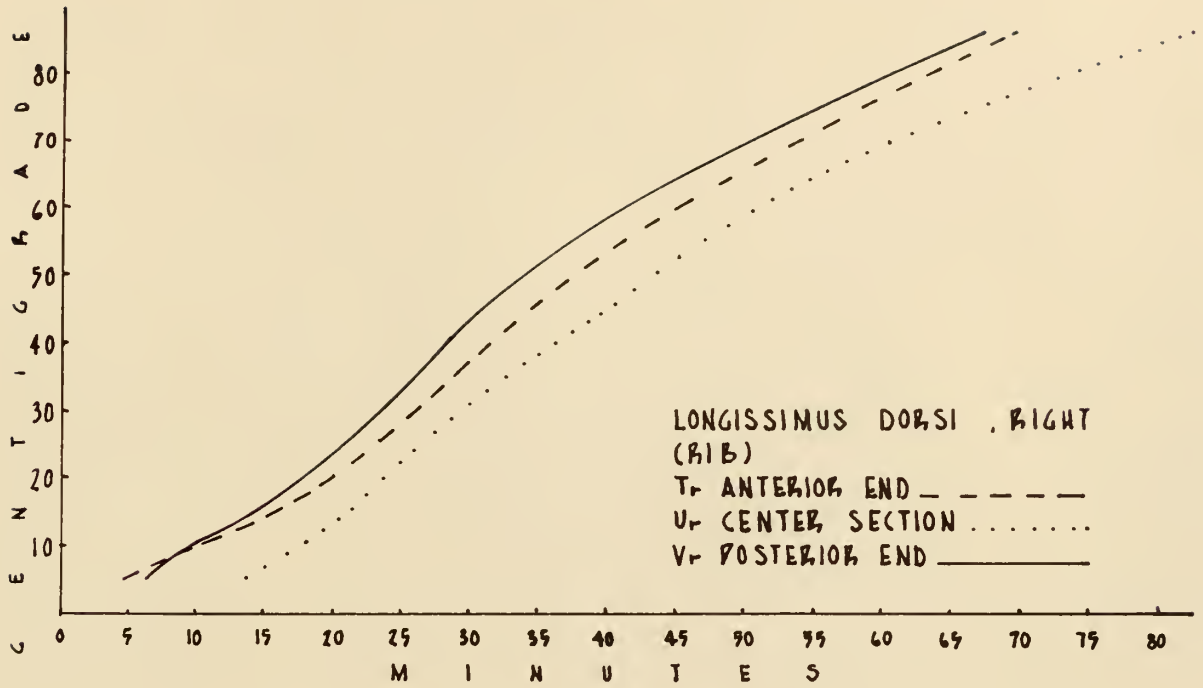


Fig. 9. Average heat penetration curves for the longissimus dorsi (rib) muscle.

end of the psoas major and longissimus dorsi muscles. The rate of heat penetration was slower in roasts from the proximal than from the distal end of the muscles from the round. This is in agreement with results obtained by Visser (1957).

The cooking time was shorter and the rate of heat penetration was more rapid in the smaller roasts, such as those from the psoas major and adductor muscles, which averaged 1.1 pounds, and was slowest in the larger blocky roasts from the semimembranosus (anterior) and vastus lateralis muscles, which averaged 1.9 and 1.7 pounds, respectively.

After the roasts were removed from the fat, there was a rise in internal temperature attributable to the fact that time is required for heat to be conducted from the outside to the center of the roast where the thermometer is placed. The rise in temperature was greatest in roasts that were removed from the fat when the internal temperature was  $45^{\circ}\text{C}$ . The temperature of these roasts rose from eight to 15 degrees so that the final temperature was near the desired  $55^{\circ}\text{C}$ , or the usual end point for rare meat. The roasts cooked to  $65^{\circ}\text{C}$ . rose about four to seven degrees in internal temperature after removal from the fat, and approximated the desired  $70^{\circ}\text{C}$ . for medium-done meat; whereas the temperature of the roasts that were cooked to  $85^{\circ}\text{C}$ . did not rise further. In general, the temperature of the larger roasts rose more than that of the smaller ones.

#### Penetrometer Tests

The penetrometer has been used to measure the tenderness of

whole raw and cooked meat. However, in planning this study, it was believed that the penetrometer might more accurately measure the consistency of raw ground meat and that this consistency might in some way be related to the water holding capacity of the meat; that is, the softer meat might tend to lose more of its water content during cooking than the meat that was less soft. In handling meat in the laboratory it was noted that there was a great difference in the consistency of ground meat among the various muscles and between animals. Correlation coefficients were run for penetrometer readings versus cooking losses, penetrometer readings versus juiciness scores, and penetrometer readings versus tenderness scores to study possible relationships between consistency and the juiciness and tenderness of the cooked meat.

Penetrometer readings on ground raw meat are given in Table 7. They ranged from 4.14 to 5.72 millimeters. The higher readings indicate a softer consistency. Correlation coefficients for penetrometer readings versus cooking losses, penetrometer readings versus juiciness scores, and penetrometer readings versus tenderness scores were all non-significant except the positive coefficient for the penetrometer reading and cooking losses for the adductor muscle, Table 8. The small number of degrees of freedom made it necessary to have a near perfect correlation in order to obtain significance. There were a number of high correlation coefficients for these factors even though they were non-significant.

All correlation coefficients for cooking losses versus

Table 7. Average of penetrometer readings for muscles from two animals.

Muscle	:	Penetrometer reading 1/10 mm.
Psoas major		
ABl		46.5
ABr		47.4
Adductor		
CDl		41.4
CDr		50.3
Rectus femoris		
EF1		48.8
ERR		52.4
Vastus lateralis		
GHl		52.6
GHR		43.1
Semitendinosus		
JKl		49.0
JKr		52.5
Ll		51.0
Lr		52.8
Longissimus dorsi (loin)		
MNl		52.8
MNR		51.2
Ol		55.9
Or		45.1
Semimembranosus (posterior)		
PQl		55.0
PQR		54.6
Semimembranosus (anterior)		
RS1		46.6
RSr		49.2
Longissimus dorsi (rib)		
TUl		53.6
TUR		50.8
Vl		56.5
Vr		57.2

Table 8. Correlation coefficients for cooking losses and penetrometer readings, juiciness scores and penetrometer readings, and tenderness scores and penetrometer readings.

Factor	: Correlation : coefficient
<b>Cooking losses and penetrometer readings</b>	
Psoas major	.468
Adductor	.966 *
Rectus femoris	.603
Vastus lateralis	.839
Semimembranosus (posterior)	.802
Semimembranosus (anterior)	.036
Semitendinosus	.341
Longissimus dorsi (loin)	-.275
Longissimus dorsi (rib)	-.130
<b>Juiciness scores and penetrometer readings</b>	
Psoas major	-.087
Adductor	.950
Rectus femoris	-.901
Vastus lateralis	.621
Semimembranosus (posterior)	-.543
Semimembranosus (anterior)	-.280
Semitendinosus	-.469
Longissimus dorsi (loin)	.395
Longissimus dorsi (rib)	-.040
<b>Tenderness scores and penetrometer readings</b>	
Psoas major	.112
Adductor	-.284
Rectus femoris	-.195
Vastus lateralis	.826
Semimembranosus (posterior)	-.758
Semimembranosus (anterior)	.796
Semitendinosus	.341
Longissimus dorsi (loin)	-.075
Longissimus dorsi (rib)	.107

\* - significant at the .05 level

penetrometer readings were positive except for the longissimus dorsi (loin and rib), and three of the positive coefficients were quite high. It is possible that there is an inverse relationship between the consistency of raw meat and the loss

of water during cooking.

Of the two very high correlation coefficients for juiciness scores versus penetrometer readings, one was positive and the other negative. The same was true for tenderness scores and penetrometer readings. The correlation coefficients for both of these comparisons were erratic and tended to cancel each other.

### SUMMARY

The effect of three internal temperatures on the cooking time and losses, shear force values, press fluid yields, and palatability of roasts from certain beef muscles cooked in deep fat was studied. The long hindquarters of three U. S. Good grade steers were sent from a Kansas City packing company to the Kansas State College Animal Husbandry Meats Laboratory where they were dissected into the paired psoas major, adductor, rectus femoris, vastus lateralis, semitendinosus, longissimus dorsi (loin and rib sections), and semimembranosus (posterior and anterior) muscles and their respectively coded roasts. The roasts were wrapped in aluminum foil and frozen at  $-20^{\circ}\text{F}$ . in an upright freezer and stored in the freezer until they were thawed at  $43^{\circ}\text{F}$ . for approximately 48 hours before cooking.

The internal temperatures of  $45^{\circ}$ ,  $65^{\circ}$ , and  $85^{\circ}\text{C}$ . were chosen as end points for cooking roasts which were to be rare, medium-, and well-done, respectively. A randomized incomplete block design was used for determining the end point temperature of roasts from the semitendinosus and longissimus dorsi (loin and rib), which were cooked to the three temperatures. For



roasts from the remaining muscles, which were cooked to 45° and 65°C., a randomized complete block design was used to determine the internal temperatures.

The roasts were cooked in deep fat maintained at 100°C. The time required for every five degree rise in internal temperature was recorded and total cooking losses were calculated. Shear force values and press fluid yields were determined on the cooked meat. A palatability panel scored the meat for flavor, aroma, juiciness, and tenderness. Samples of raw ground meat were tested for consistency by means of the penetrometer.

Analyses of variance and t-tests were used to determine differences, attributable to internal temperature, in cooking time, cooking losses, press fluid yields, shear values, and scores for palatability factors. Least significant difference was used wherever it was appropriate. Correlation coefficients for roasts from each muscle cooked to each internal temperature were computed for: tenderness scores versus penetrometer readings, tenderness scores versus shear values, juiciness scores versus press fluid yields, juiciness scores versus penetrometer readings, cooking losses versus juiciness scores, cooking losses versus press fluid yields, and cooking losses versus penetrometer readings. Also, correlation coefficients were calculated for these same factors for roasts from all muscles cooked to each end point temperature.

The total cooking time for all roasts ranged from 17 to 83 minutes and cooking time, in minutes per pound, ranged from 19 to 63 minutes. As the internal temperature of the roasts was

increased, mean cooking time, in minutes per pound, increased significantly for the roasts from all muscles, and was accompanied by a significant increase in mean cooking losses from all roasts except those from the adductor and semimembranosus (posterior) muscles.

Significant differences in press fluid yields from roasts cooked to different internal temperatures were found for all muscles except the adductor. The amount of press fluid yielded by all roasts decreased with increased internal temperature. The only significant correlation coefficients for cooking losses and press fluid yields were for roasts from the rectus femoris cooked to  $65^{\circ}\text{C}$ . and from the vastus lateralis cooked to  $45^{\circ}$  and  $65^{\circ}\text{C}$ . When all of the muscles cooked to each internal temperature were considered together, the correlation coefficients were significant at the one percent level for roasts cooked to  $45^{\circ}\text{C}$ . and at the one-tenth percent level for roasts cooked to  $65^{\circ}\text{C}$ .

Judges' scores for juiciness and for preference for juiciness decreased with increasing internal temperature. The roasts from all muscles except the semimembranosus (posterior) cooked to  $45^{\circ}\text{C}$ . were significantly more juicy than those cooked to  $65^{\circ}\text{C}$ ., and those from the longissimus dorsi (loin and rib) were significantly more juicy when cooked to  $65^{\circ}\text{C}$ . than when cooked to  $85^{\circ}\text{C}$ . Significant differences between preference scores for juiciness for roasts from the adductor, vastus lateralis, semimembranosus (posterior), semitendinosus, and longissimus dorsi (loin) indicated that the judges preferred the roasts from these muscles that were cooked to  $45^{\circ}\text{C}$ . to those that were cooked to  $65^{\circ}\text{C}$ . The

only significant correlation coefficient for juiciness scores and cooking losses was for roasts from the semimembranosus (anterior) muscle. When correlation coefficients for cooking losses and juiciness scores for all muscles cooked to a given internal temperature were calculated, the coefficients were significant at the two percent level for roasts cooked to  $45^{\circ}$  and  $65^{\circ}\text{C}$ . Correlation coefficients for press fluid yields and juiciness scores were non-significant with the exception of a negative coefficient for roasts from the adductor muscle cooked to  $45^{\circ}\text{C}$ . The majority of the coefficients, however, were positive, even though non-significant.

Tenderness scores decreased slightly and shear values increased slightly with an increase in internal temperature, but these changes were not great enough to be significant. Correlation coefficients for tenderness scores versus shear values for roasts from all muscles cooked to each temperature were highly significant and very highly significant for roasts cooked to  $45^{\circ}$  and  $65^{\circ}\text{C}$ ., respectively.

There was a significant increase in aroma scores with increased internal temperature, and slight but non-significant increase in flavor scores for roasts from most of the muscles.

Results of penetrometer tests indicated that there might be some relationship between the consistency of raw ground meat and the water holding capacity. All but one of the correlation coefficients for cooking losses versus penetrometer readings were positive and some of them were high. However, the small number of degrees of freedom made them non-significant.

The rate of heat penetration curves revealed a slight leveling off beginning around  $55^{\circ}\text{C}$ ., which resulted from the endothermic coagulation of muscle protein. Another slight plateau in the rise in internal temperature occurred between  $75^{\circ}$  and  $85^{\circ}\text{C}$ . The rate of heat penetration was slower in roasts from the proximal end than in those from the distal end of the muscle, and in thick, blocky roasts than in small flat roasts. The internal temperature of roasts cooked to  $45^{\circ}\text{C}$ . rose from eight to 15 degrees after they were removed from the fat; the temperature of those cooked to  $65^{\circ}\text{C}$ . rose from four to seven degrees; and the temperature of those cooked to  $85^{\circ}\text{C}$ . did not rise further.

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## APPENDIX

Table 9. Weight, in grams and pounds, and cooking time, in minutes per pound for roasts from certain muscles of three animals.

Muscle	:Int. : :temp. : : °C. :	:Animal: :number: :Code:	:	: Weight		: Cooking : time : min./lb.	
				Gms. :	Lbs. :		
Psoas major	45	IX	Ar	458.0	1.0	19.9	
			Br	529.0	1.2	20.2	
		XI	Ar	475.0	1.0	19.2	
			B1	450.0	1.0	22.6	
		XIII	Ar	490.0	1.1	21.6	
	Br		464.0	1.2	18.2		
	Av.			478.7	1.1	20.3	
		65	IX	A1	501.0	1.1	34.0
				B1	529.0	1.2	31.3
			XI	A1	484.0	1.1	29.7
Br				421.0	0.9	38.8	
XIII			A1	474.0	1.0	32.8	
		B1	603.0	1.3	32.4		
Av.				502.0	1.1	33.2	
Adductor		45	IX	Cr	780.0	1.6	23.6
				D1	551.0	1.2	25.0
			XI	C1	636.0	1.4	24.5
	D1			360.0	0.8	28.4	
	XIII		Cr	565.0	1.2	25.2	
		D1	520.0	0.9	31.1		
	Av.			552.0	1.2	26.3	
		65	IX	C1	727.0	1.6	32.7
				Dr	437.0	1.0	37.6
			XI	Cr	586.0	1.3	29.8
Dr				513.0	1.1	33.3	
XIII			C1	360.0	0.8	36.5	
		Dr	386.0	0.9	36.2		
Av.				501.5	1.1	34.4	
Rectus femoris		45	IX	E1	659.0	1.5	27.7
				F1	681.0	1.5	29.1
			XI	E1	661.0	1.5	23.1
	Fr			705.0	1.6	23.2	
	XIII		Er	644.0	1.4	26.9	
		F1	590.0	1.3	25.0		
	Av.			656.7	1.5	25.8	

Table 9. (cont.)

Muscle	:Int. : :temp. : : °C. :	:Animal: :number:	:Code:	: Weight		: Cooking : time : min./lb.
				Gms. :	Lbs. :	
Rectus femoris	65	IX	Er	756.0	1.7	31.2
			Fr	580.0	1.3	46.8
		XI	Er	627.0	1.4	37.6
			Fl	645.0	1.4	35.9
		XIII	El	630.0	1.4	36.7
			Fr	578.0	1.3	40.8
Av.			634.0	1.4	38.2	
Vastus lateralis	45	IX	Gr	1044.0	2.3	23.9
			Hr	729.0	1.6	28.7
		XI	Gr	846.0	1.9	16.4
			Hl	699.0	1.5	19.0
		XIII	G1	706.0	1.6	20.1
			Hr	716.0	1.6	18.0
Av.			790.0	1.8	21.0	
	65	IX	G1	895.0	2.0	33.8
			Hl	795.0	1.8	35.6
		XI	G1	731.0	1.6	31.4
			Hr	593.0	1.3	31.5
		XIII	Gr	747.0	1.6	30.6
			Hl	726.0	1.6	30.2
Av.			747.8	1.6	32.2	
Semitendinosus	45	IX	Jl	564.0	1.2	23.8
			Ll	495.0	1.1	24.1
		XI	Jl	499.0	1.1	23.8
			Jr	463.0	1.0	30.1
		XIII	Jl	467.0	1.0	25.8
			Kr	581.0	1.3	25.9
Av.			511.5	1.1	26.0	
	65	IX	Jr	634.0	1.4	30.9
			Kr	670.0	1.5	33.1
		XI	Kl	640.0	1.4	38.7
			Kr	638.0	1.4	34.9
		XIII	Ll	433.0	1.0	40.6
			Lr	409.0	0.9	41.7
Av.			570.7	1.3	36.6	

Table 9. (cont.)

Muscle	: Int. : : temp : : °C.	: Animal : : number :	: Code :	: Weight		: Cooking : : time : : min./lb.
				Gms.	Lbs.	
Semitendinosus	85	IX	Kl	725.0	1.6	53.7
			Lr	423.0	0.9	62.4
		XI	Ll	453.0	1.0	62.8
			Lr	529.0	1.2	57.1
		XIII	Jr	484.0	1.1	62.6
			Kl	505.0	1.1	76.7
Av.			519.8	1.2	62.6	
Longissimus dorsi (loin)	45	IX	Nl	574.0	1.3	15.0
			Ol	547.0	1.2	20.2
		XI	Mr	599.0	1.3	23.8
			Ol	444.0	1.0	16.4
		XIII	Mr	669.0	1.5	20.1
			Nl	573.0	1.3	19.5
Av.			567.7	1.3	19.2	
	65	IX	Mr	623.0	1.4	27.4
			Or	539.0	1.2	25.2
		XI	Ml	555.0	1.2	29.6
			Or	324.0	0.7	27.9
		XIII	Ml	597.0	1.3	36.8
			Nr	585.0	1.3	32.2
Av.			537.2	1.2	29.8	
	85	IX	Ml	748.0	1.6	45.5
			Nr	559.0	1.2	47.7
		XI	Nl	430.0	0.9	50.6
			Nr	425.0	0.9	54.8
		XIII	Ol	499.0	1.1	51.8
			Or	495.0	1.1	50.2
Av.			526.0	1.1	50.1	
Semimembranosus (posterior)	45	IX	Pl	831.0	1.8	23.5
			Ql	752.0	1.7	20.0
		XI	Pl	687.0	1.5	24.2
			Gr	619.0	1.4	20.4
		XIII	Pl	741.0	1.6	22.1
			Gr	666.0	1.5	22.9
Av.			716.0	1.6	22.2	
	65	IX	Pr	750.0	1.7	32.3
			Gr	581.0	1.3	31.8
		XI	Pr	658.0	1.4	34.4
			Ql	625.0	1.4	32.0
		XIII	Pr	776.0	1.7	33.1
			Ql	618.0	1.4	26.4
Av.			668.0	1.5	31.7	

Table 9. (concl.)

Muscle	: Int. : : temp. : : °C. :	: Animal : : number :	: Code :	: Weight :		: Cooking : : time : : min./lb. :	
				Gms.	Lbs.		
Semimembranosus (anterior)	45	IX	Rr	1022.0	2.3	20.8	
			Sl	786.0	1.7	25.0	
		XI	Rr	1096.0	2.4	17.9	
			Sr	879.0	1.9	20.1	
		XIII	Sl	620.0	1.4	25.0	
	Sr		744.0	1.6	21.8		
	Av.			857.8	1.9	21.8	
		65	IX	Rl	725.0	1.6	29.6
				Sr	829.0	1.8	31.1
			XI	Rl	962.0	2.1	29.6
Sl				928.0	2.0	28.6	
XIII			Rl	857.0	1.9	30.2	
			Rr	803.0	1.8	31.6	
Av.					850.7	1.9	29.8
Longissimus dorsi	45	IX	Ul	575.0	1.3	30.0	
			Vl	765.0	1.7	24.6	
		XI	Tl	539.0	1.2	20.2	
			Vr	508.0	1.1	23.5	
		XIII	Tl	478.0	1.1	28.1	
	Ur		585.0	1.3	23.2		
	Av.			575.0	1.3	24.9	
		65	IX	Tl	437.0	1.0	42.4
				Ur	660.0	1.5	35.2
			XI	Tr	615.0	1.4	32.3
Ul				580.0	1.3	34.0	
XIII			Ul	481.0	1.1	33.5	
			Vl	491.0	1.1	35.1	
Av.					544.0	1.2	35.1
	85	IX	Tr	527.0	1.2	54.8	
			Vr	758.0	1.7	42.4	
		XI	Ur	595.0	1.3	57.2	
			Vl	615.0	1.4	45.8	
		XIII	Tr	532.0	1.2	55.2	
			Vr	595.0	1.3	53.3	
		Av.			603.7	1.4	51.4

Table 10. Total cooking losses, press fluid yields, and mean palatability scores for juiciness. Maximum juiciness score possible, 10.

Muscle	:Int. : :temp. : : °C.	:Animal: :number:	:Code:	: Cooking: : losses : : per cent:	: Press : : fluid : : yields:	: Juici- : ness : scores
Psoas major	45	IX	Ar	17.5	9.4	8.9
			Br	18.7	9.0	8.7
		XI	Ar	18.9	9.5	8.9
			Bl	16.9	10.8	8.9
		XIII	Ar	17.8	10.4	9.0
			Br	14.8	10.4	9.1
Av.			17.4	10.0	8.9	
	65	IX	Al	24.6	8.4	8.3
			Bl	22.5	7.2	8.1
		XI	Al	25.4	9.4	7.7
			Br	24.0	9.2	7.9
		XIII	Al	23.0	9.4	7.7
			Bl	19.9	9.8	8.3
Av.			23.2	8.9	8.0	
Adductor	45	IX	Cr	21.8	9.0	8.2
			Dl	24.1	9.0	8.0
		XI	Cl	21.4	9.2	8.0
			Dl	22.8	8.8	8.0
		XIII	Cr	20.7	8.3	9.0
			Dl	18.1	8.6	8.5
Av.			21.5	8.8	8.3	
	65	IX	Cl	16.7	8.6	6.8
			Dr	30.0	8.2	6.8
		XI	Cr	25.1	8.8	7.1
			Dr	27.1	8.2	7.4
		XIII	Cl	24.7	9.2	7.1
			Dr	29.0	7.6	6.1
Av.			25.4	8.4	6.9	
Rectus femoris	45	IX	El	28.1	8.6	8.3
			F1	27.9	9.3	7.9
		XI	El	26.9	8.6	7.8
			Fr	19.1	10.2	8.0
		XIII	Er	23.8	8.9	8.1
			F1	20.7	8.9	8.6
Av.			24.4	9.1	8.1	



Table 10. (cont.)

Muscle	: Int. : : temp. : : °C. :	: Animal : : number :	: Code :	: Cooking : : losses : : percent :	: Press : : fluid : : yields :	: Juici- : ness : : scores :
Rectus femoris	65	IX	Er	33.6	6.9	7.4
			Fr	30.5	8.8	7.9
		XI	Er	33.5	7.2	6.2
			Fl	29.8	8.4	6.2
		XIII	El	31.1	8.5	7.1
			Fr	29.1	8.6	7.0
Av.			31.3	8.1	7.0	
Vastus lateralis	45	IX	Gr	26.3	8.5	8.4
			Hr	21.1	8.9	8.4
		XI	Gr	20.8	9.6	8.0
			Hl	19.3	9.8	8.6
		XIII	G1	21.0	9.5	8.9
			Hr	16.6	10.1	8.7
Av.			20.8	9.4	8.6	
	65	IX	G1	33.4	7.2	6.4
			Hl	33.8	7.0	7.1
		XI	G1	30.5	7.6	6.9
			Hr	26.1	8.9	7.0
		XIII	Gr	29.0	8.2	6.7
			Hl	23.8	8.8	6.8
Av.			29.4	8.0	6.8	
Semitendinosus	45	IX	Jl	15.8	10.0	8.1
			Ll	17.0	10.4	8.6
		XI	Jl	18.8	9.0	8.3
			Jr	21.4	9.3	8.3
		XIII	Jl	14.3	9.7	8.4
			Kr	17.4	9.7	8.1
Av.			17.4	9.5	8.3	
	65	IX	Jr	24.9	9.0	6.7
			Kr	23.3	8.4	6.4
		XI	Kl	24.1	8.8	7.5
			Kr	27.4	8.8	6.4
		XIII	Ll	25.2	8.7	7.1
			Lr	25.7	8.8	7.0
Av.			25.1	8.8	7.0	

Table 10. (cont.)

Muscle	: Int. : : temp. : : °C. :	: Animal : : number :	: Code :	: Cooking : : losses : : percent :	: Press : : fluid : : yields :	: Juici- : : ness : : scores :
Semitendinosus	85	IX	Kl	35.2	6.4	6.1
			Lr	35.0	7.0	6.4
		XI	Ll	35.3	7.0	7.3
			Lr	35.2	6.8	7.3
		XIII	Jr	34.7	6.3	6.1
Kl	35.8	6.8	6.1			
Av.				35.3	6.4	6.6
Longissimus dorsi (loin)	45	IX	Nl	16.2	9.4	8.5
			Ol	20.8	8.3	8.8
		XI	Mr	19.2	9.6	8.8
			Ol	15.1	9.2	9.0
		XIII	Mr	18.1	9.2	8.5
Nl	15.9	9.7	8.5			
Av.				17.6	9.2	9.2
	65	IX	Mr	27.8	8.5	8.5
			Or	29.1	7.3	8.2
		XI	Ml	25.0	9.0	8.2
			Or	26.5	8.2	8.0
		XIII	Ml	26.3	8.4	6.7
Wr	25.8	7.4	6.5			
Av.				26.8	8.1	7.6
	85	IX	Ml	36.0	6.9	6.8
			Nr	37.4	5.2	6.8
		XI	Nl	35.8	5.0	5.8
			Nr	34.8	6.2	5.2
		XIII	Ol	34.1	7.2	5.5
Or	33.1	6.4	6.8			
Av.				35.2	6.3	6.2
Semimembranosus (posterior)	45	IX	P1	23.7	9.6	8.6
			Q1	18.5	9.5	8.6
		XI	P1	22.4	8.6	8.6
			Qr	20.2	8.4	8.8
		XIII	P1	17.5	11.0	9.1
Qr	18.8	9.2	8.6			
Av.				20.2	9.4	8.7
	65	IX	Pr	29.1	8.8	7.1
			Qr	25.5	8.5	7.4
		XI	Pr	29.2	8.0	7.5
			Q1	26.9	7.5	7.5
		XIII	Pr	13.4	8.8	7.3
Q1	23.3	9.0	7.5			
Av.				24.6	8.4	7.4

Table 10. (concl.)

Muscle	:Int. : :temp.: : °C. :	: Animal : : number:	: Code :	: Cooking : : losses : : percent :	: Press : : fluid : : yields :	: Juici- : ness : : scores :
Semimembranosus (anterior)	45	IX	Rr	26.0	9.0	7.7
			Sl	26.1	8.9	7.6
		XI	Rr	22.3	9.0	7.6
			Sr	22.9	10.3	8.0
		XIII	Sl	20.3	9.4	8.6
			Sr	19.2	9.2	8.7
		Av.			22.8	9.3
	65	IX	Rl	30.8	8.9	6.7
			Sr	33.3	8.4	6.6
		XI	Rl	31.9	8.0	6.1
			Sl	31.5	8.7	6.1
		XIII	Rl	30.0	8.0	7.1
			Rr	26.9	9.0	7.4
		Av.			30.7	8.5
Longissimus dorsi (rib)	45	IX	Ul	23.1	8.0	8.7
			Vl	23.7	9.3	9.4
		XI	Tl	33.6	9.7	9.3
			Vr	20.5	8.5	9.1
		XIII	Tl	18.8	9.0	8.7
			Ur	18.6	9.3	8.9
		Av.			23.0	9.0
	65	IX	Tl	28.8	7.5	8.1
			Ur	33.3	7.7	7.0
		XI	Tr	30.7	6.8	7.0
			Ul	30.2	8.0	7.4
		XIII	Rl	30.0	8.0	7.7
			Rr	26.9	9.0	7.4
		Av.			28.5	7.6
	85	IX	Tr	38.5	6.9	6.7
			Vr	36.1	7.4	6.9
		XI	Ur	35.8	5.7	5.3
			Vl	35.0	5.8	5.1
		XIII	Tr	36.8	8.9	6.9
			Vr	30.8	8.9	6.6
		Av.			35.5	7.0

Table 11. Mean shear values and palatability scores for tenderness, aroma, and flavor. Maximum score possible, 10.

Muscle	:Int. : :temp.: : °C.	:Animal: :number:	:Code:	:Shear: :force: : lbs.:	:Tender-: :ness : scores	:Aroma: : scores	: Flavor : scores
Psoas major	45	IX	Ar	9.2	9.7	7.4	7.6
			Br	10.0	9.2	7.7	7.4
		XI	Ar	12.2	8.9	7.7	7.7
			Bl	11.6	8.7	7.9	8.0
		XIII	Ar	10.5	9.1	7.4	8.0
			Br	12.3	9.0	7.3	8.0
Av.				11.0	9.1	7.6	7.8
	65	IX	Al	14.4	9.4	8.4	8.6
			Bl	10.2	9.3	8.4	8.4
		XI	Al	16.6	9.0	8.1	8.1
			Br	12.7	8.7	8.3	8.3
		XIII	Al	17.2	8.6	7.6	7.6
			Bl	12.7	8.7	7.7	8.0
Av.				14.0	9.0	8.1	8.2
Adductor	45	IX	Cr	12.9	7.5	7.0	7.3
			Dl	15.3	7.8	6.8	7.3
		XI	Cl	21.4	7.3	7.3	7.3
			Dl	18.8	7.4	7.3	7.0
		XIII	Cr	23.3	7.9	7.2	7.2
			Dl	15.7	7.4	7.1	7.1
Av.				17.9	7.6	7.1	7.2
	65	IX	Cl	15.2	8.0	8.2	8.2
			Dr	20.5	7.3	8.2	7.7
		XI	Cr	20.7	7.3	8.2	7.7
			Dr	19.2	7.3	7.7	7.3
		XIII	Cl	20.6	7.2	6.9	7.5
			Dr	31.1	7.0	7.0	7.1
Av.				21.2	7.4	7.6	7.5
Rectus femoris	45	IX	El	11.0	8.4	7.2	7.4
			F1	21.8	8.6	8.0	8.4
		XI	El	19.0	8.2	7.8	7.5
			Fr	18.5	7.5	7.7	7.5
		XIII	Er	19.2	6.6	7.6	7.9
			F1	15.1	7.1	7.4	8.0
Av.				17.4	7.7	7.6	7.8

Table 11. (cont.)

Muscle	Int. temp. : °C.	Animal number	Code	Shear force : lbs.	Tender-ness : scores	Aroma : scores	Flavor : scores
Rectus femoris	65	IX	Er	10.7	8.7	8.3	8.7
			Fr	17.0	8.6	8.3	8.1
		XI	Er	17.3	7.7	8.7	7.2
			Fl	28.0	7.7	8.0	7.2
		XIII	El	26.0	9.0	7.7	7.7
			Fr	24.9	7.0	8.0	7.3
Av.			20.6	8.1	8.2	7.7	
Vastus lateralis	45	IX	Gr	12.7	7.9	7.1	7.3
			Hr	15.3	7.6	7.6	7.9
		XI	Gr	25.7	8.0	7.9	7.5
			Hl	30.5	8.2	8.1	7.6
		XIII	G1	12.7	7.3	7.9	7.7
			Hr	25.8	7.6	7.6	8.1
Av.			20.4	7.8	7.7	7.7	
	65	IX	G1	13.9	7.6	8.3	8.0
			H1	18.4	7.4	8.1	8.0
		XI	G1	24.2	8.4	8.5	7.9
			Hr	22.3	8.0	8.4	7.9
		XIII	Gr	21.6	8.0	7.7	8.0
			H1	17.4	7.4	7.6	7.9
Av.			19.6	7.8	8.1	8.0	
Semitendinosus	45	IX	J1	33.1	8.4	7.1	7.7
			L1	21.7	8.4	7.1	7.7
		XI	J1	37.9	8.0	7.7	7.5
			Jr	23.9	7.7	7.2	7.5
		XIII	J1	49.4	7.6	7.6	7.4
			Kr	21.7	7.9	7.3	7.7
Av.			31.3	8.0	7.3	7.6	
	65	IX	Jr	20.4	7.7	7.6	7.4
			Kr	16.9	7.6	8.3	7.9
		XI	K1	22.1	7.7	7.8	7.5
			Kr	23.9	7.7	8.0	8.0
		XIII	L1	24.8	7.4	7.6	7.6
			Lr	23.5	7.7	7.1	7.9
Av.			21.9	7.6	7.7	7.7	

Table 11. (cont.)

Muscle	:Int. : :temp.: : °C.	:Animal: :number:	:Code:	:Shear: :force: : lbs.	:Tender- :ness : scores	:Aroma : scores	:Flavor : scores	
Semitendinosus	85	IX	Kl	17.5	8.1	8.0	7.7	
			Lr	20.9	8.1	7.9	8.0	
			XI	Ll	27.1	7.7	8.8	8.5
				Lr	27.1	7.8	8.5	8.2
			XIII	Jr	21.4	7.9	8.4	8.3
Kl	21.2	7.7		7.9	7.0			
Av.			21.9	7.9	8.2	8.0		
Longissimus dorsi (loin)	45	IX	Nl	12.6	7.8	7.2	6.8	
			Ol	11.3	8.5	7.5	7.2	
			XI	Mr	14.3	7.7	8.0	7.2
				Ol	14.9	7.8	8.0	7.0
			XIII	Mr	11.1	8.5	7.3	8.5
Nl	13.5	8.5		7.7	8.3			
Av.			13.0	8.1	7.7	7.5		
	65	IX	Mr	16.4	8.3	7.8	8.0	
			Or	9.2	8.0	7.7	7.3	
			XI	Ml	13.5	7.7	7.8	7.5
				Or	13.6	7.8	7.5	7.5
			XIII	Ml	13.8	9.8	7.3	7.7
Nr	15.2	7.8		7.5	8.2			
Av.			13.6	8.2	7.6	7.7		
	85	IX	Ml	12.6	8.3	8.2	8.5	
			Nr	10.5	8.2	8.2	8.2	
			XI	Nl	16.2	7.8	7.7	8.2
				Nr	17.2	6.7	7.7	7.7
			XIII	Ol	13.7	8.3	7.5	6.7
Or	18.0	8.2		7.5	6.8			
Av.			14.7	7.9	7.8	7.7		
Semimembranosus (posterior)	45	IX	P1	14.9	8.1	7.2	7.6	
			Q1	22.8	7.2	7.2	7.4	
			XI	P1	18.0	7.2	6.8	7.0
				Qr	27.0	7.0	7.5	7.0
			XIII	P1	21.5	8.1	7.7	8.0
Qr	26.4	7.6		8.0	8.0			
Av.			21.8	7.5	7.4	7.5		
	65	IX	Pr	27.1	7.1	7.9	8.0	
			Qr	17.1	8.2	8.0	8.0	
			XI	Pr	21.4	6.5	7.8	8.5
				Q1	27.1	7.0	7.8	8.2
			XIII	Pr	21.0	7.1	7.7	9.0
Q1	27.7	7.0		8.3	7.7			
Av.			23.6	7.1	7.9	8.2		

Table 11. (concl.)

Muscle	:Int. : :temp.: : °C. :	:Animal: :number:	:Code:	:Shear: :force: : lbs.:	:Tender-: :ness : scores	:Aroma : scores	:Flavor : scores
Semimembranosus (anterior)	45	IX	Rr	14.4	7.1	7.6	7.9
			Sl	18.1	6.9	7.6	7.9
		XI	Rr	16.3	8.3	7.6	7.3
			Sr	14.9	8.0	7.6	7.4
		XIII	Sl	21.8	6.3	7.9	7.3
			Sr	18.3	6.9	7.7	7.4
		Av.			17.3	7.2	7.7
	65	IX	Rl	17.8	7.3	8.1	8.0
			Sr	25.6	6.1	8.0	8.1
		XI	Rl	21.2	6.7	7.6	7.6
			Sl	21.1	7.0	7.6	7.3
		XIII	Rl	21.7	7.0	7.9	7.4
			Rr	24.4	7.4	7.7	7.0
		Av.			22.0	6.9	7.8
Longissimus dorsi (rib)	45	IX	Ul	11.1	8.9	7.1	7.4
			Vl	8.9	9.0	7.3	7.7
		XI	Tl	18.7	8.6	7.9	8.0
			Vr	12.4	8.9	8.1	8.1
		XIII	Tl	17.7	8.0	7.7	7.3
			Ur	11.6	8.4	7.7	7.9
		Av.			13.4	8.6	7.6
	65	IX	Tl	16.0	8.6	7.9	8.1
			Ur	12.1	8.4	7.7	8.3
		XI	Tr	16.0	7.6	8.0	8.1
			Ul	18.8	8.0	8.3	8.1
		XIII	Ul	10.8	7.7	7.7	7.9
			Vl	14.4	8.4	7.4	7.9
		Av.			14.7	8.1	7.8
	85	IX	Tr	15.2	8.0	8.0	7.6
			Vr	11.1	8.7	7.6	8.1
		XI	Ur	22.0	7.1	8.9	8.4
			Vl	16.3	7.3	8.9	8.0
		XIII	Tr	18.7	7.9	7.6	7.9
			Vr	14.6	7.6	7.9	7.9
		Av.			16.3	7.8	8.2

Table 12. Scores assigned to judges' preference ratings for juiciness and tenderness. Low numbers indicate high preference.

Muscle	:Int. :temp.	:Animal: :number:	: Code :	: Juiciness :	: Tenderness :
Psoas major	45	IX	Ar	2.4	2.0
			Br	2.6	3.0
		XI	Ar	2.3	2.4
			Bl	2.3	2.1
		XIII	Ar	2.4	2.4
			Br	2.6	2.5
Av.			2.4	2.4	
	65	IX	Al	2.5	2.4
			Bl	2.5	2.6
		XI	Al	2.7	2.7
			Br	2.7	2.8
		XIII	Al	2.7	2.1
			Bl	2.3	2.6
Av.			2.6	2.5	
Adductor	45	IX	Cr	2.3	2.6
			Dl	1.7	2.2
		XI	Cl	2.1	2.6
			Dl	2.1	2.3
		XIII	Cr	1.9	2.5
			Dl	1.9	2.5
Av.			2.0	2.4	
	65	IX	Cl	2.8	1.9
			Dr	3.2	3.2
		XI	Cr	3.2	2.4
			Dr	2.6	2.3
		XIII	Cl	2.9	2.5
			Dr	3.2	2.5
Av.			3.0	2.5	
Rectus femoris	45	IX	El	2.5	2.1
			Fl	2.6	2.6
		XI	El	2.3	1.8
			Fr	1.7	2.5
		XIII	Er	2.1	2.1
			Fl	1.9	2.2
Av.			2.2	2.2	



Table 12 (cont.)

Muscle	:Int. :temp.	:Animal: :number:	: Code	: Juiciness	: Tenderness
Rectus femoris	65	IX	Er	2.4	2.9
			Fr	2.5	2.4
		XI	Er	3.1	2.5
			Fl	2.9	2.8
			El	2.3	2.1
		XIII	El	2.3	2.2
			Fr	2.3	2.2
Av.			2.6	2.5	
Vastus lateralis	45	IX	Gr	1.9	1.9
			Hr	1.9	2.5
		XI	Gr	2.1	2.8
			Hl	1.9	2.1
			G1	1.8	2.8
		XIII	G1	1.9	2.4
			Hr	1.9	2.4
Av.			1.9	2.4	
	65	IX	G1	3.4	2.6
			Hl	2.8	3.1
		XI	G1	3.1	2.6
			Hr	2.9	2.6
			Gr	3.1	2.1
		XIII	Gr	3.1	2.1
			Hl	3.1	2.7
Av.			3.1	2.6	
Semitendinosus	45	IX	Jl	2.4	3.1
			Ll	2.5	2.9
		XI	Jl	2.6	1.7
			Jr	1.8	2.8
			Jl	2.6	3.1
		XIII	Jl	2.6	3.1
			Kr	2.9	3.3
Av.			2.5	2.8	
	65	IX	Jr	3.5	3.9
			Kr	4.2	4.3
		XI	Kl	3.0	3.1
			Kr	3.0	3.9
			Ll	3.2	3.9
		XIII	Ll	3.2	3.9
			Lr	3.8	3.9
Av.			3.4	3.8	

Table 12. (cont.)

Muscle	:Int. :temp.	:Animal :number:	: Code	: Juiciness	: Tenderness
Semitendinosus	85	IX	Kl	4.4	2.7
			Lr	4.1	4.1
		XI	Ll	3.3	2.8
			Lr	3.1	3.3
		XIII	Jr	4.2	2.7
	Kl	4.3	2.9		
Av.			3.9	3.1	
Longissimus dorsi (loin)	45	IX	Nl	3.0	4.3
			Ol	2.9	3.0
		XI	Mr	4.0	3.8
			Ol	3.2	3.5
		XIII	Mr	2.3	2.9
	Nl	2.7	3.1		
Av.			3.0	3.4	
	65	IX	Mr	2.8	3.2
			Or	2.8	3.2
		XI	Ml	4.0	3.5
			Or	2.6	2.9
		XIII	Ml	2.8	3.3
	Nr	3.5	4.6		
Av.			3.1	3.4	
	85	IX	Ml	4.4	3.7
			Nr	4.5	3.5
		XI	Nl	3.2	2.8
			Nr	3.7	4.4
		XIII	Ol	5.1	3.8
	Or	4.7	3.8		
Av.			4.3	3.6	
Semimembranosus (posterior)	45	IX	P1	2.2	2.2
			Q1	2.0	3.1
		XI	P1	2.1	1.9
			Qr	2.9	2.2
		XIII	P1	2.4	1.7
	Qr	1.9	2.4		
Av.			2.2	2.2	
	65	IX	Pr	3.2	3.0
			Qr	2.6	1.6
		XI	Pr	2.4	3.2
			Q1	2.6	2.6
		XIII	Pr	3.1	2.8
	Q1	2.5	3.1		
Av.			2.7	2.7	

Table 12. (concl.)

Muscle	:Int. :temp.	:Animal: :number:	: Code	: Juiciness	: Tenderness	
Semimembranosus (anterior)	45	IX	Rr	2.1	2.5	
			Sl	2.2	2.1	
		XIII	Rr	1.6	2.1	
			Sr	1.4	1.6	
			Sl	2.9	3.0	
	Av.	65	IX	Rr	2.1	2.3
				Sl	2.9	2.1
			XIII	Sr	3.0	3.3
				Rl	3.1	3.5
				Sl	2.5	2.9
Av.		Rl	2.4	2.3		
		Rr	2.4	2.4		
Longissimus dorsi (rib)	45	IX	Ul	2.9	3.0	
			Vl	2.4	1.8	
		XIII	Tl	3.0	2.4	
			Vr	2.3	2.1	
			Tl	3.0	3.6	
	Av.	65	IX	Ur	2.9	2.7
				Vl	4.0	2.6
			XIII	Tr	3.1	3.4
				Ul	3.2	4.2
				Vl	3.1	4.1
	Av.	85	IX	Ul	3.1	4.0
				Vl	3.5	3.9
			XIII	Tr	3.3	2.6
				Vr	4.5	3.7
				Ur	4.1	5.0
Av.		IX	Vl	4.1	3.6	
			Vr	4.7	4.2	
		XIII	Ur	4.7	4.2	
			Vl	4.7	4.2	
			Tr	3.9	4.2	
Av.		Vr	4.2	4.1		
			4.4	4.2		

Table 13. Mean squares and significance for cooking factors for the semitendinosus and longissimus dorsi muscles.

Source of variation	D/F	Cooking losses	Cooking time	Shear values	Press fluid yields
<b>Semitendinosus</b>					
Temperature	2	432.12 **	2116.99 ***	175.47 *	15.96 ***
Blocks	5	4.78 ns	47.35 ns	61.07 ns	0.41 ns
Error	10	1.74	19.12	40.05	0.24
Total	17				
<b>Longissimus dorsi (loin)</b>					
Temperature	2	467.56 ***	1481.06 ***	4.68 ns	13.02 ***
Blocks	5	6.27 *	19.03 ns	11.28 *	0.78 *
Error	10	1.53	9.09	2.80	0.20
Total	17				
<b>Longissimus dorsi (rib)</b>					
Temperature	2	233.66 ***	1074.24 ***	12.82 ns	6.44 **
Blocks	5	31.04 ns	29.04 ns	22.59 ns	0.58 ns
Error	10	10.52	15.30	7.50	0.76
Total	17				

ns - non-significant  
 \* - significant at the .05 level  
 \*\* - significant at the .01 level  
 \*\*\* - significant at the .001 level

Table 14. Mean squares and significance for palatability factors and preference scores for the semitendinosus and longissimus dorsi muscles.

Source of variation	D/F	Aroma		Flavor		Juiciness		Tenderness					
		Mean Sq.	Signif.	Mean Sq.	Signif.	Mean Sq.	Signif.	Mean Sq.	Signif.				
<b>Semitendinosus</b>													
Temperature	2	1.27	**	.21	ns	3.22	***	4.90	***	1.66	**	.21	*
Block	5	.17	ns	.07	ns	.48	*	.31	ns	.48	ns	.09	ns
Error	10	.10		.15		.10		.13		.15		.04	
Total	17												
<b>Longissimus dorsi (loin)</b>													
Temperature	2	.06	ns	.08	ns	2.96	*	13.50	***	.04	ns	.16	ns
Block	5	.05	ns	.06	ns	.12	ns	.39	ns	.24	ns	.71	ns
Error	10	.10		.58		.49		.47		.35		.24	
Total	17												
<b>Longissimus dorsi (rib)</b>													
Temperature	2	.41	*	.18	*	3.96	***	11.56	***	4.09	***	1.14	**
Block	5	.43	*	.12	ns	.03	ns	.25	ns	.29	ns	.39	ns
Error	10	.08		.04		.17		.35		.35		.12	
Total	17												

ns - non-significant  
 \* - significant at the .05 level  
 \*\* - significant at the .01 level  
 \*\*\* - significant at the .001 level

Table 15. Values of "t" and significance for cooking and palatability factors for six muscles.

Muscle	Cook. : losses : t.	Cook. : time : ***	Cook. : Shear : values : * 45°	Press : fluid : *** 45°	Aroma : *** 65°	Flavor : ns 65°	Juiciness :		Tenderness :	
							Press : ns 45°	Fluid : ns 45°	Score : Pref. : ns 45°	Score : Pref. : ns 45°
Psoas major	10.76	13.86	2.64	4.45	4.45	1.68	1.11	5.51	0.76	1.79
	sign. favors	*** 45°	* 45°	*** 45°	*** 65°	ns 65°	ns 45°	*** 45°	ns 45°	ns 45°
Adductor	1.87	5.76	1.25	1.39	1.80	2.36	5.82	5.19	0.09	1.14
	sign. favors	** 45°	ns 45°	ns 45°	ns 65°	ns 65°	*** 45°	** 45°	ns 45°	ns 45°
Rectus femoris	6.14	5.92	1.26	3.74	3.48	0.81	1.89	4.22	1.62	1.45
	sign. favors	** 45°	ns 45°	* 45°	* 65°	ns 65°	ns 45°	** 45°	ns 45°	ns 65°
Vastus lateralis	9.25	9.95	0.30	8.51	1.98	2.20	12.60	12.92	3.07	0.18
	sign. favors	** 45°	ns 65°	*** 45°	ns 65°	ns 65°	*** 45°	*** 45°	* 45°	ns 65°
Semimembranosus (posterior)	2.51	7.42	0.74	3.45	3.38	2.78	2.64	1.74	1.14	1.21
	sign. favors	ns 45°	ns 45°	* 45°	* 65°	* 65°	* 45°	ns 45°	ns 45°	ns 45°
Semimembranosus (anterior)	10.61	10.03	4.22	2.79	1.58	0.29	2.06	8.30	1.26	0.87
	sign. favors	*** 45°	** 45°	* 45°	ns 65°	ns 65°	ns 45°	*** 45°	ns 45°	ns 45°

ns - non-significant  
 \* - significant at the .05 level  
 \*\* - significant at the .01 level  
 \*\*\* - significant at the .001 level

SCORE CARD FOR BEEF

JUDGE \_\_\_\_\_ CODE \_\_\_\_\_ DATE \_\_\_\_\_

Sample Number	Aroma	Flavor	Juiciness	Tenderness	Number of chews	Comments
1.						
2.						
3.						
4.						
5.						
6.						

Descriptive Terms for scoring:

- 10. Extremely good
- 9. Very good
- 8. Good
- 7. Moderately good
- 6. Slightly good
- 5. Slightly poor
- 4. Moderately poor
- 3. Poor
- 2. Very poor
- 1. Extremely poor

Rate samples according to preference:

- |                |               |
|----------------|---------------|
| For tenderness | For juiciness |
| 1. _____       | 1. _____      |
| 2. _____       | 2. _____      |
| 3. _____       | 3. _____      |
| 4. _____       | 4. _____      |
| 5. _____       | 5. _____      |
| 6. _____       | 6. _____      |

THE EFFECT OF INTERNAL TEMPERATURE ON THE  
PALATABILITY OF BEEF COOKED IN DEEP FAT

by

MARILYN McNELIS

B. S., Kansas State College  
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AN ABSTRACT OF A THESIS

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The effect of the degree of protein coagulation, as determined by internal temperature, on the palatability, particularly the juiciness and tenderness, of meat has been studied. The results are incomplete and in disagreement. Thus, there is a need for more study in this area of meat research. One of the aims of this study was to obtain cooked meat that was representative of rare, medium-, and well-done, with which to study the rate of heat penetration, cooking losses, and palatability.

A penetrometer has been used for measuring the consistency of whole raw and cooked meat, but there has been no published work in which the consistency of ground raw meat has been determined by the penetrometer. Another aim of this study was to discover if there was a correlation between penetrometer readings for ground raw meat and the characteristics of cooked meat, such as tenderness, juiciness, and cooking losses.

The long hindquarters of three U. S. Good grade steers were sent from a Kansas City packing company to the Kansas State College Animal Husbandry Meats Laboratory where they were dissected into the paired psoas major, adductor, rectus femoris, vastus lateralis, semitendinosus, longissimus dorsi (loin and rib sections), and semimembranosus (posterior and anterior) muscles and their respectively coded roasts. The roasts were wrapped in aluminum foil and frozen at  $-20^{\circ}\text{F}$ . in an upright freezer and stored in the freezer until they were thawed at  $43^{\circ}\text{F}$ . for approximately 48 hours before cooking.

A randomized incomplete block design was used for determining the end point temperature of roasts from the semitendinosus

and longissimus dorsi (loin and rib) muscles, which were cooked in deep fat maintained at  $100^{\circ}\text{C.} \pm 4^{\circ}\text{C.}$  to  $45^{\circ}$ ,  $65^{\circ}$ , and  $85^{\circ}\text{C.}$  For roasts from the remaining muscles, which were cooked to  $45^{\circ}$  and  $65^{\circ}\text{C.}$  a randomized complete block design was used to determine the internal temperatures.

The time required for every five degree rise in internal temperature was recorded and total cooking losses were calculated. Shear force values and press fluid yields were determined on the cooked meat. A palatability panel scored the meat for flavor, aroma, juiciness, and tenderness. Samples of raw ground meat were tested for consistency by use of the penetrometer.

Analyses of variance and t-tests were used to determine differences, attributable to internal temperature, in cooking time, cooking losses, press fluid yields, shear values, and scores for palatability factors. Least significant difference was used wherever it was appropriate. Correlation coefficients for roasts from each muscle cooked to each internal temperature were computed for: tenderness scores versus penetrometer readings, tenderness scores versus shear values, juiciness scores versus press fluid yields, juiciness scores versus penetrometer readings, cooking losses versus juiciness scores, cooking losses versus press fluid yields, and cooking losses versus penetrometer readings. Also, correlation coefficients were calculated for these same factors for roasts from all muscles cooked to each end point temperature.

The total cooking time for all roasts ranged from 17 to 83 minutes and cooking time, in minutes per pound, ranged from 19

to 63 minutes. As the internal temperature of the roasts was increased, mean cooking time, in minutes per pound, increased significantly for the roasts from all muscles, and was accompanied by a significant increase in mean cooking losses from all roasts except those from the adductor and semimembranosus (posterior) muscles.

Significant differences in press fluid yields from roasts cooked to different internal temperatures were found for all muscles except the adductor. The amount of press fluid yielded by all roasts decreased with increased internal temperature. The only significant correlation coefficient for cooking losses and press fluid yields was for roasts from the rectus femoris cooked to 65°C. When all of the muscles cooked to each internal temperature were considered together, the correlation coefficients were significant at the one percent level for roasts cooked to 45°C. and at the one-tenth percent level for roasts cooked to 65°C.

Judges' scores for juiciness and for preference for juiciness decreased with increasing internal temperature. The roasts from all muscles except the semimembranosus (posterior) cooked to 45°C. were significantly more juicy than those cooked to 65°C., and those from the longissimus dorsi (loin and rib) were significantly more juicy when cooked to 65°C. than when cooked to 85°C. Significant differences between preference scores for juiciness for roasts from the adductor, vastus lateralis, semimembranosus (posterior), semitendinosus, and longissimus dorsi (loin) indicated that the judges preferred the roasts from these muscles

that were cooked to 45°C. to those that were cooked to 65°C. The only significant correlation coefficient for juiciness scores and cooking losses was for roasts from the semimembranosus (anterior) muscle. When correlation coefficients for cooking losses and juiciness scores for all muscles cooked to a given internal temperature were calculated, the coefficients were significant at the two percent level for roasts cooked to 45° and 65°C. Correlation coefficients for press fluid yields and juiciness scores were non-significant with the exception of a negative coefficient for roasts from the adductor muscle cooked to 45°C. The majority of the coefficients, however, were positive, but non-significant.

Tenderness scores decreased slightly and shear values increased slightly with an increase in internal temperature, but these changes were not great enough to be significant. Correlation coefficients for tenderness scores versus shear values for roasts from all muscles cooked to each temperature were highly significant and very highly significant for roasts cooked to 45° and 65°C., respectively.

There was a significant increase in aroma scores with increased internal temperature, and slight but non-significant increase in flavor scores for roasts from most of the muscles.

Results of penetrometer tests indicated that there might be some relationship between the consistency of raw ground meat and the water holding capacity. All but one of the correlation coefficients for cooking losses versus penetrometer readings were positive and some of them were high. However, the small

number of degrees of freedom made them non-significant.

The rate of heat penetration curves revealed a slight leveling off beginning around  $55^{\circ}\text{C}$ ., which resulted from the endothermic coagulation of muscle protein. Another slight plateau in the rise in internal temperature occurred between  $75^{\circ}$  and  $85^{\circ}\text{C}$ . The rate of heat penetration was slower in roasts from the proximal end than in those from the distal end of the muscle, and in thick, blocky roasts than in small flat roasts. The internal temperature of roasts cooked to  $45^{\circ}\text{C}$ . rose from eight to 15 degrees after they were removed from the fat; the temperature of those cooked to  $65^{\circ}\text{C}$ . rose from four to seven degrees; and the temperature of those cooked to  $85^{\circ}\text{C}$ . did not rise further.

