A STUDY OF SOME SECONDARY FACTORS INFLUENCING TENDERNESS OF THE BOVINE LONGISSIMUS DORSI MUSCLE

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INTRODUCTION

Tenderness is a complex entity recognized as being the most desirable quality attribute of meat. Cover et al. (1962) fragmented tenderness into six components as follows: tenderness of connective tissue; two components of softness (to tongue and to tooth pressure); and three muscle-fiber components (ease of fragmentation, adhesion and mealiness). Factors directly related to tenderness include animal age, sex, breeding, nutrition, exercise, marbling and chemical changes. In addition to the above, preparatory techniques also influence tenderness. A precise measurement of meat tenderness is difficult to obtain with techniques presently available. The Warner-Bratzler shear device has been used extensively in meat tenderness research, and shear results and taste panel scores for tenderness have been closely correlated. Despite its popularity, some authors have pointed out serious limitations in the Warner-Bratzler machine, and have recommended that the terms "tenderness" and "Warner-Bratzler shear value" not be used synonymously.

Considerable variation in cooking procedures as well as size, thickness and shape of cooked meat samples used for shear determinations may be found in the literature. Yet, little information is available as to the influence of these factors on results obtained.

There were two major objectives in this study. One objective was to determine the influence of sample core diameter and steak thickness on Warner-Bratzler shear values using steaks cooked to uniform doneness in deep fat. The second was to compare deep fat and microwave or "electronic" cookery as factors influencing the tenderness of the bovine longissimus dorsi muscle. Measurements used for this comparison were Warner-Bratzler shear values, panel chew-count, cooking loss and expressible fluid. The microwave oven was chosen for the comparison with deep fat primarily because of its eventual value as a useful tool in meat research. In addition, equipment modifications for core removal and expressible fluid determination were evaluated. An attempt was also made to assess experimental error inherent in the Warner-Bratzler shear technique.

REVIEW OF LITERATURE

This review includes some of the work relative to the following: (1) The influence of animal and muscle variation on tenderness. (2) Tenderness of the *longissimus dorsi* muscle as influenced by cooking, and (3) objective tenderness measurements.

Animal Variation.

Species.

Tenderness is an important consideration in pork and lamb, as well as beef. Pork and lamb cuts are usually tender because of age, and show little tenderness variation as a result of uniformity in age, weight and level of nutrition. Since the tenderness variation among animals and between cuts of pork and lamb is not great this factor has received little attention. Beef on the other hand, is more mature at the time of slaughter and is generally less tender, as explained by Dawson (1959) and Weir (1960). Since there is considerable variation in tenderness in beef, both among animals and between individual muscles, many workers have attempted to more clearly establish the cause of the variation in this palatability characteristic.

Breeds.

There is considerable published data indicating that the English breeds of beef cattle generally produce more tender meat than "dairy type" animals. In addition, there is evidence that meat from Brahman animals may be less tender than meat from some of the other beef breeds. Hereford and Angus were found by Cole et al. (1958) to have more tender meat than two dairy breeds, while Brahman meat was less tender. Palmer et al. (1961) reported Hereford steers to have more tender meat than Hereford x Brahman steers. Carpenter et al. (1955) suggested that as the percentage of Brahman breeding increased, meat tenderness decreased. Using the shear method, Burns et al. (1958) found that meat from Angus and Hereford steers was more tender than meat from Brahman steers, and that meat from crossbreeds was intermediate in tenderness. Breed differences have been further substantiated by Kieffer et al. (1959), Huffman et al. (1962), and Alsmeyer et al. (1959). The effect of breed on the tenderness of beef was examined by Husaini et al. (1950a). Contrary to the results of others, meat from ten Holstein and ten Hereford steers, 2½ years of age, showed no difference in tenderness due to breeding. In addition, Cover et al. (1957) noted no significant effect of breed on tenderness scores or shear values of meat from 18 purebred Hereford steers and 20 Brahman x Hereford steers.

Within Breed.

Although there are some contradictions in the literature, several authors have linked age, sex, carcass grade and nutrition to differences in tenderness within a particular breed of beef animals. Nelson et al. (1930) found that shear values of meat from calves were higher than those from yearlings or 2-year-old steers. Cline et al. (1932) observed that cow meat was less tender than that from heifers.

Relative tenderness of meat from the round and loin of yearling steers and mature cows was compared by Brady (1937). The average Warner-Bratzler shear value for muscles from steers was 17.8 ± 1.2

pounds and 28.4 ± 1.2 pounds for those from cows. Hiner and Hankins (1950) found that as animal age advanced from 2½ to 66 months, tenderness decreased. Later, Hiner et al. (1955) tested meat from Shorthorns of different ages for tenderness. They attributed the decreased tenderness in more mature animals to increased connective tissue. Shear values of the cooked meat from Holstein heifers also increased with an increase in age from 2 to 12 months, according to observations by Jacobson and Fenton (1956a).

Differences in the eating quality of beef from steers 18 and 30 months of age were reported by Simone et al. (1959). Results of a laboratory panel indicated that age significantly influenced tenderness. Tuma et al. (1963) found meat from 6-month-old calves to be less tender at two days post-mortem than meat from 18-month-old beef animals; however, after a 14 day aging period, meat from the 6-month-old calves was more tender. A significant animal age x aging interaction as shown by both panel tenderness score and shear force values, suggested a different rate of tendering during aging for each age group.

There are indications that higher carcass grades do not always assure more tender meat. Husaini et al. (1950b) and Cover et al. (1958) concluded that carcass grades for beef are not satisfactory indicators of tenderness. Some of the lower grades of meat from 203 carcasses studied had tenderness scores comparable to some meat from the higher grades. Two years later, Cover and Hostetler (1960) collected tenderness data from 91 steers produced and fed under controlled conditions. They concluded that carcass grade and marbling were not consistently or closely related to measures of connective tissue or muscle fiber tenderness. These results were confirmed by Lowe and Kastelic (1961).

Wellington and Stouffer (1959) reported that a trained taste panel observed increased tenderness with more abundant marbling in cooked rib-eye steaks. Differences in mechanical shear results were not significant, however. Paul and Bratzler (1955a), Griswold (1955) and Harrison et al. (1949) found tenderness to be related to grade. The higher carcass grades yielded more tender meat in these studies.

Hall et al. (1944) fed high phosphorus and high calcium rations to cattle and found slightly improved tenderness in rib roasts from those fed a high phosphorus ration, but other authors report no consistent effect on tenderness by a single nutrient.

The influence of three levels of nutrition (low, medium and high) on the tenderness of cooked meat from 24 Holstein heifers was studied by Jacobson and Fenton (1956b). They reported significantly higher tenderness scores for longissimus dorsi roasts from animals fed the higher levels of nutrient intake.

Alsmeyer (1964) fed 15 pairs of identical twin heifers a high roughage ration or a high concentrate ration. Meat from animals fed the high concentrate ration was significantly more tender than that from their mates fed the high roughage ration, as determined by the Warner-Bratzler shear, although panel tenderness scores were not significantly different between the two groups. Earlier, Edwards et al. (1961) reported that the ration fed to beef animals influenced the rate of fat deposition and composition of fat within muscles. Cattle studied were fed different combinations of grass and grain.

Muscle Variation.

Between Muscles.

It is generally known that certain bovine muscles are more tender than others. Studies conducted by Hiner and Hankins (1950) classified muscles from beef carcasses into four degrees of tenderness. The least tender muscles were from the neck and foreshank; next came the round; third, were the chuck, rib, shortloin, and loin end; and the tenderloin was most tender. Tenderness of the three large muscles in the round (semimembranosus, semitendinosus and biceps femoris)was not considered significantly different. Ginger and Weir (1958) studied tenderness variations in three beef muscles, and reported that the biceps femoris and semitendinosus muscles were more uniform in tenderness than the semimembranosus.

Exercise appears to influence meat tenderness by resulting in more connective tissue and increased muscle cell density. It was demonstrated by Hiner et al. (1955) that exercised muscles had more and larger elastin and collagenous fibers than those not used much. In recent work, Helander (1961) reported that the degree of muscle activity influenced the composition of muscle cells in rabbits and guinea pigs. He reported that exercise increased the myofilamental density of the muscle cell, however restricted activity reduced myofilamental density and increased sarcoplasmic content.

Other muscle tenderness variation was noted by Ramsbottom et al. (1945), Ramsbottom and Strandine (1948), Strandine et al. (1949) and Paul et al. (1956).

Within the Longissimus dorsi Muscle.

There is little consistency among results concerning tenderness variation along the length of the longissimus dorsi muscle. Satorius and Child (1938) observed no significant variation in tenderness between the 7-8th, 9-10th and 11-12th rib of loin roasts of beef and pork.

Hankins and Hiner (1940) reported the rear portion of the shortloin to be significantly more tender than the anterior position, based on studies of four steaks from each location.

Tenderness of muscles from three heifer carcasses were studied by Ramsbottom et al. (1945). They found the longissimus dorsi muscle to be less tender at the anterior end than at the posterior or middle. Essentially opposite results were obtained by Weir (1953), Ginger (1957), Walker and Henrickson (1960) and Mjoseth (1962).

Chemical Differences.

Muscles are known to be composed primarily of water, proteins, fats, carbohydrates and inorganic material. Efforts have been made to relate these components to tenderness.

Water.

Water, the most abundant component of beef muscle, plays an important role in the hydrolysis of protein during cooking, and appears to vary in quantity in different muscles. Ramsbottom and Strandine (1948) reported wide variation in moisture content in 50 muscles of three U.S. Good carcasses. Moisture content ranged from 62.5 percent in the intercostal muscles to 76 percent in the carpi radialis, with an average of 72.2 percent, and that for the longissimus dorsi muscle was 72.9 percent.

Moisture content averaged 67.03 percent $\pm$ 2.19 in an investigation involving post-mortem and tenderness changes in muscles from six heifers conducted by Wierbicki et al. (1956). Tuma et al. (1963) reported that the moisture content of the beef longissimus dorsi muscle differed little among 18, 42 and 90-month-old animals, but was higher for those 6 months of age.

Juiciness, expressible fluid, and moisture are terms commonly associated with the tenderness of meat and several determination methods have been developed.

Wierbicki and Deatherage (1958) reported a modification of the original filter paper technique, developed by Grau and Hamm (1953), for determination of the water holding capacity of meat. Their modification included a formula which expressed the percentage of "bound water" as the percentage of "free water" subtracted from 100.

A filter paper technique was also used by Briskey et al. (1959) to determine the ratio of meat to water in pork. The four groups of hams, which varied from dark and dry to soft and watery, showed no significant differences. The following year, Briskey et al. (1960) reported the water area as a percentage of total moisture in a study involving eight pork muscles. This technique was modified somewhat from that used in 1959.

Tuma (1962) used a Carver press and a modified version of the technique reported by Wierbicki and Deatherage (1958). Three 500 mg. samples were removed from the center of each steak and exposed to 500 pounds pressure per square inch for one minute in a Carver press. A ratio of the moisture area to the meat area was determined by dividing the area of the meat ring into the moisture ring area. His results indicated a relationship between the moisture-meat ratios and age groups of beef animals from which meat samples were taken. They found that aging and marbling were significantly associated with moisture areas. There was decreased moisture area with increased marbling and aging to 14 days. This confirmed results obtained by other authors using different methods.

Proteins.

Tenderness was considered to be related to connective tissue proteins and proteins of the muscle cells by Deatherage and Harsham (1947). Collagen and elastin fibers were found to be related to tenderness of heated meat from a wide variety of beef samples of known history in work by Hiner et al. (1955). They emphasized, however, that tenderness in beef is a function of many interrelated factors. Wierbicki and Deatherage (1958) found tenderness and texture of cooked meat to be related to the degree of hydration of muscle proteins.

Ritchey et al. (1963) with data from 91 animals 16 months of age, found that the longissimus dorsi contained less collagen nitrogen than the biceps femoris muscle in raw steaks and in steaks cooked to final internal temperatures of 61° to 80°C. Collagen nitrogen content was greater in cooked samples than in raw samples tested by Skelton et al. (1963). They reported collagen nitrogen to be more abundant in the semitendinosus than in the longissimus dorsi muscle, with right and left sides essentially equal. Some authors have noted that variations and inconsistencies in collagen determinations in the past have been partly due to methods of determination.

Roberta et al. (1961) studied variations in the "free" amino acid content of nine beef muscles using paper chromatography. Variation of the curve peak obtained from the chromatogram of a photoelectric densitometer was greatest in the leucine-isoleucine spot. The more tender cuts contained more leucine-isoleucine than the less tender ones, suggesting that tenderness determination through the analysis of amino acids may be possible. Their results followed a pattern similar to that reported by Hiner and Hankins (1950).

Parrish et al. (1961) reported the coefficient of correlation of the meat hydroxyproline and sensory tenderness values for 32 loin steaks and 60 round steaks to be -0.84 ($P < 0.001$). The authors further stated that hydroxyproline content was a better measure of tenderness of less tender steaks than of the more tender ones. For example, their data indicated that hydroxyproline content as a measure of connective tissue would be of less value as a tenderness indicator in the better grades and cuts of beef, since factors in addition to connective tissue content play a predominant role in tenderness.

Wierbicki et al. (1954) studied the relation of tenderness to protein alterations during post-mortem aging in meat from 48 beef animals. Their results indicated that connective tissue may not contribute to increased tenderness on post-mortem aging inasmuch as total alkali insoluble protein does not change. Evidence was presented by the authors which suggested that increased tenderness with post-mortem age may be related to dissociation of actomyosin or other changes which increase protein extractability, and redistribution of ions causing increased hydration and tenderness.

Fat.

Wellington and Stouffer (1959) reported that an experienced taste panel observed increased tenderness that was highly significantly correlated with more abundant marbling. Ramsbottom et al. (1945) found no relationship between shear readings and intramuscular fat in beef muscels. They advanced the thought, however, that differences in the amount of connective tissue associated with the intramuscular fat may explain why there is no positive relationship.

Ramsbottom and Strandine (1948) removed 50 of the larger muscles from three U.S. Good carcasses. Chemical analysis revealed that fat content varied from 18.1 percent in the intercostal muscles to 1.5 percent in the carpi radialis. Average fat content for the 50 muscles studied was 5.7 percent. The longissimus dorsi muscle had an average of 6.3 percent fat. From muscles of four beef animals, Swift and Berman (1959) found average fat content of the longissimus dorsi muscle to be 2.48 percent as compared to 2.10 percent for the semitendinosus.

pH.

Ramsbottom and Strandine (1948) examined pH variation between muscles within an animal. They reported that pH values of 50 beef muscles ranged from 5.5-6.0 with a mean of pH 5.7. The longissimus dorsi and semitendinosus muscles had pH values of 5.7 and 5.5 respectively. They found no evidence that pH was related to tenderness, however. Tuma et al. (1963) reported that the pH of steaks was slightly lower with increased animal age when animals 6, 42 and 90 months of age were considered. The trend did not hold true for 18-month-old animals, however, and the differences were not significant.

Husaini et al. (1950b) noted no relationship between tenderness and pH of shortloin steaks from animals with grade variation.

An effort to relate tenderness to protein alteration during post-mortem aging of beef, was made by Wierbicki et al. (1954). Muscle pH dropped from 7.3-7.4 in the living animal, to 5.4-5.6 in the carcass within 48 hours after slaughter. The drop in pH was reportedly concurrent with the disappearance of adenosine triphosphate (ATP), and the appearance of lactic acid.

Wierbicki et al. (1956) found that both pH and juice lost during cooking changed with the post-mortem age and appeared to be interrelated.

Physical Characteristics.

Strandine *et al*. (1949) studied the chemical and histological variations in 50 principal beef muscles and 12 chicken muscles. The study demonstrated that variability exists between muscles within a species and in different species. Variations in the size and arrangement of fasciculi and connective tissue were noted when muscles were cut transversely. Fascicular patterns were constant for a given muscle within a species, but different from different muscles of the same species and for muscles of different species. They further observed that both elastin and collagenous fibers varied from muscle to muscle with respect to their size and quantity.

Brady (1937) reported the number of muscle fibers in a muscle bundle to be related to tenderness (correlation +.55) but concluded that fiber diameter was a poor indicator of tenderness in the beef *longissimus dorsi* and *semitendinosus*. Muscle fiber diameter was found to be a poor indicator of beef tenderness in the same beef muscles in a study reported by Tuma *et al*. (1962)

Hiner *et al*. (1953) published results which indicated that smaller fibers were indicative of tenderness within a given muscle. It was noted that as fiber diameter increased, resistance to shearing increased. These studies involved 52 beef animals varying in age from 10 weeks to 9 years. Results of histological examinations revealed that the amount and distribution of collagen and elastin were associated with tenderness.

Wang *et al*. (1956), working with raw and cooked beef samples from 44 *longissimus dorsi* and 13 *semitendinosus* muscles, found that cooking increased the extensibility of muscle fibers. They found a "fair" negative correlation (-0.43 to -0.85) between muscle fiber extensibility and panel tenderness of samples. The positive correlations between fiber extensibility and shear force ranged from 0.36 to 0.82 in the longissimus dorsi muscle.

Cover et al. (1962) found muscle fiber extensibility in the longissimus dorsi to be closely related to shear force values. Muscle fiber extensibility was found to be greater at 100°C than at 61°C.

Cooking Method.

Cooking results in various changes in the tenderness of beef muscles. Ramsbottom et al. (1945) found that most of the 25 beef muscles from U.S. Good beef carcasses tested in their study decreased in tenderness on cooking. They stated that although connective tissue and fatty tissue are made more tender by cooking, the decrease in tenderness noted may be associated with coagulation and denaturation of muscle proteins, coupled with shrinkage and hardening of the muscle fibers. Shear readings of the cooked meat were positively correlated with shear readings of the raw meat, organoleptic ratings and histological scores.

Cover and Hostetler (1960) compared braised and oven roasted samples cooked under different conditions (cooking medium, temperature and cooking time) and reported that beef cuts from the loin and bottom round responded differently to the same cooking conditions. Loin steaks were improved about equally by each of the conditions of cooking, but tenderness of bottom round steaks from the same carcass were markedly affected by cooking condition. Bottom round steaks oven roasted rare contained more tough connective tissue after cooking than did those cooked well done. Braising to medium-rare tenderized the connective tissue about the same as did oven roasting well done. The most tender bottom round steaks were braised very well done. They pointed out that connective tissue and muscle fibers are not "uniformly distributed in muscles; and that some cooking methods may tenderize connective tissue while toughening muscle fibers". They further suggested that "the moisture in the moist heat methods appeared to have been needed to obtain high meat temperature rather than to furnish water needed for chemical change (hydrolysis) of collagen into gelatin".

Cooking Media.

The two more common categories of cooking media are normally referred to as "dry heat" and "moist heat". Paul et al. (1956) cooked Commercial grade beef to 71° and 80°C by both dry and moist heat. The dry method was found to be most desirable with regard to palatability and yield. Dry heat also produced more tender cuts than moist heat in a study by Hood et al. (1955). Winegarden et al. (1952) however, reported that collagenous tissue softened when heated in water at a sufficiently high temperature. During this study, it was noted that in roasts cooked rare or medium (55° - 65°C) there appeared to be little change in connective tissue, but at higher temperatures, physical changes in the collagenous tissue occurred rapidly, resulting in softening.

Lowe and Kastelic (1961) cooked roasts from beef animals varying in age and carcass grade. Steaks were cooked to an internal temperature of 70° and 90°C. A panel scored roasts cooked to 70°C more tender than those cooked longer, but this difference was not confirmed by shear values of the same cuts.

Deep fat has been used by several authors as a cooking medium in beef research. Harrison et al. (1949) cooked beef muscles to an internal temperature of 70°C in fat held at 96° to 98°C, and Paul and Bratzler (1955b) cooked 1-inch steaks in fat maintained at 147°C to an internal temperature of 63°C. Mjoseth (1962) cooked 2-inch thick *longissimus dorsi* and *semitendinosus* steaks to an internal temperature of 150°F in deep fat preheated to 275°F in a study of tenderness variation in certain bovine muscles.

Heat Penetration.

It was found by Cover (1937) and (1941) that cooking temperature and time were important factors in determining tenderness of meat. She further noted that slow cooking increased tenderness of roasts. Later, Cover (1943) found that paired roasts cooked at 80°C had consistently lower shear values than those cooked at 125°C. Comparing the influence of two methods of cooking on Commercial round steaks, Clark et al. (1955) concluded that the internal temperature to which the meat was cooked was more important in determining palatability than the cooking method.

Tuomy et al. (1963) found that heat initially toughened meat, and that the toughening increased as the temperature was increased. They further noted that at temperatures below 82°C, the tenderness of cooked meat was quite dependent on temperature, with little or no effect due to time. At 82°C and above, the rate and degree of tenderness were dependent upon both time and temperature.

Beef muscles of varying tenderness were cooked to rare, medium and well done by oven roasting, deep fat (110°C) and deep fat (100°C) by Visser et al. (1960). Heat penetration was faster in meat cooked in deep fat. Time required to reach the desired end point was 2 to 3 times less than for oven roasting. As the internal temperature of the meat increased, there was usually a significant increase in cooking losses. Shear values were slightly lower for oven roasts than for those cooked in fat to the same internal temperature.

Electronic Oven.

Electronic or microwave cooking is an outgrowth of World War II radar. A magnetron tube in the oven changes electricity into microwaves, which penetrate the food and produce heat. Although the commercial use of electronic ovens is increasing rapidly, little research knowledge is available concerning the influence of this cooking method on meat tenderness.

In an early study at the Quartermaster Food and Container Institute, Bollman et al. (1948) compared beef rib roasts cooked to an internal temperature of 71°C conventionally and electronically. Electronic cooking time for a three pound roast was approximately 13 minutes, whereas, two hours was required in an electric oven at 149°C. Roasts cooked electronically were turned during the cooking period. In addition, steaks of varying thickness were cooked rare, medium rare and well done by both methods. They found that it was difficult to cook larger cuts evenly in the electronic oven, and that electronic cooking was much more uniform and resulted in less dehydration in thin cuts such as steaks. Acceptability of steaks cooked in electronic ovens was comparable to those cooked conventionally. They reported that larger cuts of meat cooked in an electronic oven could be made acceptable, but weight losses would make the practice uneconomical in view of moisture and trimming losses.

Marshall (1960) cooked paired five pound roasts from Choice grade top round of beef in an electronic oven and in a conventional oven at

149°C. All roasts were reportedly cooked to an internal temperature of 80°C. It was noted by the author, that the temperature of one roast cooked electronically rose to 84°C while standing at room temperature for 15 minutes. She found all palatability ratings to be lower for the roasts cooked electronically. It was concluded that portions of the electronically cooked roasts became very hard and dry, and were unpalatable.

A thorough review of this study indicated that the poor results obtained from roast cooked by microwaves, may have been partly due to the relatively high internal temperature which apparently overcooked the roasts, removed most of the free moisture and prevented further distribution of heat.

It was reported by Fenton (1957) that microwave cooking of meat usually resulted in more cooking drip, and that overcooking resulted in higher losses.

The effect of microwave and conventional cooking on pork patties, roasts and chops was investigated by Apgar et al. (1959). They found that conventional cooking of pork required about five times the cooking time necessary for microwave cooking. Fat appeared uncooked in chops cooked electronically without browning units. Pork chops from the longissimus dorsi muscle that were cooked by microwaves had increased juiciness scores, while roasts showed decreased juiciness. Microwave cooking resulted in higher shear values for both chops and roasts in these comparisons. Headly and Jacobson (1960) compared microwave and conventional cookery of lamb roasts. Microwave cooking was four times faster than the conventional electric oven, and required only an average of 13 minutes to cook roasts averaging 4.5 pounds each, whereas 52 minutes was required for the conventional method. They noted a temperature rise of from 29° to 34°F internal temperature after roasts were removed from the oven. Maximum temperatures were reached after a standing period ranging from 15 to 23 minutes. In order to overcome this temperature increase, roasts cooked electronically were removed from the oven when the internal temperature reached 66°C, whereas those cooked conventionally were allowed to reach 82°C. Shrinkage was greater in roasts cooked by microwaves, with average cooking losses of 43 percent compared to 35 percent for the conventional method. They reported no influence of cooking method on shear values or "chew" counts.

An electronic range was used by Phillips _et al_. (1960) to cook chicken in a comparison with conventional methods. They reported mean cooking losses for samples cooked by microwaves to be 23.3 percent compared to 24.4 percent for the conventional oven. The difference in cooking loss was not significant.

Copson (1962) suggested that roasts about twice as long as they are wide give best results when cooked in an electronic oven, and that overcooking of a small end of a roast or steak may be avoided by shielding the smaller portion for a fraction of the cooking period.

A study conducted for the U.S. Navy Research and Development Facility by Pollak _et al_. (1959), involved the use of a Tappan Model RL-1 Microwave Cooker. Their results for meat cooked by this method were characterized by non-uniform heat distribution and high cooking losses, ranging from 3-16 percent higher than in a conventional electric range. They observed that the temperature of an average family size roast increased in temperature approximately 20 percent during a 20-30 minute standing time.

Some limitations of microwave ovens when used for "raw to done" cooking were listed by Thatcher (1963). He stated that no microwave heating device has yet been developed which would give perfectly uniform heat distribution. In this regard, he further pointed out that some parts of meat heat faster than others, due to varying amounts of lean, fat and bone. In addition, he noted that microwave energy penetrates beyond the surface of the food, and that the cooking rate is so rapid that not all of the chemical reactions which normally occur during cooking have an opportunity to take place.

Objective Tenderness Measurements.

Shear.

Most of the more useful objective tenderness determinations have been accomplished by mechanical methods. Although several devices have been developed for this purpose, the Warner-Bratzler shear described by Warner (1928) and later modified and improved by Bratzler (1932), was described as the most widely used method for estimating tenderness in meat by Deatherage (1951).

Bratzler (1932) listed several factors influencing Warner-Bratzler shear values. These factors included degree of doneness and uniformity of size and shape of samples. Connective tissue, fat deposits, temperature and the speed of shearing were also mentioned as factors to be considered. It was stressed that samples should be cut parallel to the direction of the majority of muscle fibers.

The value of Warner-Bratzler shear determinations as an estimate of tenderness was summarized by Pearson (1963). From the results of numerous experiments, he found that the correlations between sensory methods of tenderness determination and Warner-Bratzler shear values ranged from 0.60 to 0.85, with 0.75 as the average.

Deatherage and Garnatz (1952) compared shear strength measurements to tenderness determinations by sensory panel. Matched pairs of broiled shortloin steaks were used for experimental material. A correlation coefficient of -0.37 was obtained when shear values and apnel scores were compared for 23 control sides. The authors noted that shear values and panel scores measured some property of meat in a fairly reproducible manner. They presumed, however, that shear strength and panel scores were not representing the same property of meat, in view of the poor correlation. In conclusion, they offered a recommendation that the synonymous use of the terms tenderness and shear strength, "as determined by the Warner-Bratzler shear" should be avoided.

Hurwicz and Tischer (1954) chose parawax and beeswax as standard materials for testing the variability of the Warner-Bratzler machine. The shear force tests were made on 1/2 inch cylinders of wax at four temperatures (32°, 45°, 60° and 80°F) in order to obtain varying degrees of hardness. The authors were critical of the machines' inability to account for the "time-load" effect, and concluded with a recommendation that the machine be "redesigned in an attempt to lower the experimental error inherent in it".

Chew Count.

The chew count method of measuring tenderness was proposed by Lowe (1949). This test involves counting the number of chews required to masticate a cooked meat sample to the state at which it would normally be swallowed. Although this is an objective approach to tenderness measurement, it is more subjective than the mechanical methods.

Harrington and Pearson (1962) stated that the chew count is probably the most objective of the sensory procedures, and found a high correlation between chew counts and shear values. There was an average increase of one pound shear value for each increase of four in chew count. Some members of the chew panel were more repeatable than others.

Steak Thickness and Core Size.

Much of the shear work previously reported was accomplished using cores ranging from 1/2 to 1 inch in diameter, and taken from steaks 1 to 2 inch in thickness, although Cover and Smith (1956) reported the use of 3/4 inch steaks. Some of these studies are summarized in Table I. The most common sample shape has been referred to as a "Core" or "Cylinder", however Hanning et al. (1957) removed fibers from the longissimus dorsi muscle and arranged them parallel to each other in bundles 5/8 inch in diameters.

Cores measuring 1/2 and 1 inch in diameter were compared by Paul and Bratzler (1955a). Their results suggested that either size could be used to measure shear tenderness. Hiner and Hankins (1950) reported the removal of 1 inch cylinders from 1 1/2 inch steaks. Each cylinder was sheared three times.

In studies of beef quality by Pearson and Miller (1950), three 1 inch cores were removed from steaks reported to be approximately 1 1/2 inches thick. Part two of the study involved the removal of five 1/2 inch cores from each steak for shear determinations.

Tuma et al. (1962), working with the longissimus dorsi muscle, used three 1 inch cores designated dorsal, medial and lateral and made three shears per core. These cooked steaks were two inches thick.

TABLE I

SUMMARY OF STUDIES CONCERNED WITH SAMPLING CHARACTERISTICS

Reference	Steak Thickness (In)				Core Diameter (In)			
	1	1 1/2	2	Other	1/2	3/4	1	Other
Strandine *et al*. (1949)					x			
Ramsbottom & Strandine (1948)					x			
Hiner & Hankins (1950)		x					x	
Pearson & Miller (1950)		x			x		x	
Deatherage & Garnatz (1952)							x	
Weir (1953)							x	
Paul & Bratzler (1955)					x		x	
Cover & Smith (1956)				3/4	x			
Hanning *et al*. (1957)							x	5/8
Sleeth *et al*. (1957)							x	
Bramblett *et al*. (1959)							x	
Saffle & Bratzler (1959)	x				x			
Alsmeyer *et al*. (1959)	x				x			
Wellington & Stouffer (1959)	x						x	
Anderson (1959)	x		x				x	
Cover *et al*. (1962)	x				x			
Tuma *et al*. (1962)			x				x	
Mjoseth (1962)	x		x				x	
Blumer (1963)				3/4		x		

EXPERIMENTAL PROCEDURE

Equipment Design and Development

Device for Core Removal.

A rapid and efficient means of core removal was sought during preliminary studies. A cylindrical borer mounted on a drill stand as described by Mjoseth (1962), eliminated the occurance of "hour glass" core shapes which were described as affecting shear values by Bratzler (1949). In the use of this borer, however, much care was necessary to avoid distortion of the core when removing it from the cutting head. In some instances, during preliminary work, it was necessary to detach the cutting head from the drive shaft in order to remove a core without damage. Although far superior to the hand method, this procedure was, in some instances, time consuming and required special care.

Modification I (Plate I) featured the addition of a metal plunger which would slide upward as the meat core entered the cylindrical cutting head during the removal of a core from a meat sample. This modification acheived the primary objective of speed, but had the disadvantage of occasional mal-function and difficulty in cleaning.

Modification II was used throughout this study as illustrated in Plate II and was capable of producing uniformly shaped cores at a rapid rate. Cores were easily ejected from the attachment by raising the cutting head on the shaft. No evidence of damage or sample

PLATE I.

Modifications of Core Removal Device

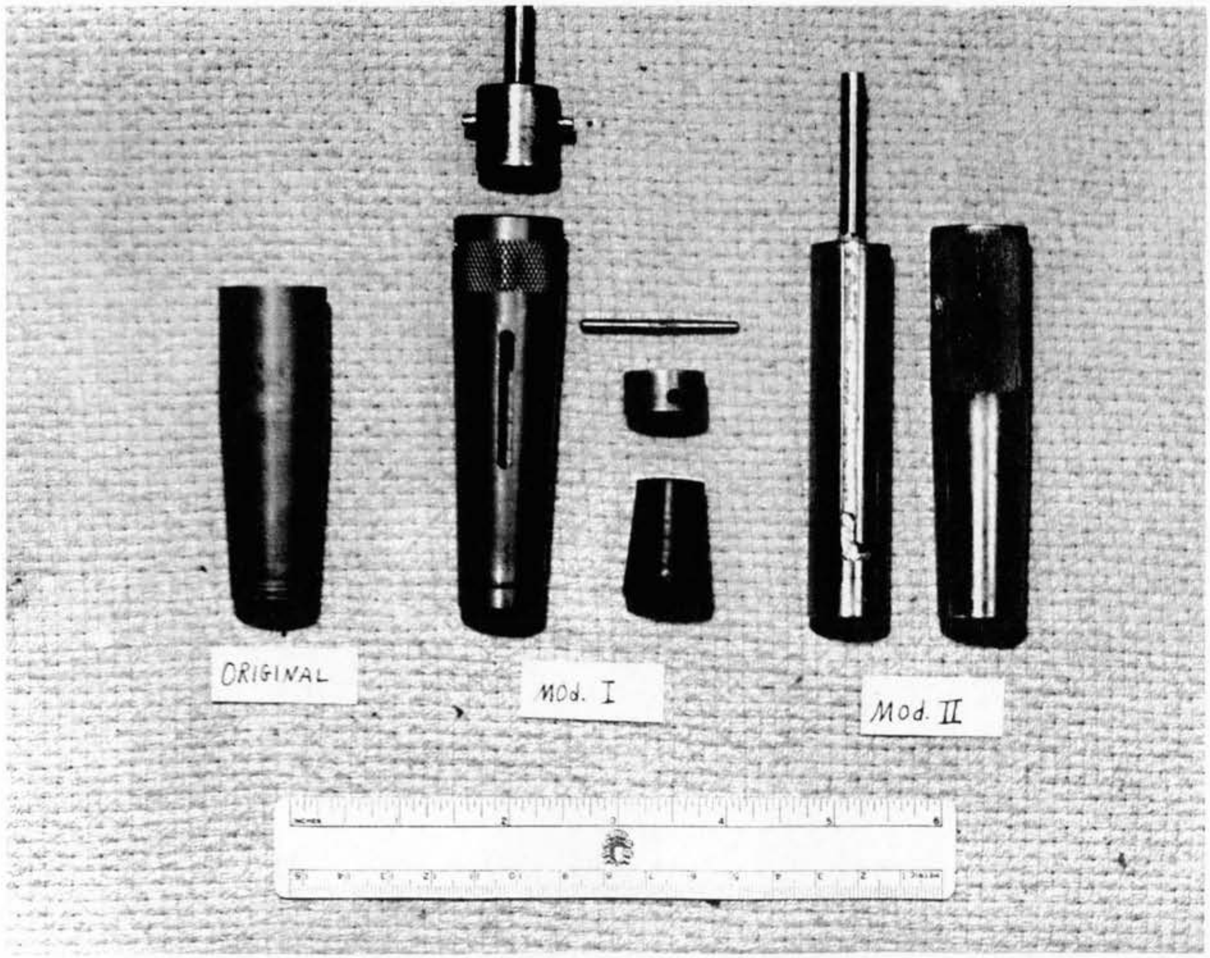
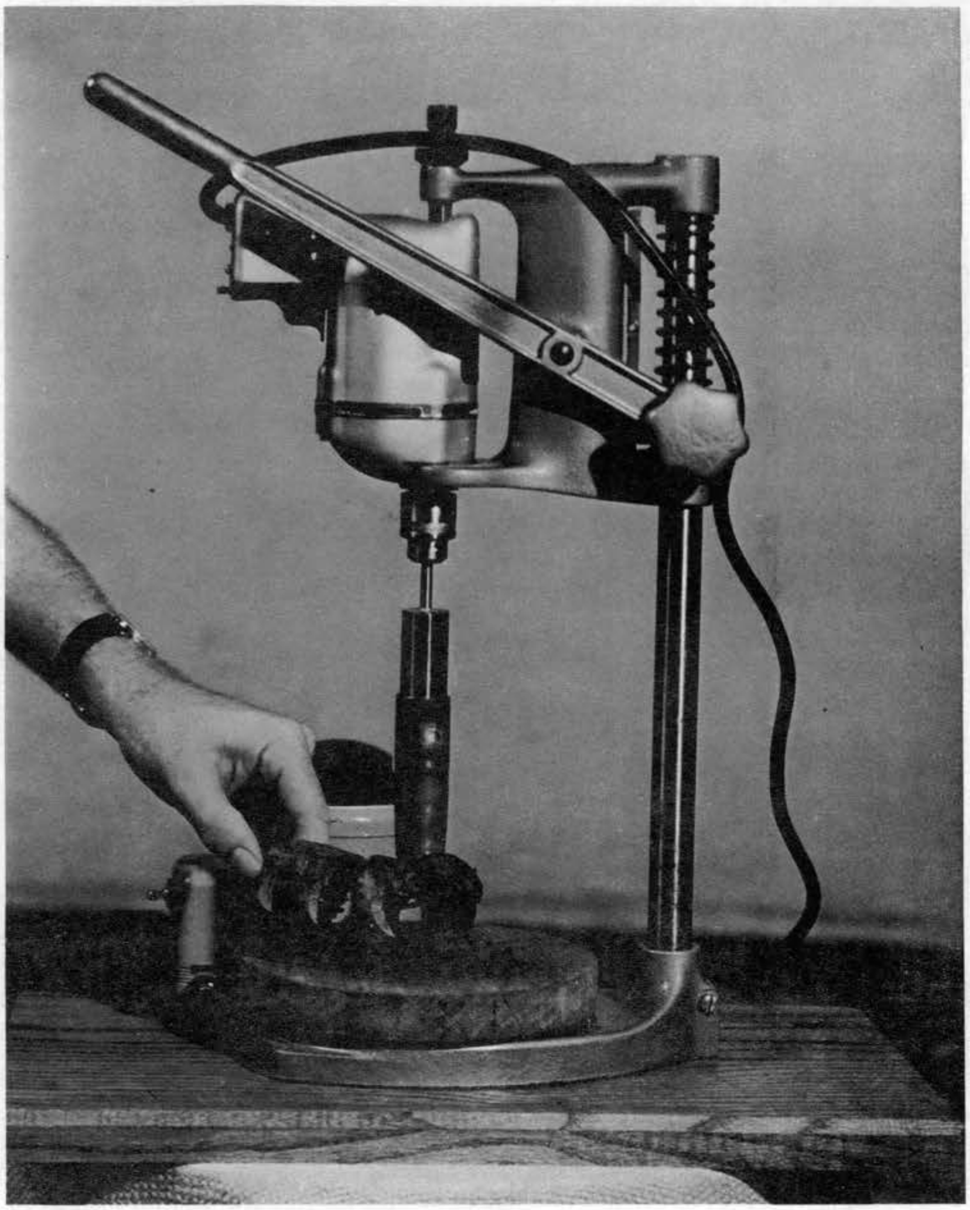


PLATE II.

Bore Device (Modification II) Attached to Drill Press



distortion was noted. No mal-function was experienced and the attachment was easily disassembled for cleaning.

Cutting attachments were made in sizes corresponding to the three core diameters (1, 3/4 and 1/2 inch) used in the study. Cutting edges were sharpened and cork stoppers used to protect the edges from damage during handling and storage.

Paraffin Test.

A block of commercial paraffin approximately two inches thick, and assumed to be of uniform consistency, was used in a test to observe error in the Warner-Bratzler shear machine (Plate III). The paraffin and all equipment used in the test were maintained at 41°C. In preliminary work, this temperature was found to be the most desirable for use, as the paraffin did not flake (as at lower temperatures) or become flexible (as at higher temperatures), but resulted in a smooth shear with values ranging near that of meat samples. The paraffin was kept inside a small oven, in order to maintain a uniform temperature and minimize air currents.

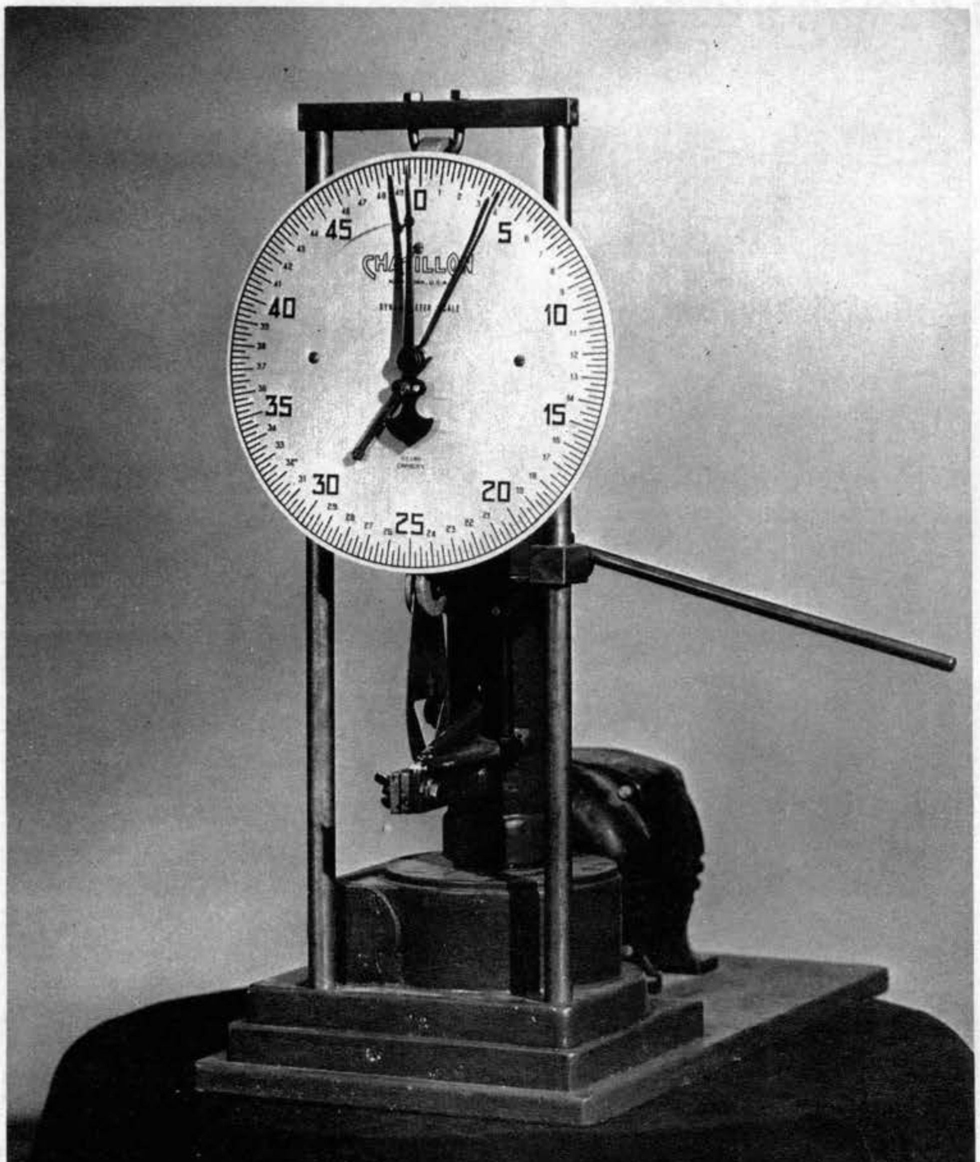
Fifty each 1/2, 3/4 and 1 inch diameter cores were removed from the tempered paraffin block. Cores were then returned to the oven until they were individually tempered and removed for shearing. Each paraffin core was sheared once, resulting in 50 shear values per core size.

Volumetric Measuring Device.

The necessity of grinding the cooked meat samples became evident when it was determined that the meat rings, resulting from pressed unground cooked meat on Whatman No. 1 filter paper were irregular in shape and extremely difficult to measure. In order to provide cooked

PLATE III.

Warner-Bratzler Shear Machine



samples of the same approximate size, a volumetric measuring device was developed by modifying a 30 cc hypodermic syringe to serve this purpose (Plate IV). The metal tip and forward end of the syringe were removed at the first graduation, permitting samples of the desired size to be measured volumetrically.

Source of Meat

Three specific age groups of Hereford heifers from purebred bulls and grade dams were used as the source of experimental material. Under uniform nutritional and environmental conditions, the animals were calved in the fall of 1961, and were nursed and creep fed until the following summer. From that time, the heifers were fed a fattening ration consisteing of 350 pounds of ground whole corn, 200 pounds of cottonseed hulls, 100 pounds of wheat bran, 100 pounds of cottonseed meal, 100 pounds of whole oats and 50 pounds of blackstrap molasses. General carcass data on each of the animals is presented in Table XIX Appendix. The longissimus dorsi muscle from the left side of each carcass was utilized in the study.

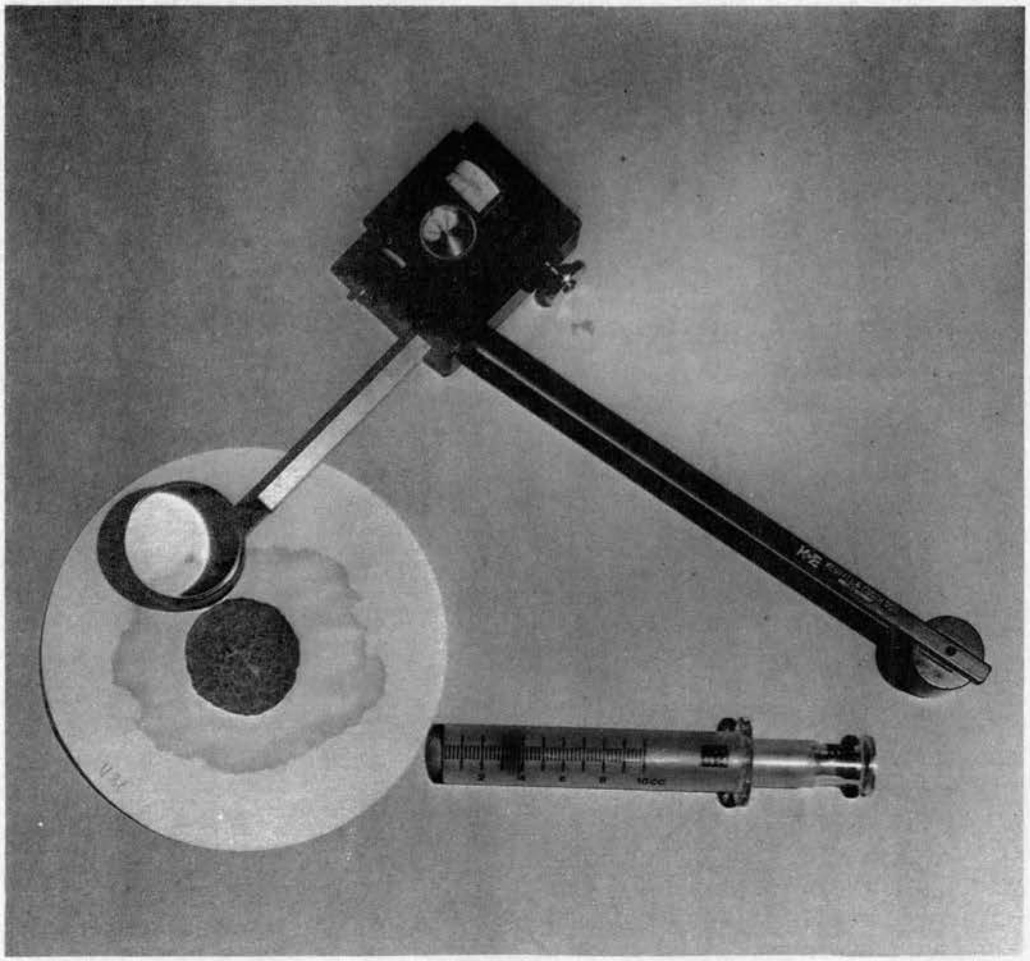
Methods

Slaughter.

Muscles from twelve heifers were used in Experiment I. Of these, six were slaughtered at 15 months of age and the remaining six at 18 months. Steaks utilized in Experiment II came from carcasses of four heifers slaughtered at 24 months of age. Slaughter was conducted as recommended by Deans (1951). All carcasses were initially chilled to 34°F and split 24 hours after slaughter, then ribbed and graded after 48 hours.

PLATE IV.

Volumetric Measuring Device and Compensating Polar Planimeter Used in Moisture-Meat Ratio Determinations



Experiment I

Approximately 72 hours after slaughter, 1, 1 1/2 and 2 inch steaks were removed from the left longissimus dorsi muscle beginning at the 13th thoracic vertebra and proceeding posterior (Tables XX and XXI Appendix). Thickness location was designated by a plan of randomization, which divided each muscle into three sections with three steaks each. This permitted statistical analysis using a split plot design. Steaks were fully trimmed of intermuscular fat and connective tissue, individually wrapped in .0015 gauge aluminum foil and identified by steak number, location and thickness.

Freezing and Storage.

When the steaks were prepared as previously described, they were quick-frozen by forced air to -4°C, and stored in a freezer compartment (-4°C) for approximately 60 days. Twelve hours prior to cooking, the steaks to be cooked were removed to a walk-in cooler and thawed at 1°C.

Cooking.

Steaks were removed from the cooler in groups of four (the number cooked together), to minimize temperature variation at the start of cooking. The foil was removed and excess moisture was blotted from the surface of the steaks with paper towels. Weight prior to cooking was determined using a Harvard Trip Balance. Dial type thermometers were inserted for temperature determination at the center of each steak during cooking. A numbered metal tag was attached to each steak for identification.

Fifteen pounds of commercial hydrogenated vegetable shortening was placed in a Toastmaster Automatic Fry Kettle, Model N2115, 230 volt

A.C. and brought to a constant temperature of 113°C. The initial steak temperature was approximately 1°C. Each steak was carefully placed in a wire basket so as to have maximum surface area exposed to the cooking medium and completely submerged in the shortening. When the internal temperature of the steaks reached 68°C, they were removed, blotted and again weighed. From the weights recorded, cooking loss and percent cooking loss were calculated for each steak. Cooking time was also observed and recorded.

Core Removal and Shearing.

Core sizes 1, 3/4 and 1/2 inch diameter were randomized within each steak thickness, with a total of three cores of equal size removed from each steak at dorsal, medial and lateral positions, carefully avoiding excessive fat deposits and connective tissue. The core size randomization plan for steaks from 15 and 18 month age groups is given in Tables XX and XXI Appendix respectively. Core size, core position and steak thickness of representative cooked steaks are illustrated in Plate V.

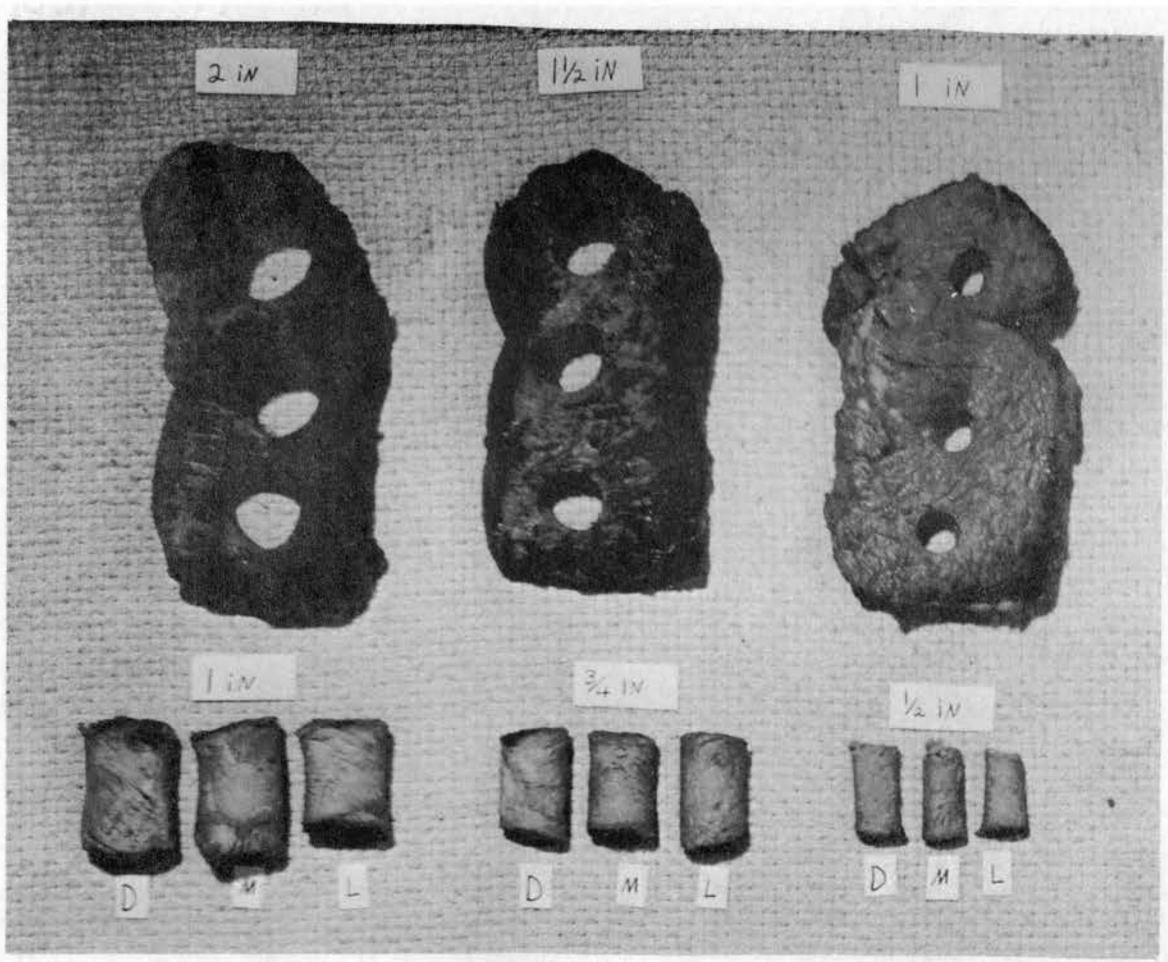
For core removal, steaks were placed on a circular hardwood stand with a neoprene center which prevented dulling the cutting edge of the bore as it passed through the steak (Plate II). Immediately following core removal, each core was sheared three times with the Warner-Bratzler shear. Three shear values per core, or nine values per steak used in the experiment were recorded in pounds of force.

Experiment II

Four two-inch steaks were removed from each left <u>longissimus dorsi</u> muscle beginning at the 13th thoracic vertebra and proceeding

PLATE V.

Representative Cooked Steaks Showing Core Size and Core Position



toward the posterior of the muscle. Two steaks from each muscle were randomly selected for each of the cooking methods considered in the study in accordance with the statistical design outlined in Table XXII Appendix. These steaks were trimmed of intermuscular fat and weighed so that initial weights of individual steaks could be recorded. They were wrapped as described for those in Experiment I and identified by animal number, steak location and cooking method.

Cooking.

Steaks cooked in deep fat and in the electronic oven were heated to the same internal temperature and compared. The procedure for deep fat cookery was the same as described for Experiment I.

All steaks cooked in the General Electric Institutional Type Electronic Oven (without browning unit) were handled in the same manner as those cooked in deep fat, until after thawing. Weights were also determined in the same manner as for the other steaks. After weighing, however, each steak to be cooked electronically was placed in a shallow 6-inch Pyrex dish (without cover), and an alcohol filled thermometer was inserted for temperature determination at the center of the steak. The container, with the steak and thermometer, was then placed inside the oven so that the thermometer could be observed through the closed perforated oven door.

It was desired that the steaks be cooked to 68°C internal temperature, in order to parallel the temperature of those cooked in deep fat. In preliminary studies, it was observed that steaks of this size, shape and density continued to increase in temperature for more than five minutes after removal from the oven. These pilot studies further revealed that steaks taken to an internal temperature of 56°C in the oven would reach a peak internal temperature of approximately 68°C after removal.

Steaks were cooked individually with a beginning internal temperature of approximately 2°C. The time required for the internal temperature of each steak to reach 56°C while the unit was in operation, was recorded as cooking time. After removal of the steaks from the oven, the internal temperature was recorded at two minute intervals until the temperature reached a peak and started to decrease. At this point, the thermometer was removed from the meat samples. The steaks were blotted with paper towels and weighed in order that weight loss and percent cooking loss could be computed.

Core Removal and Shearing.

For standardization purposes all steaks cooked by microwaves and in deep fat were wrapped in foil, after cooking was completed, and chilled for approximately 12 hours to 1°C, along with all equipment to be used in this phase. Core removal and shear measurements were made at this constant temperature.

Cylinder shaped cores one inch in diameter were removed from the dorsal, medial and lateral positions of steaks cooked by each method. Core removal was accomplished by use of the cutting attachment described as Modification II shown in Plate I.

Immediately after the cores were removed, each was cut twice using the Warner-Bratzler shear. Two shear values per core position were obtained, or a total of six values per steak.

Chew Count.

A six member panel was used to determine the number of chews required for a sample of each steak cooked in deep fat and by the microwave method. Panel members were instructed to count the number of chews prior to the first desire to swallow. Samples from four steaks were tested in each of three sittings. Bite size samples 1/2 inch in diameter were warmed to approximately 32°C and placed on numbered sections of a warm plate for testing. The section number served as identification, and the number of chews required for each sample was recorded on a score sheet provided for each panel member.

Expressible Fluid.

A Carver press and a modified version of a filter paper technique described by Tuma (1962) was used to determine expressible fluid. The portion of the steak remaining after core removal was shredded in a Waring Blendor and made into a paste by use of an Omni-mixer. An ice pack was used on the outside of the container to prevent heating during the latter process. The ground samples were temporarily sealed in glass jars to minimize moisture loss prior to the determination.

Samples molded and volumetrically measured were placed on the center of Whatman No. 1 filter paper, which had been scattered in a desiccator over saturated KCl for 24 hours prior to use, in order to standardize the moisture content of the paper. The samples and paper were then placed between two 6 x 6 inch plexiglas plates. Five samples were prepared from each steak, and were placed in the Carver press together in a vertical stack. Pressure of 500 pounds per square inch was applied for three minutes and released.

The pressed samples formed two distinct rings on the paper; a meat ring and an outer moisture ring. Upon removal from the press, the samples were kept between the plexiglas plates and placed in an oven (approximately 48°C) to dry for 12 hours, after which each ring was measured twice to insure accuracy, using a compensating polar planimeter (Plate IV). The moisture-meat ratio was determined by dividing the area of the meat ring into the moisture ring area.

RESULTS AND DISCUSSION

Equipment Design and Development

Device for Core Removal.

Modification II of the device for core removal (Plate I and II) was found to be desirable for the removal of 1/2, 3/4 and 1 inch diameter cores from cooked longissimus dorsi steak 1, 1 1/2 and 2 inches thick. The two piece device helped to produce cores of uniform size and shape at a relatively rapid rate. Cores were easily ejected from the device and no sample damage or distortion was noted. The efficiency of the attachment warrants its use, especially when large numbers of cores are to be taken from meat samples.

Paraffin Test.

A study of inherent error in the Warner-Bratzler shear technique was conducted with commercial paraffin. Shear test made on 1/2, 3/4 and 1 inch diameter core samples of paraffin, sheared at 41^{o}C and assumed to be uniform in consistency, resulted in mean shear values of 5.36, 8.69 and 10.82 pounds respectively, with respective coefficients of variability of 6.16, 5.29 and 5.36. The greatest amount of variation, as determined by this method, occurred in the 1/2 inch paraffin cores. Much of this variation can be assumed to be inherent in the Warner-Bratzler machine or "technique". The results are in general agreement with the findings of Hurwicz and Tischer (1954), although these authors experienced more variation in shear values. The materials and working temperatures used in this study were not the same as those employed by the above authors, who conducted tests using only 1/2 inch cores.

A comparison of the mean shear values for paraffin and longissimus dorsi steaks from two age groups cooked in deep fat is presented in Figure 1. For each material, as the core diameter increased, the pounds of force required to shear the core increased. Although the mean shear values for paraffin were consistently lower than those representing each steak core size, the relative linear trend was essentially the same for both materials. A visible difference in the linear trend was noted for 1 inch cores. Mean shear values for meat from the 15 month animals showed a greater rate of increase from 3/4 to 1 inch cores than between 1/2 and 3/4 inch cores, whereas 1 inch cores of paraffin reflected a slight decline in rate.

Experiment I

Core Size and Steak Thickness.

Difference in shear values for the three core sizes considered were found to be highly significant ($P < .01$) for steaks from both age groups. The analysis of variance for shear values of cooked steaks from animals of 15 and 18 month age groups are shown in Tables II and III respectively.

A linear trend was found to exist among mean shear values from 1/2, 3/4 and 1 inch diameter cores taken from cooked longissimus dorsi steaks of animals slaughtered at 15 and 18 months of age (Figure 1). A comparison of mean shear values for each age group and core size showed that values for steaks from the 15 month animals had a greater rate of

FIGURE 1

INFLUENCE OF CORE SIZE ON SHEAR VALUES FROM PARAFFIN
BOVINE LONGISSIMUS DORSI MUSCLE

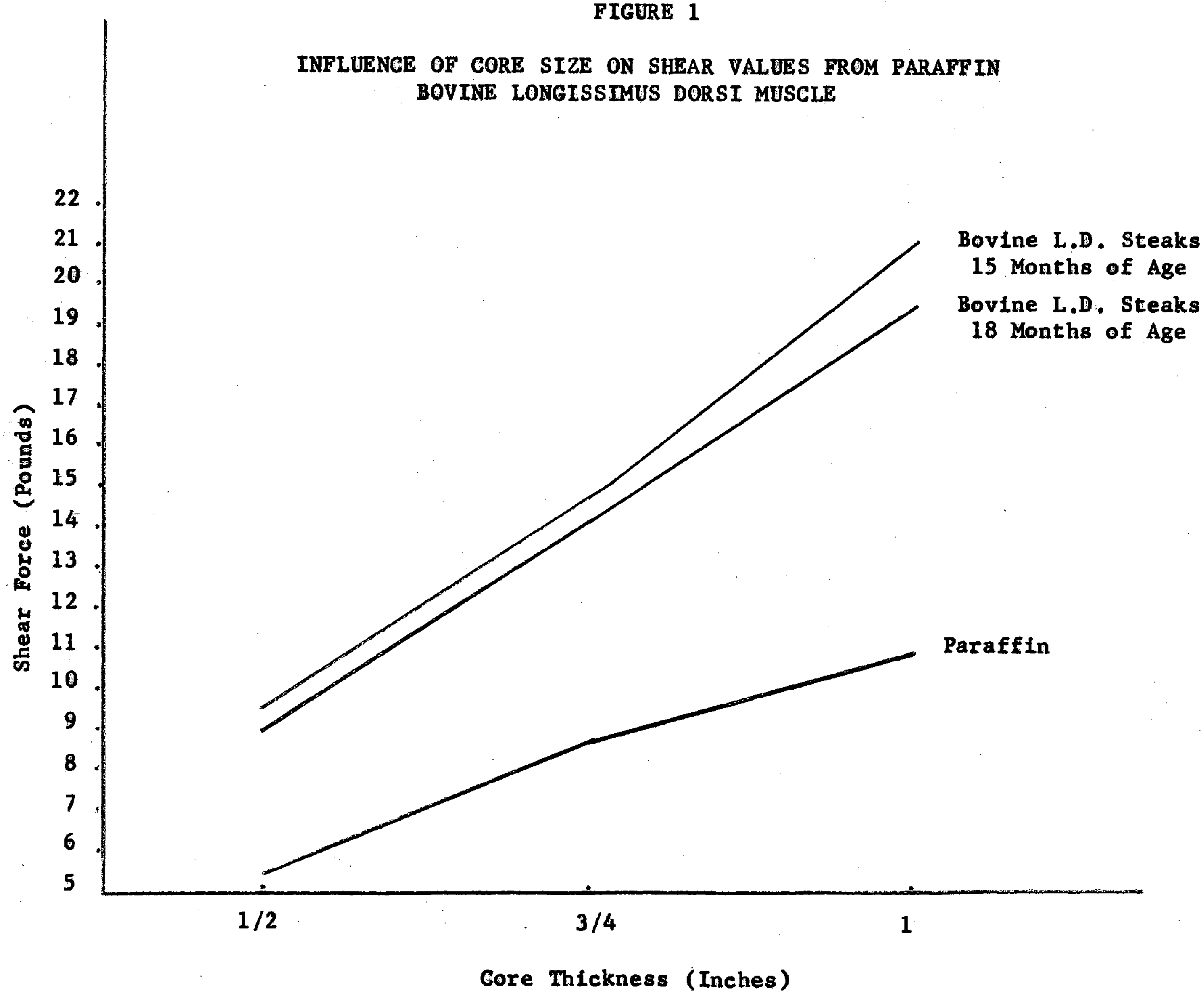


TABLE II

ANALYSIS OF VARIANCE FOR DIFFERENCES IN WARNER-BRATZLER SHEAR VALUES OF STEAKS FROM SIX BOVINE LONGISSIMUS DORSI MUSCLES[1]

Source	df	M.S.	F-Test
Main Plot			
Total	53		
Pieces	17	10.01	.07
Steak Thickness	2	14.90	.11
Animal	5	13.58	.10
Error (A)	10	131.25	
Sub Plot			
Within Pieces	36	39.17	6.99**
Core Size	2	623.55	111.34**
Thickness x Core Size	4	3.80	.67
Error (B)	30	5.60	

[1] 15 Months of Age

** $P < .01$

TABLE III

ANALYSIS OF VARIANCE FOR DIFFERENCES IN WARNER-BRATZLER SHEAR VALUES OF STEAKS FROM SIX BOVINE LONGISSIMUS DORSI MUSCLES[1]

Source	df	M.S.	F-Test
Main Plot			
Total	53		
Pieces	17	6.88	.06
Steak Thickness	2	9.20	.08
Animal	5	8.87	.08
Error (A)	10	105.76	
Sub Plot			
Within Pieces	36	31.12	7.61**
Core Size	2	491.95	120.28**
Thickness x Core Size	4	3.68	.90
Error (B)	30	4.09	

[1] 1 onths of Age

** $P < 01$

increase from 3/4 to 1 inch cores than did values from the 18 month group.

A graphic presentation of the relationship between mean shear values representing the three core sizes in both age groups can be seen in Plate VI. Values were consistently lower for samples from the 18 month old animals than those representing the 15 month group.

Standard deviations and coefficients of variation for shear values representing each core size are given in Table IV for steaks from the 15 month old animals and in Table V for samples from animals of the 18 month age group. Little difference in variation was evident between the three core sizes for the 15 month group. Within the older group, however, there was less variation as core size increased.

The coefficient of variation for shear values among animals from the 18 month group was considerably greater than for values from the 15 month age group. The variation resulting from steak thickness was inconsistent.

Mean shear values as influenced by core size and animal variation are shown in Plate VII and VIII. These plates demonstrate the relationship between mean shear values for each of the three core sizes considered, and are expressed in terms of values for all steaks from individual animals.

None of the differences in shear values due to steak thickness were statistically significant, as shown in Tables II and III. Mean shear values for steaks 1, 1 1/2 and 2 inches thick, illustrated in Plate VI show that thicker steaks from the 18 month group had slightly lower shear values, indicating that they were more tender.

Mean shear values as influenced by steak thickness and animal

PLATE VI.

MEAN SHEAR VALUES AS INFLUENCED BY CORE SIZE AND STEAK THICKNESS

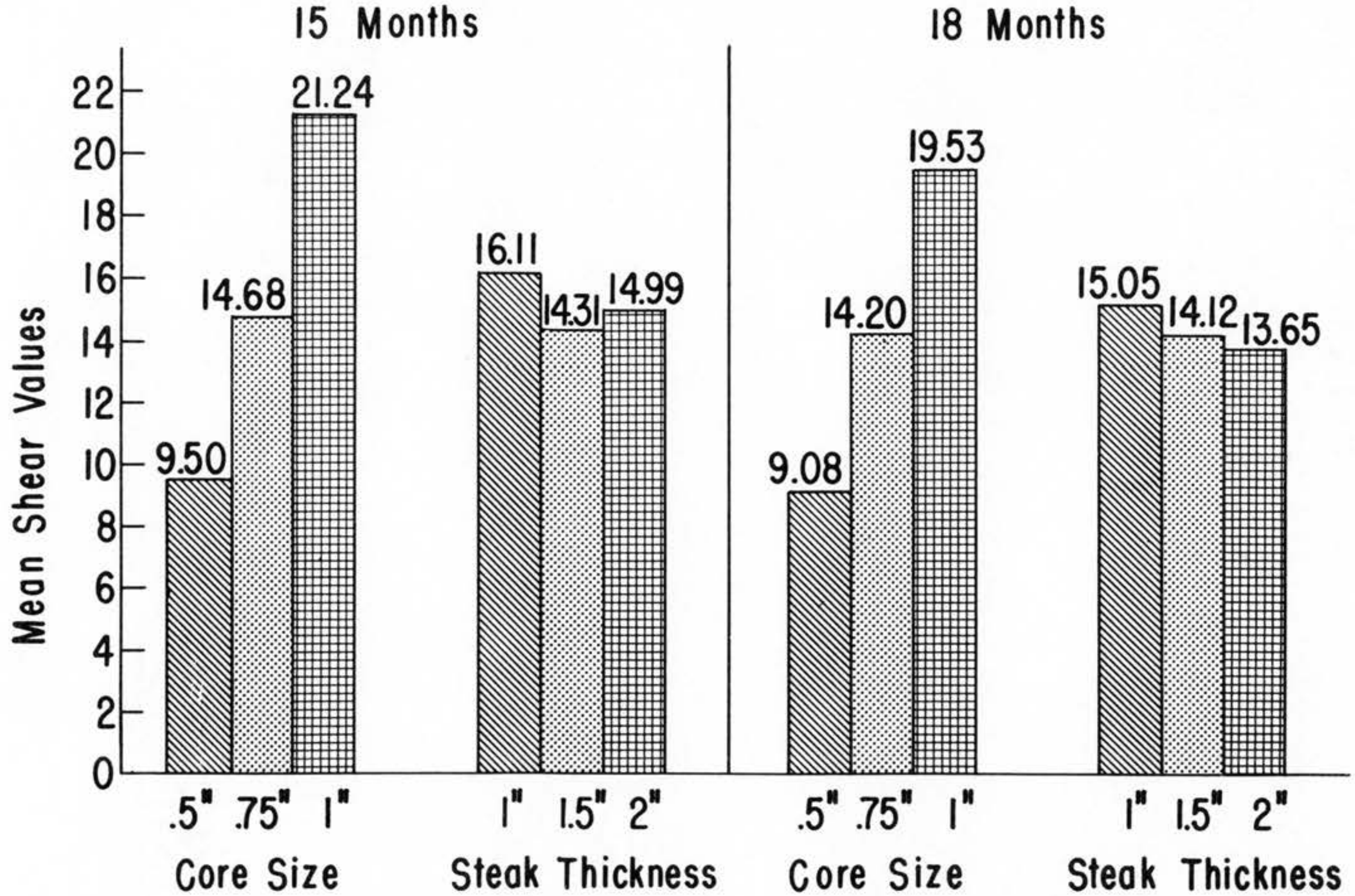


TABLE IV

VARIATION IN SHEAR VALUES OF COOKED STEAKS AS INFLUENCED BY CORE SIZE AND STEAK THICKNESS[1]

	Core Size			Steak Thickness		
	1/2"	3/4"	1"	1"	1 1/2"	2"
Mean	9.50	14.68	21.24	16.11	14.31	14.99
S.D.	1.50	2.21	3.53	6.30	4.90	5.31
C.V.	15.8	15.1	16.6	39.1	34.2	35.4

	Animal Number					
	3	16	20	25	32	36
Mean	13.48	15.32	16.64	16.44	14.47	14.51
S.D.	5.15	4.87	5.98	6.63	5.09	5.76
C.V.	38.20	31.79	35.94	40.33	35.18	39.70

[1]15 Months of Age

TABLE V

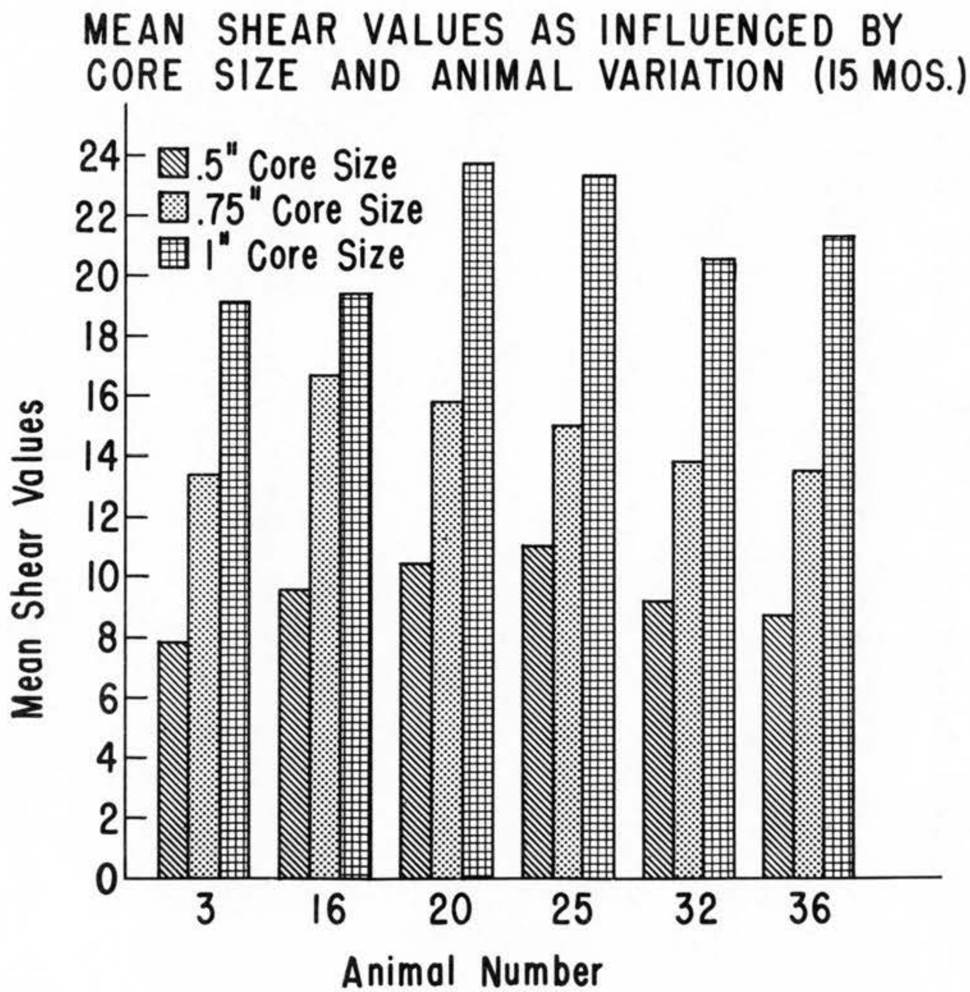
VARIATION IN SHEAR VALUES OF COOKED STEAKS AS INFLUENCED BY CORE SIZE AND STEAK THICKNESS[1]

	Core Size			Steak Thickness		
	1/2"	3/4"	1"	1"	1 1/2"	2"
Mean	9.08	14.20	19.53	15.05	14.12	13.65
S.D.	2.71	2.22	1.65	5.05	3.83	4.95
C.V.	29.8	15.6	8.4	33.6	27.1	36.3

	Animal Number					
	6	7	22	27	31	42
Mean	12.96	14.46	15.89	14.21	14.53	13.57
S.D.	7.43	8.45	8.84	7.98	8.19	7.74
C.V.	57.33	58.44	55.63	56.16	56.37	57.04

[1]18 Months of Age

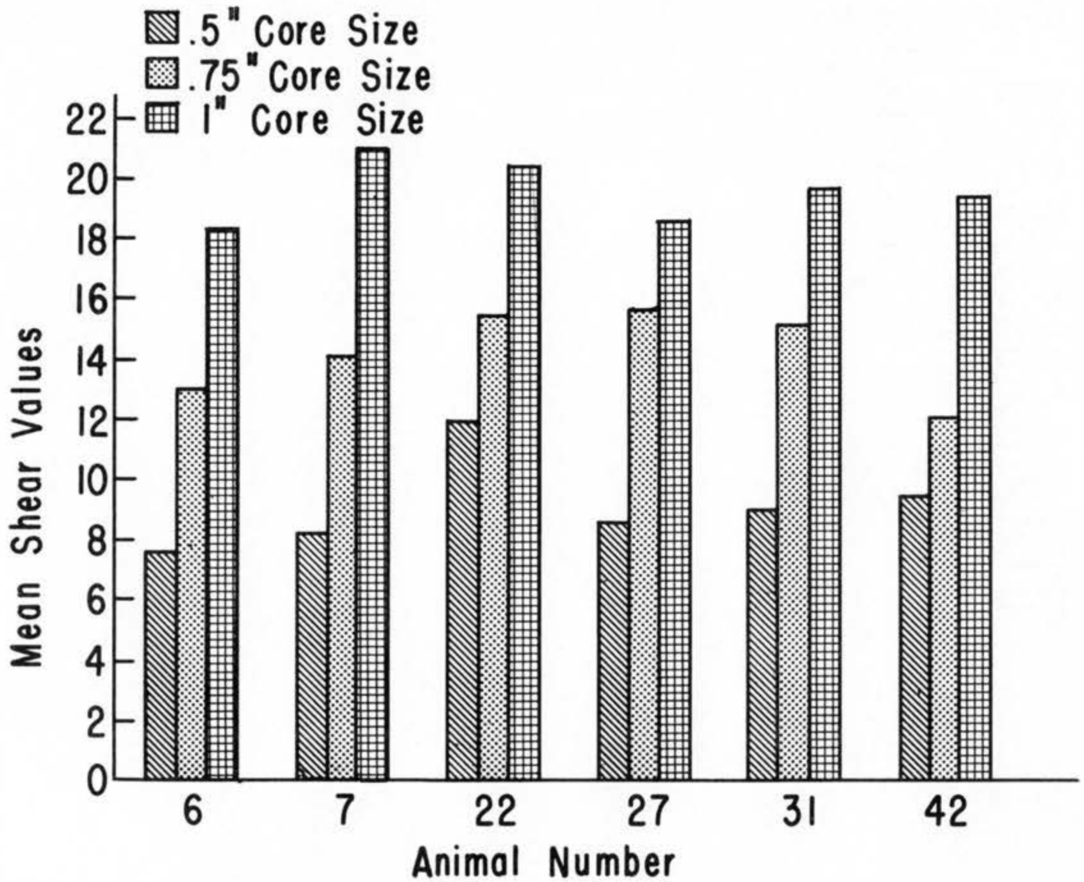
PLATE VII.



MEAN SHEAR VALUES AS INFLUENCED BY CORE SIZE AND ANIMAL VARIATION (15 MOS.)
.5" Core Size
.75" Core Size
1" Core Size
Mean Shear Values
0
2
4
6
8
10
12
14
16
18
20
22
24
3
16
20
25
32
36
Animal Number

PLATE VIII.

MEAN SHEAR VALUES AS INFLUENCED BY
CORE SIZE AND ANIMAL VARIATION (18 MOS.)



variation are given in Plates IX and X. These values, representing all shears from individual animals, reflected the decreasing trend in shear froce required for cores from thicker steaks, which was previously pointed out.

The differ in shear values within pieces of longissimus dorsi muscle (Tables XX nd XXI Appendix) was found to be highly significant ($P < .01$) for ste from both age groups (Tables II and III). This indication of variation throughout the length of the longissimus dorsi muscle supports the findings of Hankins and Hiner (1940), Ramsbottom et al. (1945) and Mjoseth (1962).

Shear difference due to animal influence was not statistically significant for steaks from either group of heifers (Tables II and III), although composite shear values for steaks from individual animals ranged from 13.5 to 16.6 pounds for the 15 month group, and 12.9 to 16.0 pounds for the 18 month group (Plate XI).

Cooking Loss.

Average percent cooking loss and standard deviations for steaks categorized by steak thickness and animal number are given in Tables VI and VII. Steak thickness appeared to have little or no influence on percent weight loss as a result of cooking.

Experiment II

Steaks from bovine longissimus dorsi muscles cooked in an electronic oven or in deep fat demonstrated some differences in chew count and percent cooking loss, although differences in Warner-Bratzler shear value and expressible fluid due to cooking method were not significant.

PLATE IX.

MEAN SHEAR VALUES AS INFLUENCED BY STEAK THICKNESS AND ANIMAL VARIATION (15 MOS.)

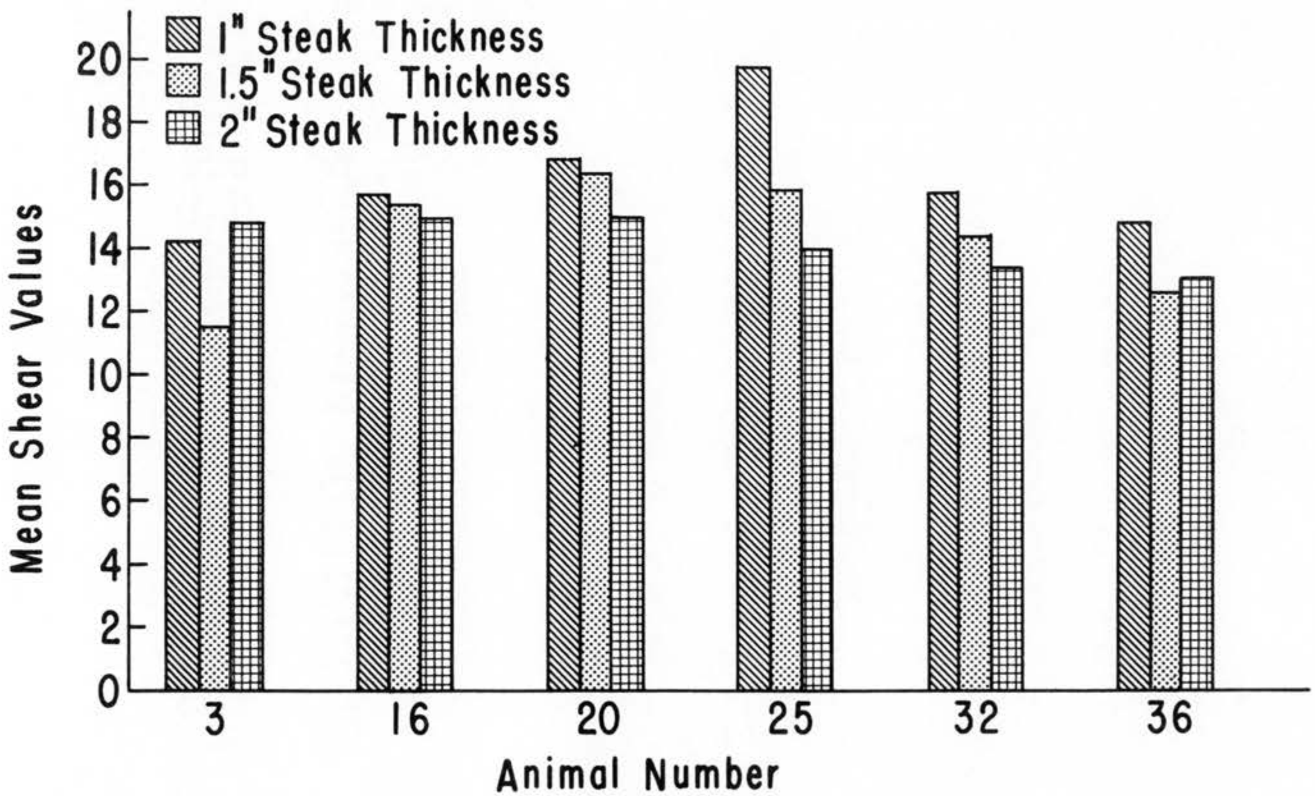
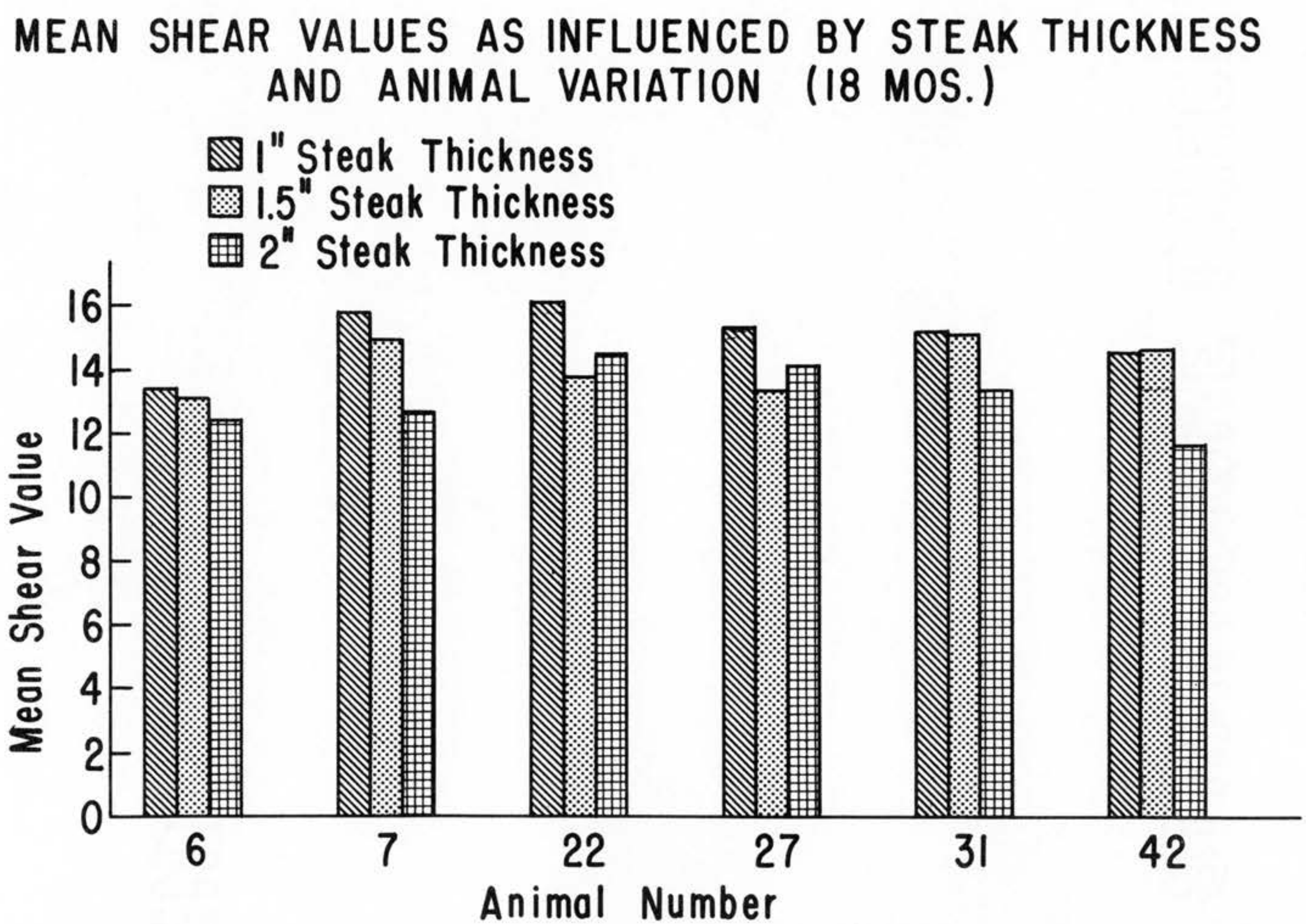


PLATE X.

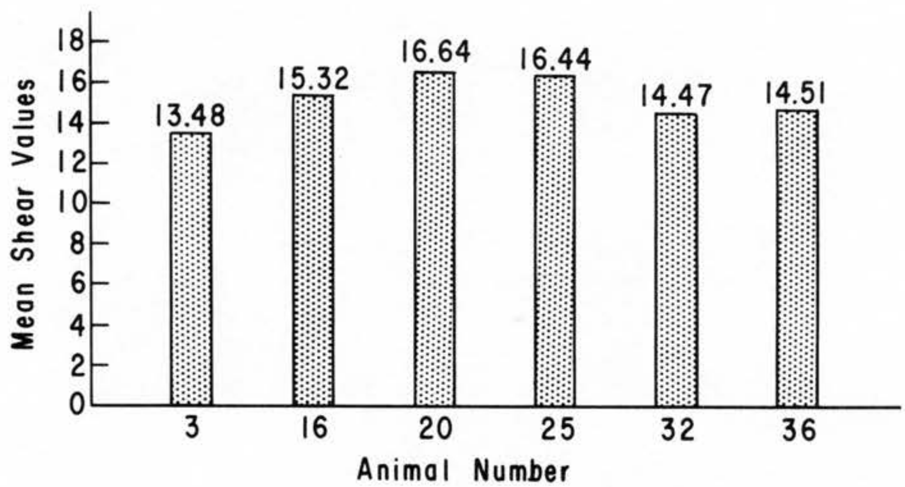


MEAN SHEAR VALUES AS INFLUENCED BY STEAK THICKNESS AND ANIMAL VARIATION (18 MOS.)
1" Steak Thickness
1.5" Steak Thickness
2" Steak Thickness
Mean Shear Value
0
2
4
6
8
10
12
14
16
6
7
22
27
31
42
Animal Number

PLATE XI.

Shear Values as Influenced by Animal Variation

15 Months



18 Months

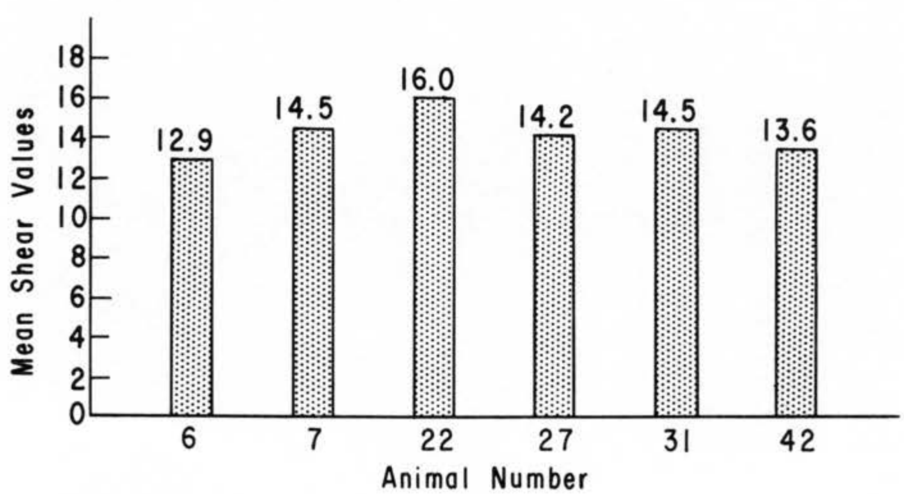


TABLE VI

AVERAGE PERCENT COOKING LOSS AND STANDARD DEVIATION FOR STEAKS FROM ANIMALS 15 MONTHS OF AGE

	Steak Thickness			Animal Number					
	1"	1 1/2"	2"	3	16	20	25	32	36
Mean	30.15	30.84	32.17	30.37	31.67	31.41	29.89	31.13	72.48
S.D.	2.83	2.49	2.15	2.60	1.62	3.02	2.34	2.96	1.99

TABLE VII

AVERAGE PERCENT COOKING LOSS AND STANDARD DEVIATION FOR STEAKS FROM ANIMALS 18 MONTHS OF AGE

	Steak Thickness			Animal Number					
	1"	1 1/2"	2"	6	7	22	27	31	42
Mean	31.17	32.51	31.49	31.24	32.23	30.03	31.31	32.96	32.58
S.D.	1.94	2.01	3.82	1.63	1.92	4.90	2.55	1.89	1.76

Cookery.

When steaks were removed from the oven at an internal temperature of 56°C, the internal temperature of each steak continued to increase for about six minutes before the expected cooling phase began. The curve in Figure 2 illustrates the temperature changes that were recorded one minute after the steaks were removed from the oven and at two minute intervals thereafter, until a decrease in temperature was noted. The steak internal temperature increased an average of 12 degrees in six minutes during this period. Temperature change in steaks after being cooked in deep fat was due only to neutralization of the temperature between the surface and center of the steak. The average cooking time (in oven) for steaks heated electronically was only 4.5 minutes, which was less than the period required for the subsequent temperature increase. The average time required to cook steaks in deep fat was 18.6 minutes, or more than four times longer than in the electronic oven.

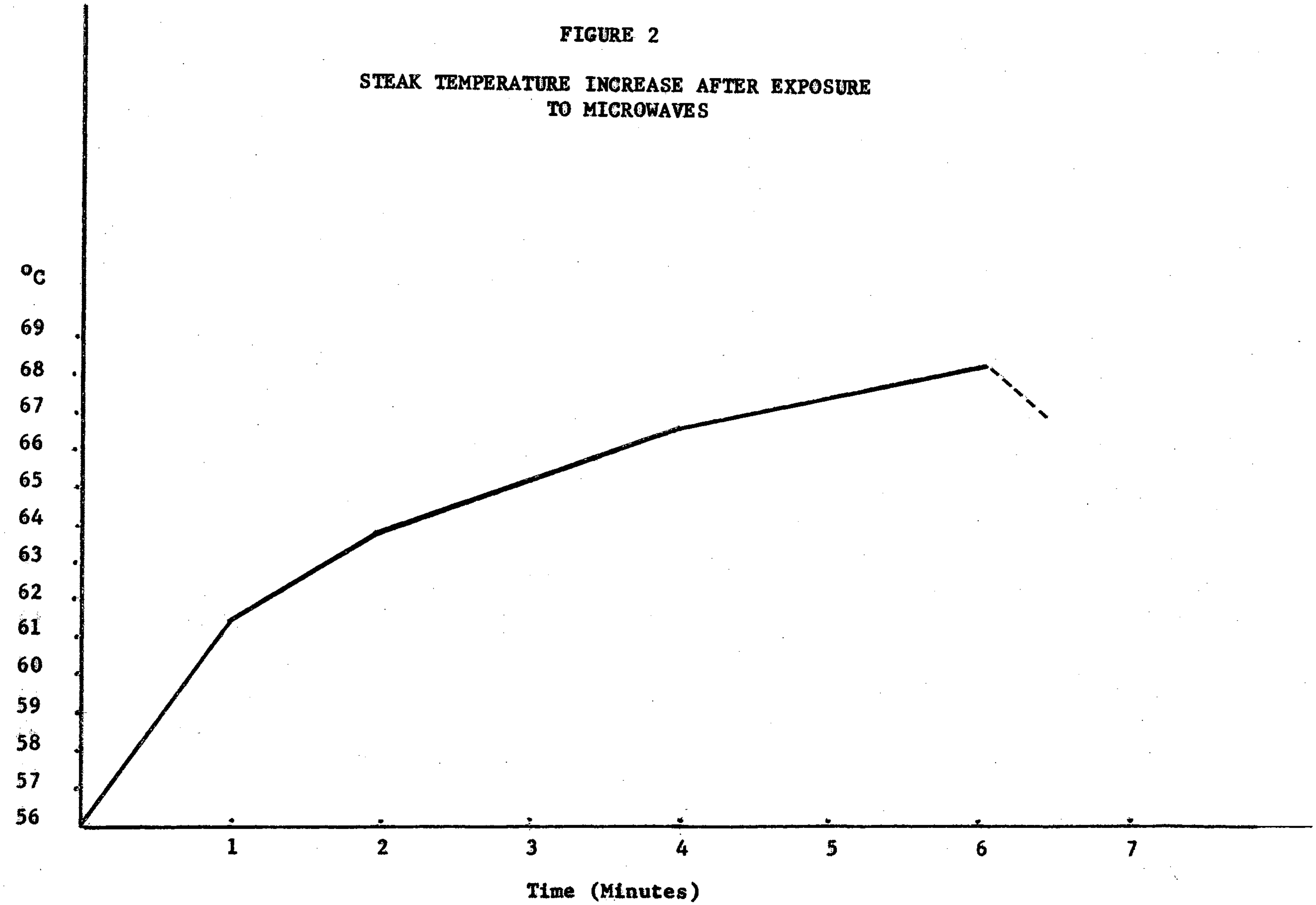
During the standby period following microwave cooking, uneven pink areas were observed on the surface of the steaks, and some were present even after cooling. This heating variation indicated that some hot spots may exist in the electronic oven. Intramuscular fat appeared to undergo little if any visible change while in the oven, but could be observed melting during the standby period.

Shear.

Analysis of variance of the shear data for longissimus dorsi steaks cooked by microwaves or in deep fat showed no significant difference in shear value attributable to method of cookery (Table VIII). Mean shear

FIGURE 2

STEAK TEMPERATURE INCREASE AFTER EXPOSURE TO MICROWAVES



values ranged from 15.79 pounds for steaks cooked by microwaves to 16.30 pounds for those cooked in deep fat. The mean values suggested that those steaks cooked in the electronic oven may have been slightly more tender.

TABLE VIII

ANALYSIS OF VARIANCE OF SHEAR VALUES

Source	df	M.S.	F-Test
Total	15		
Animals	3	8.517	4.41*
Steak Positions	3	2.019	1.05
Treatments	1	1.061	.55
Error	8	1.930	

* $P < .05$

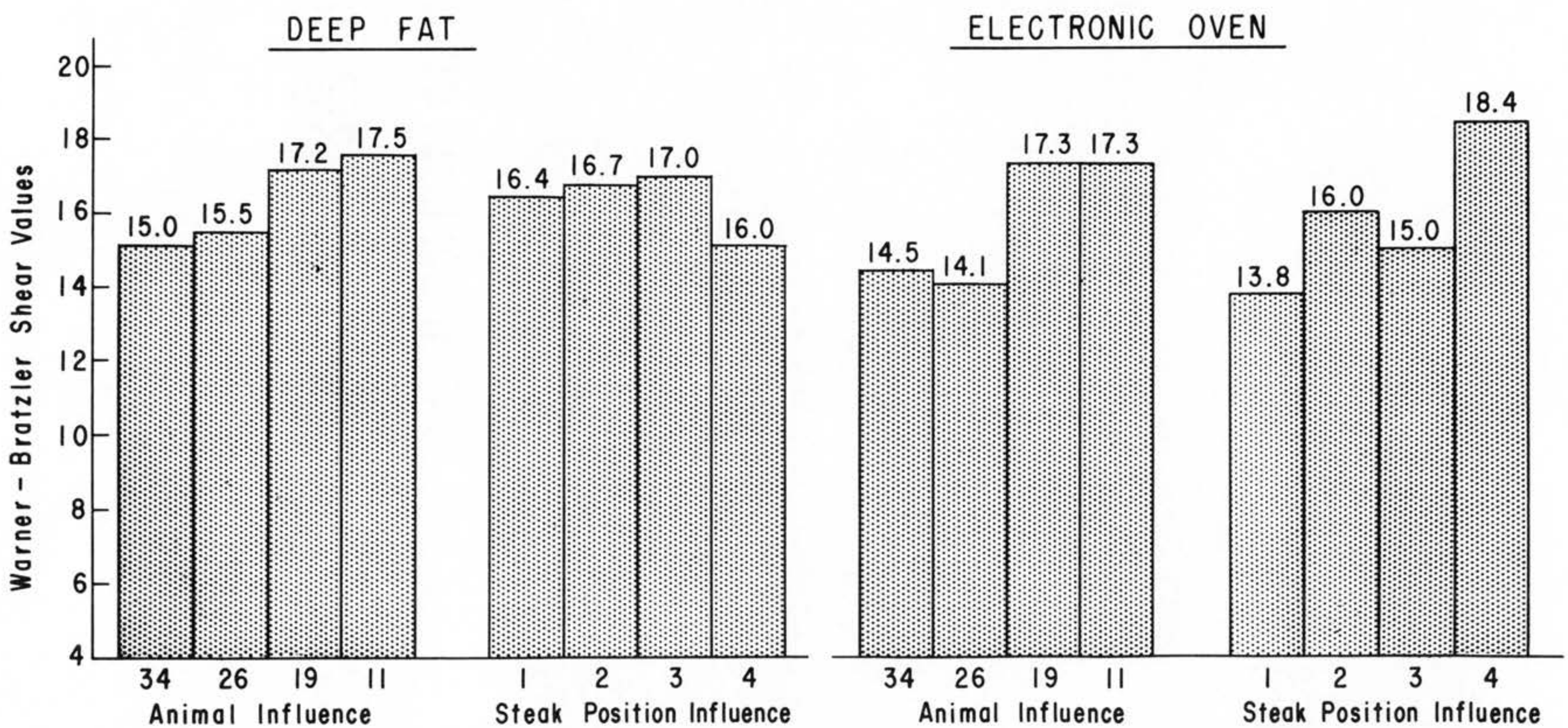
Mean shear values for steaks, as influenced by cooking method, steak position and animal difference are shown in Plate XII. The variation due to animal difference was found to be significant ($P < .05$). By comparing mean shear values representing steaks from specific animals which were cooked by each method (Plate XII), it is apparent that the difference in shear values attributable to animal difference can be demonstrated using either method of cookery. Aggregate mean shear values categorized by individual steak position in the respective longissimus dorsi muscle and by animal number are presented in Table IX. Variation in shear values due to steak position was not significant (Table IX), and no definite trend could be noted between the different cooking methods as shown in Plate XII.

The influence of core position (dorsal, medial and lateral) on

PLATE XII.

Shear Values in Longissimus dorsi Steaks as Influenced by

Cooking Method, Steak Position and Animal Difference



mean shear values from longissimus dorsi steaks cooked in deep fat and with microwaves can be seen in Table X. Values from the steaks cooked by microwaves increased from dorsal to lateral positions. Steaks cooked in deep fat, however, had the highest mean shear values at the medial position, with values for the dorsal and lateral positions being essentially the same as these electronically cooked steaks. The design of the experiment did not permit a complete statistical analysis of the data.

TABLE IX

MEAN SHEAR VALUES REPRESENTING ANIMALS AND STEAK POSITION

Animal No.	Position a	b	c	d	Animal Mean
34	13.67	15.22	14.54	15.59	14.76
26	13.84	16.42	14.38	14.59	14.81
19	14.88	16.71	19.42	17.92	17.23
11	17.93	17.04	15.67	18.88	17.38
Mean	15.08	16.35	16.00	16.75	

TABLE X

THE INFLUENCE OF CORE POSITION ON MEAN SHEAR VALUES IN LONGISSIMUS DORSI STEAKS

Cooking Method	Deep Fat			Electronic Oven		
Core Position	Dorsal	Medial	Lateral	Dorsal	Medial	Lateral
$\bar{x}$ Shear Value	13.27	20.62	17.57	13.35	15.93	17.46
S.D.	2.45	1.86	3.30	3.05	3.38	2.99

It is well known that "within muscle" variation does occur in the longissimus dorsi, but the very distinct difference in mean shear values at the medial core positions warrants a more detailed study of the degree of cooking uniformity inherent in each method.

Chew Count.

Analysis of chew count data showed a greater difference in tenderness due to the two cooking methods than did shear results, and indicated a more substantial advantage for steaks cooked by microwaves. Treatment differences were found to be significant ($P < .05$) for the number of chews required for samples from steaks cooked by the two methods (Table XI).

TABLE XI

ANALYSIS OF VARIANCE OF CHEW COUNT

Source	df	M.S.	F-Test
Total	15		
Animals	3	48.313	11.715**
Steak Positions	3	6.018	1.459
Treatments	1	27.057	6.461*
Error	8	4.124	

* $P < .05$
** $P < .01$

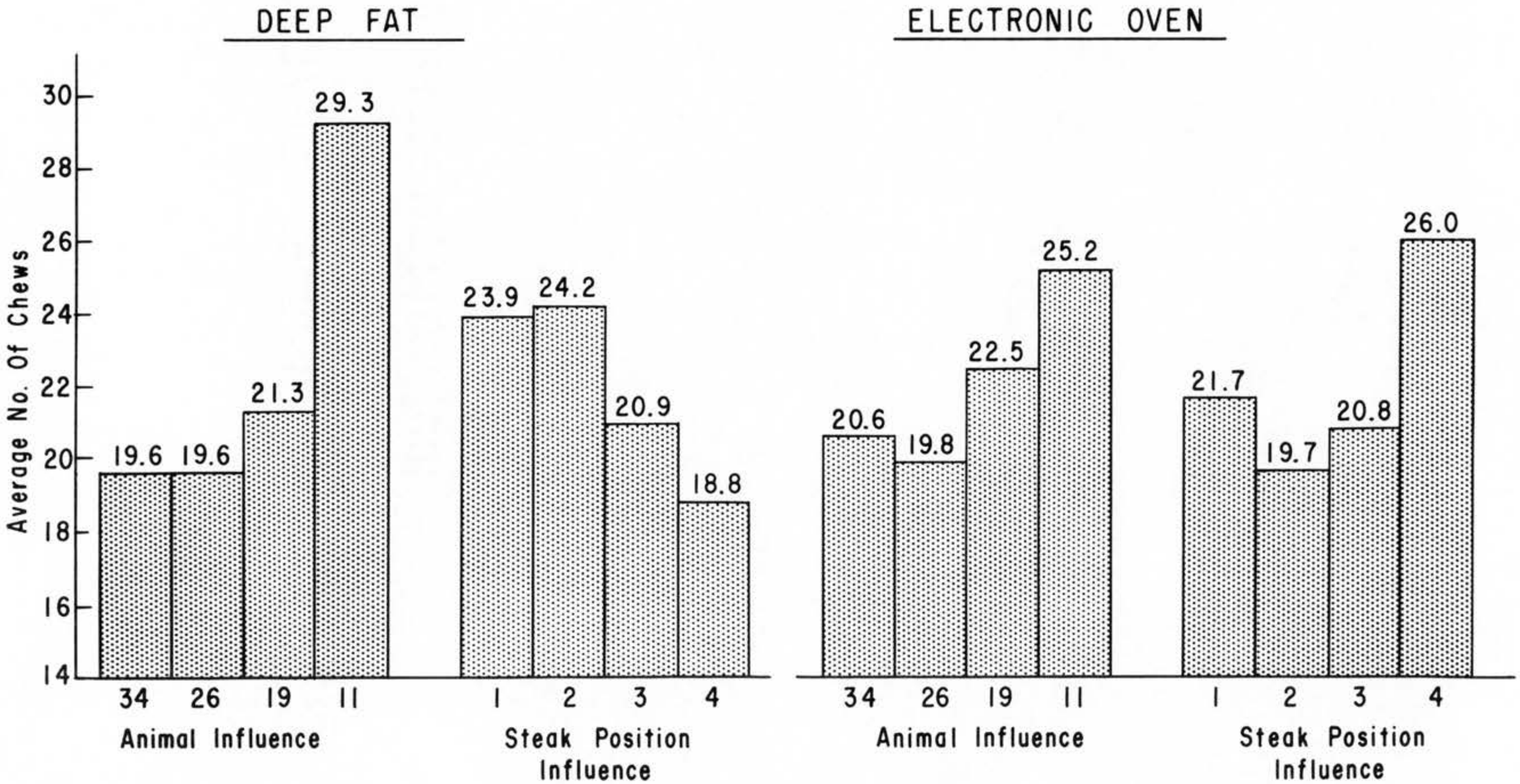
The mean panel chew counts representing all samples from steaks cooked with microwave energy and in deep fat were 22.02 and 22.46 respectively. The average number of chews as influenced by cooking method, steak position and animal difference are shown graphically in Plate XIII. Tenderness difference due to animal influence measured by chew count, appeared to be demonstrated equally well by either cooking method, as was noted with regard to shear results.

Differences in the number of chews required for samples of steaks from different animals were highly significant ($P < .01$), however, steak position differences were not significant as can be seen from data

PLATE XIII.

Chew Count in Longissimus dorsi Steaks as Influenced by

Cooking Method, Steak Position and Animal Difference



in Table XI. The average number of chews grouped by steak, steak position and animal are shown in Table XII. The range of chew count as influenced by animal difference was from 19.71 to 27.25 chews.

TABLE XII

MEAN CHEW COUNT REPRESENTING ANIMALS AND STEAK POSITIONS

Animal No.	Position a	b	c	d	Animal Mean
34	23.83	17.33	20.17	19.00	20.08
26	19.50	20.50	20.17	18.67	19.71
19	21.00	22.00	21.67	23.00	21.92
11	30.83	27.83	21.33	29.00	27.25
Mean	23.79	21.92	20.84	22.42	

Cooking Loss.

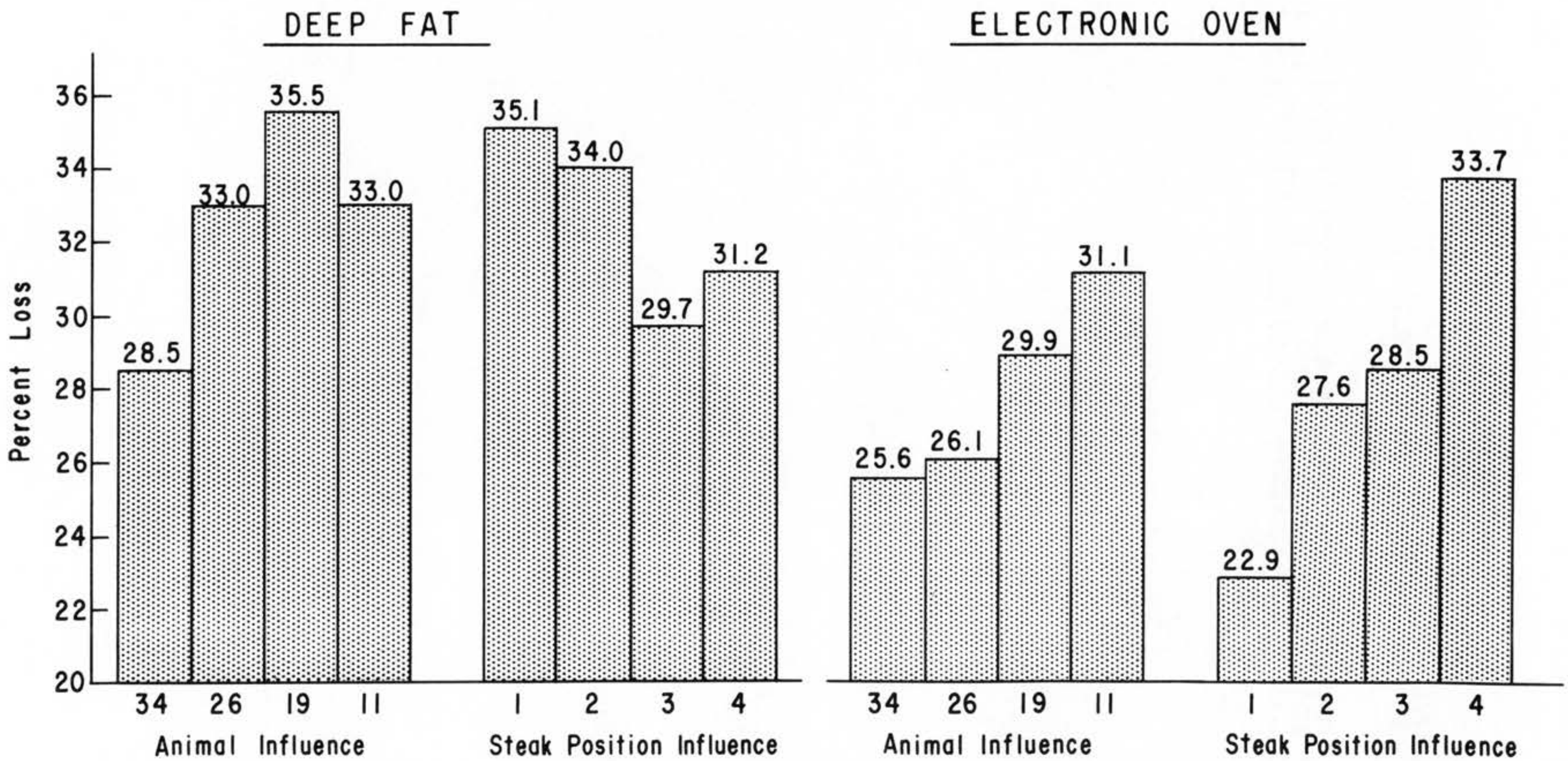
The greatest difference detected in steaks cooked by microwave energy and in deep fat was the weight loss resulting from cooking. The average weight lost by steaks cooked in the electronic oven was 28.20 percent compared to 32.50 percent for those cooked to the same final internal temperature in deep fat. Analysis of variance showed this difference in weight loss to be highly significant ($P < .01$, Table XIII), while cooking loss attributed to animal influence was significant only at the 5 percent level of probability.

Average percent cooking loss for steaks representing individual animals showed a range of from 28.5 to 35.5 percent when cooked in deep fat, while the loss from steaks cooked by microwave energy ranged from 25.6 to 31.1 percent (Plate XIV).

When steaks were cooked in the microwave oven, and the cooking loss data averaged for each position of the longissimus dorsi muscle, it was observed that the loss increased from the anterior toward the

PLATE XIV.

Percent Cooking Loss in Longissimus dorsi Steaks as Influenced by Cooking Method, Steak Position and Animal Difference



posterior of the muscle. This general trend was also evident in shear and chew count data for the same steaks (Plates XII and XIII). Other cooking loss data are presented in Table XIV.

TABLE XIII

ANALYSIS OF VARIANCE FOR COOKING LOSS

Source	df	M.S.	F-Test
Total	15		
Animals	3	44.683	5.977*
Steak Positions	3	1.431	.191
Treatments	1	88.268	11.806**
Error	8	7.476	

* P < .05
** P < .01

TABLE XIV

MEAN PERCENT LOSS REPRESENTING ANIMALS AND STEAK POSITIONS

Animal	Position				Animal
No.	a	b	c	d	Mean
34	21.8	23.9	25.3	31.6	25.75
26	29.3	35.2	25.9	30.8	30.30
19	37.0	28.2	34.0	28.8	32.00
11	33.1	32.8	33.9	33.4	33.30
Mean	30.30	30.03	29.78	31.20	

Expressible Fluid.

Analysis of expressible fluid data from the 16 steaks cooked by two methods indicated no significant difference due to cooking method, steak position or animal influence (Table XV). Steaks cooked in deep fat yielded a slightly higher moisture-meat ratio (3.92) than those cooked by microwave energy (3.54). In view of the significantly lower cooking loss for steaks heated by microwave energy, when compared to those cooked in deep fat, it was evident that the moisture-meat ratio as determined by the filter paper technique does not measure the same "fluids" as those which were lost during cooking. It may also be theorized that a lower fluid yield after cooking may be related in some way to the specific character of microwave cookery, which was described by Thatcher (1963) as being so rapid that not all of the chemical reactions which normally occur during cooking have an opportunity to take place.

TABLE XV

ANALYSIS OF VARIANCE FOR EXPRESSIBLE FLUID

Source	df	M.S.	F-Test
Total	15		
Animals	3	.498	1.420
Steak Positions	3	.130	.371
Treatments	1	.962	2.743
Error	8	.351	

Expressible fluid data as influenced by animal difference and steak position from the longissimus dorsi muscle are presented in Table XVI and shown graphically in Plate XV.

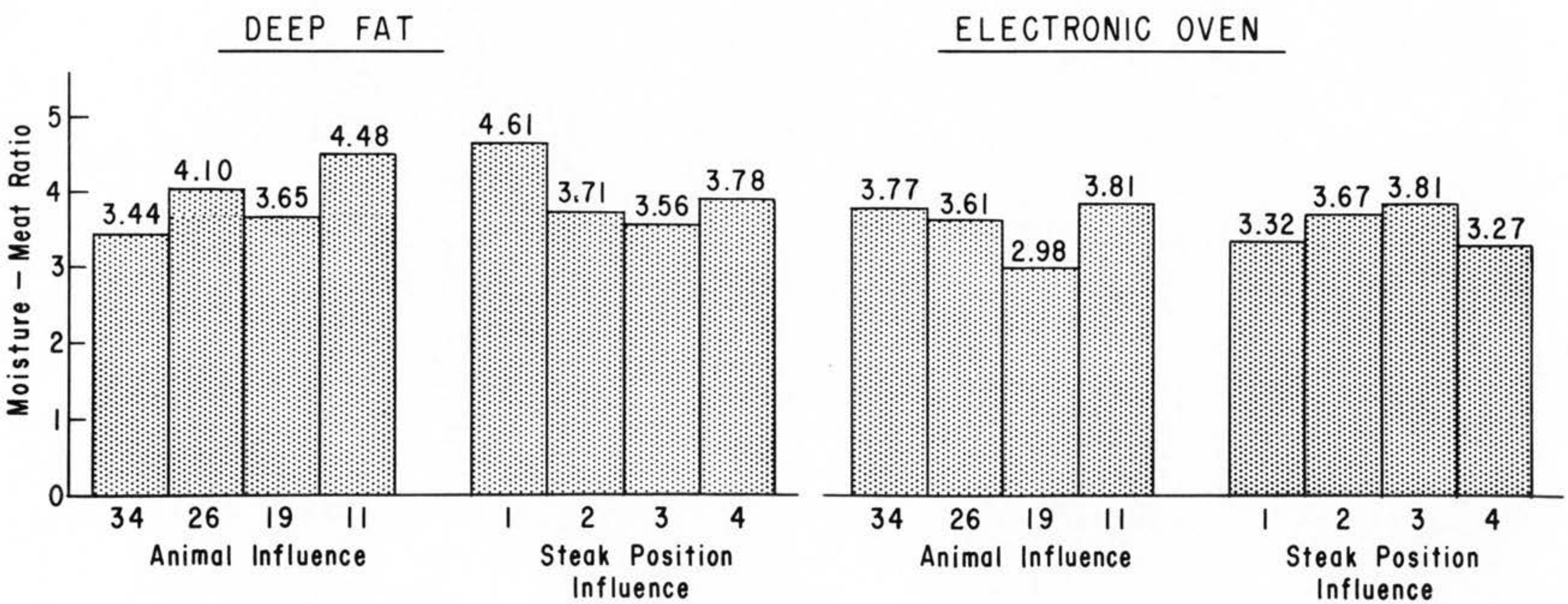
TABLE XVI

MEAN MOISTURE TO MEAT RATIOS REPRESENTING ANIMALS AND STEAK POSITIONS

Animal No.	Position a	b	c	d	Animal Mean
34	3.47	4.06	3.54	3.33	3.60
26	3.16	3.96	4.05	4.23	3.85
19	3.72	3.28	3.58	2.68	3.32
11	5.50	3.46	3.75	3.86	
Mean	3.96	3.69	3.73	3.53	

PLATE XV.

Expressible Fluid in _Longissimus dorsi_ Steaks as Influenced by Cooking Method, Steak Position and Animal Difference



A summary of means and standard deviations for shear, chew count, expressible fluid and cooking loss was tabulated separately for each method of cooking and is presented in Table XVII.

TABLE XVII

SUMMARY OF SHEAR, CHEW COUNT, EXPRESSIBLE FLUID AND COOKING LOSS DATA

	Deep Fat		Electronic Oven	
	Mean	S.D.	Mean	S.D.
Shear	16.30	1.75	15.79	1.91
Chew Count	22.46	4.42	22.03	3.48
Expressible Fluid	3.92	.70	3.54	.48
Cooking Loss	32.50	3.50	28.20	4.24

SUMMARY

The _longissimus_ _dorsi_ muscles from the left side of 16 Hereford heifer carcasses were used as experimental material. A total of 108 steaks from two animal age groups were used to determine the influence of sample core size and steak thickness on Warner-Bratzler shear values of steaks cooked in deep fat. Sixteen two inch thick _longissimus_ _dorsi_ steaks taken from the carcasses of four heifers 24 months of age, were used to compare the influence of microwave (electronic) and deep fat cookery on Warner-Bratzler shear values, chew count, cooking loss and expressible fluid. A modified device for core removal was found to be rapid and efficient when used to take 1/2, 3/4 and 1 inch diameter cores from cooked steaks. Undamaged cores of uniform size and shape resulted.

Differences in shear values for the three core sizes considered were found to be highly significant ($P < .01$) for steaks from carcasses of heifers 15 and 18 months of age. Coefficients of Variation for shear values representing each core size showed little difference between the three core sizes for the 15 month group. Variation decreased as core size increased in samples from the older group, however. Mean shear values from 50 each 1/2, 3/4 and 1 inch diameter paraffin cores, assumed to be uniform in consistency, showed essentially the same trend among the core sizes as did mean values from the same size cores from meat. The greatest amount of variation for the paraffin cores was among

those 1/2 inch in diameter.

Steaks from the older group of heifers had slightly lower mean shear values than did those from the 15 month group. Variation in shear values within pieces, along the length of the longissimus dorsi muscle was highly significant ($P < .01$), demonstrating a difference in shear values for steaks from different positions along the muscle. No significant difference in shear values was attributable to steak thickness in samples from either group of carcasses, although there was a trend toward lower values in the thicker steaks. Steak thickness appeared to have no consistent influence on weight lost during cooking.

Results from a comparison of steaks cooked in deep fat and by microwave energy showed no significant difference in Warner-Bratzler shear values due to cooking method, although mean shear values were slightly lower for steaks cooked in the microwave oven than for those cooked in deep fat. Mean shear values representing dorsal and lateral core positions were very similar for steaks cooked by both methods, but an average difference of more than four pounds was found to exist among the values representing the medial position. Values for the medial positions were 20.62 pounds for deep fat cooked steaks and 15.93 pounds for steaks cooked electronically. Variation in shear values attributable to animal difference was significant at the five percent level of probability.

Average chew count for steaks cooked in deep fat was slightly higher ($P < .05$) than that for steaks cooked by microwave energy.

The difference in weight lost during cooking was highly significant ($P < .01$). Losses from steaks cooked in deep fat were about four percent greater than for those cooked in the electronic oven. Expressible fluid determinations performed on cooked steaks showed no significant differences due to the method of cooking.

LITERATURE CITED

Alsmeyer, R. H., A. Z. Palmer, M. Kroger and W. G. Kirk. 1959. The significance of factors influencing and/or associated with beef tenderness. Proc. Recip. Meat Conf. 11:85.

_______. 1964. Unpublished data and personal communication.

Anderson, J. L. 1959. Some factors influencing the palatability of frozen beef. M. S. Thesis. Oklahoma State University.

Apgar, J., N. Cox, I. Downey and F. Fenton. 1959. Cooking pork electronically. J. Am. Dietet. A. 35:1260.

Blumer, T. N. 1963. Relationship of marbling to the palatability of beef. J. Animal Sci. 22:771.

Bollman, M. C., S. Grenner, L. E. Gordon and M. E. Lambert. 1948. Application of electronic cooking to large-scale feeding. J. Am. Dietet. A. 24:1041.

Brady, D. E. 1937. Study of the factors influencing tenderness and texture in beef. Proc. Amer. Soc. Animal Prod. 30:246.

Bramblett, V. D., R. L. Hostetler, G. E. Vail and H. N. Draudt. 1959. Qualities of beef as affected by cooking at very low temperature for long periods of time. Food Technol. 13:707.

Bratzler, L. J. 1932. Measuring the tenderness of meat by means of a mechanical shear. M. S. Thesis. Kansas State College.

Bratzler, L. J. 1949. Determining the tenderness of meat by use of the Warner-Bratzler shear machine. Proc. Recip. Meat Conf. 2:117.

Briskey, E. J., R. W. Bray, W. G. Hoekstra, P. H. Phillips and R. H. Grummer. 1959. The chemical and physical characteristics of various pork ham muscle classes. J. Animal Sci. 18:146.

________, W. G. Hoekstra, R. W. Bray and R. H. Grummer. 1960. A comparison of certain physical and chemical characteristics of eight pork muscles. J. Animal Sci. 19:214.

Burns, W. C., M. Kroger and C. M. Kincaid. 1958. Feed lot response of steers on different rations and harmone treatment. J. Animal Sci. 17:1143. (Abstract).

Carpenter, J. W., A. Z. Palmer, W. G. Kirk, F. M. Peacock and M. Kroger. 1955. Slaughter and carcass differences between Brahman and Brahman-Shorthorn crossbred steers. J. Animal Sci. 14:1228. (Abstract).

Clark, H. E., M. C. Wilmeth, D. L. Harrison and G. E. Vail. 1955. The effect of braising and pressure saucepan cookery on the cooking losses, palatability and nutritive value of the proteins of round steaks. Food Res. 20:35.

Cline, J. A., M. E. Loughead and B. C. Schwartz. 1932. The effect of two roasting temperatures on palatability of cooking roasts. Mo. Agri. Exp. Sta. Bull. 310.

Cole, J. W., C. M. Kincaid and C. S. Hobbs. 1958. Some effect of types and breeds of cattle on basic carcass characteristics. J. Animal Sci. 17:1153.

Copson, D. A. 1962. Microwave Heating. The Avi Publishing Co., Westport, Connecticut.

Cover, S. 1937. The effect of temperature and time of cooking on the tenderness of roasts. Texas Agri. Exp. Sta. Bull. 542.

________. 1941. Effect of metal skewers on cooking time and tenderness of beef. Food Res. 6:233.

________. 1943. Effect of extremely low rates of heat penetration on tenderness of beef. Food Res. 3:388.

________ and W. H. Smith, Jr. 1956. The effect of two methods of cooking on palatability scores, shear force values and collagen content of two cuts of beef. Food Res. 21:312.

________, T. C. Cartwright and O. D. Butler. 1957. The relationship of ration and inheritence to eating quality of the meat from yearling steers. J. Animal Sci. 16:946.

________, G. T. King and O. D. Butler. 1958. Effect of carcass grades and fatness on tenderness of meat from steers. Texas Agri. Exp. Sta. Bull. 889.

________ and R. L. Hostetler. 1960. An examination of some theories about beef tenderness by using new methods. Texas Agri. Exp. Sta. Bull. 947.

________, R. L. Hostetler and S. J. Ritchey. 1962. Tenderness of beef. IV. Relations of shear force and fiber extensibility to juciness and six components of tenderness. J. Food Sci. 27:527.

Dawson, E. H. 1959. When you cook. U. S. Dept. of Agri. Yearbook. 495.

Deans, R. J. 1951. A recommended procedure for slaughtering experimental cattle. Proc. Recip. Meat Conf. 4:81.

Deatherage, F. E. and A. Harsham. 1947. Relation of tenderness of beef to aging time at 32-35°F. Food Res. 12:164.

________ 1951. A survey of the organoleptic testing methods used in meats research. Proc. Recip. Meat Conf. 4:184.

________ and G. Garnatz. 1952. A comparative study of tenderness determination by sensory panel and by shear strength measurements. Food Technol. 6:260.

Edwards, R. L., S. B. Tove, T. N. Blumer and E. R. Barrick. 1961. Effects of added dietary fat on fatty acid composition and carcass characteristics of fattening steers. J. Animal Sci. 20:712.

Fenton, F. 1957. Research on electronic cooking. J. Home Econ. 49:709.

Ginger, B. 1957. Four symposia: Meat processing, nutrition, beef tenderization, irradiation. A. M. I. F. Cir. 35:61.

________ and E. Weir. 1958. Variations in tenderness within three muscles from beef round. Food Res. 23:662.

Grau, R. and R. Hamm. 1953. An easy method for determining the water-binding of muscle. Naturwissenschaften. 40:29. Cited by Tuma. 1962.

Griswold, R. M. 1955. The effect of different methods of cooking beef round of commercial and prime grades. I. Palatability and shear values. Food Res. 20:160.

Hall, J. L., D. L. Mackintosh and G. E. Vail. 1944. Quality of beef. II. Effect of dietary phosphorous deficiency on quality of beef. Kansas Agr. Exp. Sta. Tech. Bul. 58:22.

Hankins, O. G. and R. L. Hiner. 1940. Freezing makes beef tender. Food Ind. 12:49.

Hanning, F., R. W. Bray, N. N. Allen and R. P. Niedermeier. 1957. Tenderness and juiciness of veal loin roasts and chops. Food Technol. 11:611.

Harrison, D. L., B. Lowe, B. McClurg and P. S. Shearer. 1949. Physical, organoleptic and histological changes in three grades of beef during aging. Food Technol. 3:248.

Harrington, G. and A. M. Pearson. 1962. Chew count as a measure of tenderness of pork loins with various degrees of marbling. J. Food Sci. 27:106.

Headley, M. E. and M. Jacobson. 1960. Electronic and conventional cookery of lamb roasts. J. Am. Dietet. A. 36:337.

Helander, E. A. S. 1961. Influence of exercise and restricted activity on the protein composition of skeletal muscle. J. Biochem. 78:478.

Hiner, R. L. and O. G. Hankins. 1950. The tenderness of beef in relation to different muscles and age in the animal. J. Animal Sci. 9:347.

_______, O. G. Hankins, H. S. Sloane, C. R. Fellers and E. E. Anderson. 1953. Fiber diameter in relation to tenderness of beef muscle. Food Res. 18:364.

_______, E. E. Anderson and C. R. Fellers. 1955. Amount and character of connective tissue as it relates to tenderness in beef muscle. Food Technol. 9:80.

Hood, M. P., D. W. Thompson and L. Mirone. 1955. Effects of cooking methods on low grade beef. Univ. of Georgia Agri. Exp. Sta. Bul. N.S. 4.

Huffman, D. L., A. Z. Palmer, J. W. Carpenter, D. D. Hargrove and M. Koger. 1962. Effect of breeding, level of feeding and antemortem injection of papain on the tenderness of weanling age calves. J. Animal Sci. 21:381.

Hurwicz, H. and R. G. Tischer. 1954. Variations in determination of shear force by means of the "Bratzler-Warner Shear". Food Technol. 8:391.

Husaini, S. A., F. E. Deatherage, L. E. Kunkle, and H. N. Droudt. 1950a. Studies on meat. I. The biochemistry of beef as related to tenderness. Food Technol. 4:7.

_______, F. E. Deatherage, and L. E. Kunkle. 1950b. Studies on meat. II. Observations on relation of biochemical factors to changes in tenderness. Food Technol. 4:9.

Jacobson, M. and F. Fenton. 1956a. Effects of three levels of nutrition and age of animal on the quality of beef. I. Palatability, cooking data, moisture, fat and nitrogen. Food Res. 21:415.

_______, and F. Fenton. 1956b. Effects of three levels of nutrition and age of animal on the quality of beef. II. Color, total iron content and pH. Food Res. 21:427.

Kieffer, N. M., R. L. Henrickson, D. Chambers and D. F. Stephens. 1959. The influence of sire upon some carcass characteristics of angus steers and heifers. Oklahoma Agri. Exp. Sta. MP-58.

Lowe, B. 1949. Organoleptic tests developed for measuring the palatability of meat. Proc. Recip. Meat Conf. 2:111.

_______ and J. Kastelic. 1961. Organoleptic, chemical, physical and microscopic characteristics of muscles in eight beef carcasses, differing in age of animal, carcass grade and extent of cooking. Iowa Agri. Exp. Sta. Bul. 495.

Marshall, N. 1960. Electronic cookery of top round of beef. J. Home Econ. 52:31.

Mjoseth, J. H. 1962. A study of tenderness variation in certain bovine muscles. M. S. Thesis. Oklahoma State University.

Nelson, P. M., B. Lowe and M. D. Helser. 1930. Influence of animal age upon the quality and palatability of beef. Part II. The roast beef preparation, quality and palatability. Iowa Agri. Exp. Sta. Bul. 272.

Palmer, A. Z., D. L. Huffman, J. W. Carpenter, R. L. Shirley and J. F. Hentges, Jr. 1961. The effect of ante-mortem injection of sodium chloride, papain, and papain derivatives on the tenderness of beef cattle. Fla. Agri. Exp. Sta., An. Sci. Mimeo Series 62-8.

Parrish, F. C., M. E. Bailey and H. D. Naumann. 1961. Hydroxyproline as a measure of beef tenderness. Food Technol. 16:68.

Paul, P. and L. J. Bratzler. 1955a. Studies on tenderness of beef. II. Varying storage times and conditions. Food Res. 20:626.

_______ and L. J. Bratzler. 1955b. Studies on tenderness of beef. III. Size of shear cores: end to end variations in the semimembranosus and adductor. Food Res. 20:635.

_______, M. Bean and L. J. Bratzler. 1956. Effect of cold storage and method of cooking on commercial grade of cow beef. Mich. Agri. exp. Sta. Bul. 256.

Pearson, A. M. and J. I. Miller. 1950. The influence of rate of freezing and length of freezer-storage upon the quality of beef of known origin. J. Animal Sci. 9:13.

_______. 1963. Objective and subjective measurements for meat tenderness. Proc. Meat Tenderness Symposium, Campbell Soup Co.

Phillips, L., I. Delaney and M. Mangel. 1960. Electronic cooking of chicken. J. Am. Dietet. A. 37:464.

Pollak, G. A. 1959. Study of microwave cooking device, Tappan Model RL-1. U. S. Naval Supply Research and Development Facility, Bayonne, N. J.

Ramsbottom, J. M., E. J. Strandine and C. H. Koonz. 1945. Comparative tenderness of representative beef muscles. Food Res. 10:497.

________ and E. J. Strandine. 1948. Comparative tenderness and identification of muscles in wholesale beef cuts. Food Res. 13:315.

Ritchey, S. J., S. Cover and R. L. Hostetler. 1963. Collagen content and its relation to tenderness of connective tissue in two beef muscles. Food Technol. 17:76.

Roberta, M. MA., M. B. Matlack and R. L. Hiner. 1961. A study of free amino acids in bovine muscles. J. Food Sci. 26:845.

Saffle, R. L. and L. J. Bratzler. 1959. The effect of fatness on some processing and palatability characteristics of pork carcasses. Food Technol. 13:236.

Satorius, M. J. and A. M. Child. 1938. Effect of coagulation on press fluid, shear force, muscle cell diameter, and composition of beef muscle. Food Res. 3:619.

Simone, M., F. Carroll and C. O. Chichester. 1959. Differences in eating quality factors of beef from 18 and 30 month steers. Food Technol. 13:337.

Skelton, M., D. Harrison, J. L. Hall, R. F. Adams and G. E. Goertz. 1963. Effect of degree of doneness on collagenous tissue in two muscles of beef. Food Technol. 17:93.

Sleeth, R. B., R. L. Henrickson and D. E. Brady. 1957. Effect of controlling environmental conditions during aging on quality of beef. Food Technol. 11:205.

Strandine, E. J., C. H. Koonz and J. M. Ramsbottom. 1949. A study of variations in muscles of beef and chicken. J. Animal Sci. 8:483.

Swift, C. E. and M. D. Berman. 1959. Factors effecting the water retention of beef. I. Variations in composition and properties among eight muscles. Food Technol. 13:7.

Thatcher, B. 1963. Microwave food heating in commercial applications. General Electric Co. Chicago Heights, Illinois.

Tuma, H. J. 1962. The influence of age on various factors associated with beef quality. Ph. D. Thesis. Oklahoma State University.

________, J. H. Venable, P. R. Wuthier and R. L. Henrickson. 1962. Relationship of fiber diameter to tenderness as influenced by bovine age. J. Animal Sci. 21:33.

________, R. L. Henrickson, G. V. Odell and D. F. Stephens. 1963. Variation in the physical and chemical characteristics of the longissimus dorsi muscle from animals differing in age. J. Animal Sci. 22:354.

Tuomy, J. M., R. J. Lechnir, and T. Miller. 1963. Effect of cooking temperature and time on the tenderness of beef. Food Technol. 17:119.

Visser, R. Y., D. L. Harrison, G. E. Goertz, M. Bunyan, M. M. Skelton and D. L. Mackintosh. 1960. The effect of degree of doneness on the tenderness and juiciness of beef cooked in the oven and in deep fat. Food Technol. 14:193.

Walker, M. and R. L. Henrickson. 1960. A pilot study of the variation in tenderness within the longissimus dorsi muscle of beef. Unpublished report. Oklahoma Agri. Exp. Sta.

Wang, HSI, D. M. Doty, F. J. Beard, J. C. Pierce and O. G. Hankins. 1956. Extensibility of single muscle fibers. J. Animal Sci. 15:97.

Warner, K. F. 1928. Progress report of the mechanical test for tenderness of meat. Proc. Am. Soc. Animal Prod. 21:114.

Weir, C. E. 1953. The variation in tenderness in the longissimus dorsi of pork. Food Technol. 7:12.

_______. 1960. The Science of Meat and Meat Products. W. H. Freeman and Co., San Francisco and London.

Wellington, G. H. and J. R. Stouffer. 1959. Beef marbling, its estimation and influence on tenderness and juiciness. Cornell Univ. Agri. Exp. Sta. Bul. 941.

Wierbicki, E., L. E. Kunkle, V. R. Cahill and F. E. Deatherage. 1954. The relation of tenderness to protein alteration during post-mortem aging. Food Technol. 8:11.

_______, L. E. Kunkle, V. R. Cahill, and F. E. Deatherage. 1956. Post-mortem changes in meat and their possible relation to tenderness together with some comparisons of meat from heifers, bulls, steers and diethylstilbesterol treated bulls and steers. Food Technol. 10:80.

_______ and F. E. Deatherage. 1958. Determination of water-holding capacity of fresh meats. J. Agri. Food and Chem. 6:387.

Winegarden, M. W., B. Lowe, J. Kastelic, E. A. Kline, A. R. Plagg and P. S. Shearer. 1952. Physical changes of connective tissues of beef during heating. Food Res. 17:172.

APPENDIX

TABLE XVIII

WARNER-BRATZLER SHEAR VALUES FOR PARAFFIN CORES
1/2, 3/4 AND 1 INCH DIAMETER

1/2"		3/4"		1"	
5.50	5.75	9.50	8.75	10.25	10.00
5.00	5.00	8.50	8.25	10.25	9.75
5.50	5.50	9.00	8.75	11.25	12.00
5.25	5.50	8.50	9.00	10.75	11.00
5.00	5.00	9.00	9.00	10.00	10.25
5.00	6.00	8.50	8.75	11.25	10.50
5.25	5.25	8.75	8.50	11.50	10.50
5.75	5.25	9.25	9.25	11.00	10.75
5.50	5.00	8.50	8.25	12.25	11.25
5.25	5.25	8.25	8.75	11.25	10.75
5.75	5.50	8.50	8.75	10.75	9.75
5.00	5.00	7.50	8.50	10.50	10.75
6.00	5.75	8.75	8.25	10.75	11.50
5.25	4.75	9.00	8.75	11.25	11.75
5.25	5.25	9.50	8.75	10.75	11.00
5.00	5.50	9.75	8.25	11.00	10.50
5.25	5.50	7.75	8.50	9.75	11.25
4.75	5.75	9.25	9.25	10.50	11.00
5.00	5.00	8.75	8.00	11.00	9.75
5.25	5.00	8.25	8.25	10.75	10.75
5.75	5.00	8.50	9.00	11.50	11.00
5.50	5.75	9.00	9.25	10.50	11.25
6.00	5.25	8.75	8.25	11.50	10.25
5.75	5.50	8.75	9.25	10.00	11.50
55.50	5.75	8.50	8.00	11.00	10.75

TABLE XIX

WEIGHT AND GRADE CHARACTERISTICS OF INDIVIDUAL CARCASSES AND AGE GROUPS

Age Mos.	Animal No.	Cold Carcass Wt.	Grade	Marbling
	3	434.5	Choice	Moderate
	16	523.5	Choice -	Sm. Amount
	20	419.5	Good -	Sli. Amount
15	25	417.5	Good	Traces
	32	379.0	Good	Sli. Amount
	36	472.0	Good +	Sli. Amount
	22	567.5	Good +	Sm. Amount
	6	538.0	Good +	Sm. Amount
	7	612.0	Good +	Sm. Amount
18	27	506.5	Good	Sli. Amount
	31	598.5	Choice -	Moderate
	42	473.5	Good	Sm. Amount
	11	739.5	Choice -	Sli. Abundant
	19	854.5	Good +	Modest Amount
24	26	809.5	Choice	Sli. Abundant
	34	778.5	Choice -	Sli. Abundant

TABLE XX

EXPERIMENTAL DESIGN[1]

Animal No.	[2]									
	a	b	c	d	e	f	g	h	i	Steak Position
3	5	5	5	4	4	4	3	3	3	Steak Thickness
	3	2	1	2	3	1	3	1	2	Core Size
	e	f	d	h	i	g	b	c	a	Steak Position
16	4	4	4	3	3	3	5	5	5	Steak Thickness
	1	2	3	2	3	1	3	1	2	Core Size
	i	g	h	c	a	b	f	e	d	Steak Position
20	3	3	3	5	5	5	4	4	4	Steak Thickness
	3	2	1	2	3	1	3	2	1	Core Size
	c	a	b	f	d	e	i	g	h	Steak Position
25	5	5	5	4	4	4	3	3	3	Steak Thickness
	1	2	3	3	1	2	1	2	3	Core Size
	d	e	f	g	h	i	a	b	c	Steak Position
32	4	4	4	3	3	3	5	5	5	Steak Thickness
	1	3	2	3	1	2	3	2	1	Core Size
	h	i	g	b	c	a	e	f	d	Steak Position
36	3	3	3	5	5	5	4	4	4	Steak Thickness
	1	3	2	1	3	2	1	2	3	Core Size

Code for Steak Thickness and Core Size
as Measured in Inches

1/2"	1
3/4"	2
1"	3
1 1/2"	4
2"	5

[1] 15 Months of Age

[2] Anterior (13th thoracic vertebra)

TABLE XXI

EXPERIMENTAL DESIGN[1]

Animal No.	[2]									
	a	b	c	d	e	f	g	h	i	Steak Position
6	5	5	5	4	4	4	3	3	3	Steak Thickness
	3	2	1	2	1	3	1	3	2	Core Size
	e	d	f	h	i	g	b	c	a	Steak Position
7	4	4	4	3	3	3	5	5	5	Steak Thickness
	2	1	3	1	3	2	3	2	1	Core Size
	i	g	h	c	a	b	f	e	d	Steak Position
22	3	3	3	5	5	5	4	4	4	Steak Thickness
	1	3	2	3	2	1	2	1	3	Core Size
	c	a	b	f	d	e	i	g	h	Steak Position
27	5	5	5	4	4	4	3	3	3	Steak Thickness
	3	2	1	2	1	3	1	3	2	Core Size
	d	e	f	g	h	i	a	b	c	Steak Position
31	4	4	4	3	3	3	5	5	5	Steak Thickness
	3	2	1	2	1	3	1	3	2	Core Size
	h	i	g	b	c	a	e	f	d	Steak Position
42	3	3	3	5	5	5	4	4	4	Steak Thickness
	1	3	2	3	2	1	2	1	3	Core Size

Code for Steak Thickness and Core Size
as Measured in Inches
1/2" - 1
3/4" - 2
1" - 3
1 1/2" - 4
2" - 5

[1] 18 Months of Age

[2] Anterior (13th thoracic vertebra)

TABLE XXII

RANDOMIZATION PLAN FOR LATIN SQUARE

Animal No.	Position a	b	c	d
34	E	E	F	F
26	E	F	E	F
19	F	E	F	E
11	F	F	E	E

E - Electronic oven
F - Deep fat

TABLE XXIII

MEAN SHEAR VALUES FOR STEAKS FROM THE LONGISSIMUS DORSI MUSCLE OF SIX DIFFERENT ANIMALS[1]

Animal #3		Animal #16		Animal #20		Animal #25		Animal #32		Animal #36	
Steak No.	Shear Value	Steak No.	Shear Value	Steak No.	Shear Value	Steak No.	Shear Value	Steak No.	Shear Value	Steak No.	Shear Value
3 f	7.16	16 e	8.62	20 h	8.74	25 i	11.01	32 h	10.20	36 h	9.00
3 h	8.45	16 c	9.28	20 b	11.36	25 d	11.37	32 c	7.72	36 b	10.19
3 c	8.16	16 g	11.65	20 d	11.03	25 c	10.72	32 d	9.38	36 e	6.97
3 i	13.87	16 a	14.25	20 e	16.22	25 g	16.90	32 i	14.98	36 g	13.95
3 d	11.73	16 f	16.00	20 c	15.86	25 a	11.02	32 b	12.47	36 a	15.22
3 b	14.61	16 h	19.79	20 g	15.29	25 e	16.94	32 f	13.92	36 f	11.29
3 g	20.17	16 b	21.08	20 i	26.25	25 b	19.86	32 g	22.06	36 i	21.08
3 i	15.71	16 i	15.59	20 a	23.36	25 f	18.99	32 e	19.70	36 c	23.53
3 a	21.50	16 d	21.66	20 f	21.62	25 h	31.12	23 a	19.78	36 d	19.35

1 15 Months of Age.

TABLE XXIV

MEAN SHEAR VALUES FOR STEAKS FROM THE LONGISSIMUS DORSI MUSCLE OF SIX DIFFERENT ANIMALS[1]

Animal #6		Animal #7		Animal #22		Animal #27		Animal #31		Animal #42	
Steak No.	Shear Value	Steak No.	Shear Value	Steak No.	Shear Value	Steak No.	Shear Value	Steak No.	Shear Value	Steak No.	Shear Value
6 g	8.25	7 h	10.08	22 e	7.78	27 d	8.14	31 g	8.79	42 h	8.88
6 e	8.11	7 d	7.39	22 i	9.45	27 b	8.83	31 c	7.80	42 f	12.36
6 c	6.47	7 a	7.06	22 b	18.39	27 i	8.67	31 e	10.25	42 a	6.81
6 i	14.31	7 e	15.56	22 f	13.83	27 h	18.79	31 i	16.13	42 e	11.11
6 b	11.03	7 g	14.75	22 h	16.42	27 f	13.22	31 d	16.86	42 g	13.96
6 d	13.62	7 c	11.86	22 a	16.06	27 a	14.80	31 b	12.28	42 c	11.00
6 h	17.53	7 i	22.67	22 d	19.64	27 g	18.46	31 h	20.75	42 i	20.63
6 f	17.69	7 f	21.67	22 g	22.42	27 e	18.44	31 a	19.89	42 b	17.00
6 a	19.67	7 b	19.13	22 c	19.02	27 c	18.58	31 f	18.03	42 d	20.39

[1] 18 Months of Age

TABLE XXV

MEAN SHEAR VALUES FOR STEAKS IDENTIFIED BY CORE SIZE[1]

Steak No.	1/2 Inch	Steak No.	3/4 Inch	Steak No.	1 Inch
20 h	8.74	31 i	13.87	3 g	20.17
36 h	9.00	20 e	16.22	25 b	19.87
25 i	11.01	3 d	11.73	3 e	15.71
32 h	10.20	25 g	16.90	25 f	18.99
16 e	8.62	32 i	14.98	25 h	31.12
3 f	7.16	25 a	11.02	20 i	26.25
32 c	7.72	36 g	13.95	32 g	22.06
3 h	8.45	36 a	15.22	32 e	19.70
25 d	11.37	3 b	14.61	36 i	21.08
36 b	10.19	20 c	15.86	3 a	21.50
3 c	8.16	32 b	12.47	36 c	23.53
20 b	11.36	16 a	14.25	20 a	23.36
32 d	9.38	16 f	16.00	32 a	19.78
16 c	9.28	16 h	19.79	16 b	21.08
25 c	10.72	25 e	16.94	20 f	21.62
20 d	11.03	32 f	13.92	36 d	19.35
16 g	11.65	36 f	11.29	16 i	15.59
36 e	6.97	20 g	15.29	16 d	21.66

[1] 15 Months of Age

TABLE XXVI

MEAN SHEAR VALUES FOR STEAKS IDENTIFIED BY CORE SIZE[1]

Steak No.	1/2 Inch	Steak No.	3/4 Inch	Steak No.	1 Inch
42 h	8.88	42 e	11.11	42 i	20.63
42 f	12.36	42 g	13.96	7 i	22.67
7 h	10.08	7 e	15.56	31 h	20.75
31 g	8.79	7 g	14.75	22 d	19.64
7 d	7.39	31 i	16.13	22 g	22.42
6 g	8.25	22 f	13.83	27 g	18.46
7 a	7.06	22 h	16.42	27 e	18.44
22 e	7.78	27 h	18.79	6 h	17.53
6 e	8.11	27 f	13.22	6 f	17.69
27 d	8.14	6 i	14.31	27 c	18.58
27 b	8.83	31 d	16.86	22 c	19.02
42 a	6 81	31 b	12.28	7 f	21.67
31 c	7.80	22 a	16.06	31 a	19.89
6 c	6.47	42 c	11.00	42 b	17.00
22 i	9.45	6 b	11.03	6 a	19.67
22 b	18.39	7 c	11.86	7 b	19.13
31 e	10.25	27 a	14.80	31 f	18.03
27 i	8.67	6 d	13.62	42 d	20.39

1 18 Months of Age

TABLE XXVII

MEAN SHEAR VALUES FOR STEAKS IDENTIFIED BY THICKNESS[1]

Steak No.	1 Inch	Steak No.	1 1/2 Inch	Steak No.	2 Inch
20 h	8.74	16 e	8.62	32 c	7.72
36 h	9.00	3 f	7.16	36 b	10.19
25 i	11.01	25 d	11.37	3 c	8.16
32 h	10.20	32 d	9.38	20 b	11.36
3 h	8.45	20 d	11.03	16 c	9.28
16 g	11.65	36 e	6.97	25 c	10.72
3 i	13.87	20 e	16.22	25 a	11.02
25 g	16.90	3 d	11.73	36 a	15.22
32 i	14.98	16 f	16.00	3 b	14.61
36 g	13.95	25 e	16.94	20 c	15.86
19 h	19.79	32 f	13.92	32 b	12.47
20 g	15.29	36 f	11.29	16 a	14.25
3 g	20.17	3 e	15.71	25 b	19.86
25 h	31.12	25 f	18.99	3 a	21.50
20 i	26.25	32 e	19.70	36 c	23.53
32 g	22.06	20 f	21.62	20 a	23.36
36 i	21.08	36 d	19.35	32 a	19.78
16 i	15.59	16 d	21.66	16 b	21.08

[1] 18 Months of Age

TABLE XXVIII

MEAN SHEAR VALUES FOR STEAKS IDENTIFIED BY THICKNESS[1]

Steak No.	1 Inch	Steak No.	1 1/2 Inch	Steak No.	2 Inch
42 h	8.88	42 f	12.36	7 a	7.06
7 h	10.08	7 d	7.39	27 b	8.83
31 g	8.79	22 e	7.78	42 a	6.81
6 g	8.25	6 e	8.11	31 c	7.80
22 i	9.45	27 d	8.14	6 c	6.47
27 i	8.67	31 e	10.25	22 b	18.39
42 g	13.96	42 e	11.11	31 b	12.28
7 g	14.75	7 e	15.56	22 a	16.06
31 i	16.13	22 f	13.83	42 c	11.00
22 h	16.42	27 f	13.22	6 b	11.03
27 h	18.79	31 d	16.86	7 c	11.86
6 i	14.31	6 d	13.62	27 a	14.80
42 i	20.63	22 d	19.64	27 c	18.58
7 i	22.67	27 e	18.44	22 c	19.02
31 h	20.75	6 f	17.69	31 a	19.89
22 g	22.42	7 f	21.67	42 b	17.00
27 g	18.46	31 f	18.03	6 a	19.67
6 h	17.53	42 d	20.39	7 b	19.13

1 18 Months of Age

TABLE XXIX

STEAK WEIGHT AND LOSS DURING COOKING[1]

Steak No.	Initial Steak Weight	% Loss	Steak No.	Initial Steak Weight	% Loss	Steak No.	Initial Steak Weight	% Loss
20 h	183.00	27.00	3 i	164.50	25.50	3 g	152.50	31.15
36 h	168.00	28.87	20 e	231.50	29.60	25 b	260.00	29.60
25 i	143.00	26.22	3 d	227.00	27.09	3 e	222.00	30.00
32 h	140.00	30.71	25 g	130.00	28.46	25 f	190.50	31.49
16 e	257.00	30.90	32 i	129.50	28.95	25 h	146.50	33.78
3 f	221.50	32.50	25 a	258.50	27.46	20 i	161.50	35.90
32 c	241.50	31.46	36 g	187.00	26.40	32 g	139.00	31.65
3 h	154.50	31.00	36 a	312.50	31.92	32 e	201.50	25.00
25 d	192.50	31.90	3 b	340.00	30.59	36 i	174.50	32.00
36 b	322.25	34.68	20 c	330.00	32.42	3 a	317.00	31.70
3 c	340.75	33.82	32 b	252.00	33.33	36 c	333.50	36.36
20 b	303.50	34.10	16 a	321.00	30.84	20 a	319.00	34.48
32 d	192.00	35.68	16 f	299.00	33.95	32 a	253.00	32.41
16 c	326.00	31.29	16 h	176.50	33.71	16 b	333.00	33.03
25 c	258.00	29.65	25 e	199.00	30.40	20 f	223.00	38.70
20 d	219.50	29.38	32 f	213.00	31.01	36 d	189.00	34.02
16 g	173.00	31.21	36 f	243.00	31.02	16 i	182.00	29.12
36 e	239.50	31.50	20 g	160.50	31.15	16 d	293.94	30.94

1 15 Months of Age

TABLE XXX

STEAK WEIGHT AND LOSS DURING COOKING[1]

Steak No.	Initial Steak Weight	% Loss	Steak No.	Initial Steak Weight	% Loss	Steak No.	Initial Steak Weight	% Loss
42 h	169.45	35.32	42 e	242.91	32.49	42 i	170.85	30.61
42 f	255.55	33.71	42 g	185.59	29.99	7 i	206.91	30.61
7 h	200.48	32.31	7 e	257.65	32.35	31 h	200.50	30.32
31 g	196.25	30.75	7 g	197.10	31.43	22 d	252.62	31.76
7 d	317.42	29.41	31 i	177.30	32.06	22 g	179.35	30.43
6 g	158.15	30.35	22 f	242.50	34.35	27 g	162.90	33.59
7 a	263.00	34.78	22 h	188.10	28.97	27 e	230.50	27.07
22 e	255.70	33.12	27 h	187.30	31.37	6 h	150.98	33.20
6 e	238.00	30.67	27 f	262.60	34.35	6 f	219.00	32.97
27 d	234.50	32.20	6 i	160.09	33.57	27 c	382.00	31.24
27 b	382.00	33.77	31 d	285.00	33.50	22 c	261.00	34.18
42 a	292.10	33.46	31 b	369.95	31.66	7 f	304.00	35.23
31 c	336.90	36.09	22 a	311.00	31.19	31 a	347.50	34.68
6 c	341.25	29.08	42 c	327.00	30.92	42 b	333.10	32.80
22 i	176.00	27.84	6 b	347.00	31.04	6 a	298.05	29.67
22 b	297.00	30.98	7 c	356.00	30.90	7 b	372.00	33.06
31 e	351.50	33.99	27 a	390.50	29.82	31 f	349.15	33.42
27 i	167.79	28.30	6 d	255.50	30.53	42 d	253.50	33.93

1 18 Months of Age

TABLE XXXI

SHEAR VALUES FOR INDIVIDUAL LONGISSIMUS DORSI STEAKS TABULATED BY COOKING METHOD AND CORE POSITION

Animal No.	Steak Position a	b	c	d
34				
Dorsal	11.38*	15.13*	10.13	11.88
Medial	12.25*	17.52*	19.75	18.00
Lateral	17.38*	13.00*	14.54	16.88
26				
Dorsal	12.63*	12.25	10.75*	13.50
Medial	11.38*	18.25	12.75*	19.38
Lateral	17.50*	18.75	14.63*	13.88
19				
Dorsal	12.13	12.38*	15.50	13.88*
Medial	13.75	16.50*	19.13	18.25*
Lateral	14.88	21.25*	23.63	21.63*
11				
Dorsal	18.03	17.75	10.75*	19.88*
Medial	18.00	18.13	18.00*	20.75*
Lateral	17.75	20.25	18.25*	16.00*

* Cooked electronically

VITA

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Candidate for Degree of
Master of Science

Thesis: A study of some secondary factors influencing tenderness of the bovine longissimus dorsi muscle

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Education: Attended grade school at Greer, South Carolina. Graduated from Jordan High School, Greer. Received a Bachelor of Science degree from Clemson A & M College with a major in Animal Husbandry in January 1955. Military education includes: Associate Company Officers Course, The Quartermaster School, Fort Lee, Virginia; Commissary Officers Course, The Quartermaster School, Europe; Armored Officer's Maintenance Course, The Armor School, Fort Knox, Kentucky; and the Advanced Officer's Course at the Quartermaster School, Fort Lee, Virginia. Assigned to the Student Detachment, Headquarters, Fourth United States Army, with duty station Oklahoma State University from August, 1962 to May 1964.

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