TENDERNESS OF THE BICEPS FEMORIS
AS AFFECTED BY METHOD AND DEGREE OF COOKING
AND INITIAL TEMPERATURE

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Thirty beef roasts from eight steers, raised under controlled conditions, were cooked by moist and dry heat to two internal temperatures, approximating rare (60°C for dry heat and 80°C for moist heat) and well done (80°C for dry heat and 100°C for moist heat). The degree of thawing before cooking was varied. Roasts at room temperature, refrigerator temperature, and in the frozen state were cooked by the four methods. Twenty-four roasts were cooked in a conventional gas oven, while six were cooked in an electronic range.

Tenderness was evaluated by shear and taste panel, while collagen level was determined by chemical analysis. Moisture and cooking losses were calculated, and an attempt was made to relate palatability factors to the rate of cooking or heat penetration.

Cooking losses in the form of drippings and evaporation losses were higher for meat cooked by moist heat. Roasts cooked in the frozen state had lowest cooking losses, 29.1 per cent compared with 34.0 and 35.9 per cent for room and refrigerator temperatures respectively. Longer cooking resulted in greater shrinkage. In the presence of moist heat there was less variation in shrinkage due to degree of cooking than dry heat roasts. Roasts started in the frozen state required the longest

cooking time, followed by those in which cooking was started at refrigerator temperature. The room temperature roasts cooked most quickly. More time was required to reach the highest internal temperature within a cooking method, and the presence of moisture increased the rate of heat penetration. Refrigerator roasts cooked to an internal temperature of 80°C by dry heat at a rate of 40.3 minutes per pound, and cooked almost twice as quickly at 26.8 minutes per pound by moist heat.

Analysis of variance revealed significant differences in tenderness. Tenderness was affected to a highly significant degree by the cooking method according to both shear and panel scores. Meat cooked by moist heat to an internal temperature of 100°C was most tender with a panel score of 5.9 and a shear force value of 12.1 pounds. According to shear values meat cooked by dry heat to 60°C was least tender with a value of 22.2 pounds. However, the taste panel rated this method second in tenderness with a score of 5.2. Panel scores for dry and moist heat at 80°C were both 4.9, but shear values indicated greater tenderness by moist heat. Shear force was 16.6 pounds by moist heat, but 18.3 pounds with dry heat methods. A chew count by the taste panel was not found to be effective in distinguishing differences in tenderness. Chemical analysis for connective tissue in the cooked meat yielded a mean collagen content of 1.68 per cent on a dry weight basis. Differences due to the influence of cooking method were not consistent.

Correlations of -.60 were calculated between shear and taste panel, .35 between collagen and shear and .53 between collagen and taste panel.

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INTRODUCTION

When the meat consumption of Canada and the United States is compared with that of some European countries, it can be seen that Canadians rank among the highest meat consumers (Table I). Meat has a significant place in the diet of North Americans. North Americans, Europeans and Australians get their protein requirements largely from beef, pork, veal, lamb, poultry and eggs. The amount of meat eaten by Asians is considerably smaller, and they rely largely on fish and legumes for their protein. Nutritionally, foods of the meat group supply approximately 50 per cent of the protein and niacin, 43 per cent of the iron, and 25 per cent of the vitamin A, thiamin, and riboflavin consumed (63).

Of all the meat that is produced and eaten in Canada, beef makes up the largest proportion. The 1961 per capita consumption was 68.8 pounds for beef, followed by pork with 53.5 pounds. Veal trailed with 8.2 pounds, and mutton had a low of 3.7 pounds (35).

Of the multitude of factors involved in the selection, production and consumption of beef, one of the most important is tenderness. Consumer surveys indicate that tenderness is one of the most desired qualities in meat. Rhodes _et al._ (78) reported a test in which consumers, making complaints about beef quality, were asked to explain their dissatisfaction. The results are summarized in Table II.

Tenderness in meat is influenced by many conditions, which will be considered at greater length in a later section. The cooking method

TABLE I

PER CAPITA CONSUMPTION OF MEAT IN SOME EUROPEAN COUNTRIES, COMPARED WITH THAT OF CANADA AND THE U.S.A. FOR 1953-54

Country	1953-54 (kg.)
France	68.3
West Germany	42.5
United Kingdom and Ireland	55.7
Italy	17.9
Greece	14.4
Canada	75.9
United States	82.0

TABLE II

PERCENTAGE OF TOTAL CONSUMERS MAKING SPECIFIC COMPLAINTS ABOUT BEEF QUALITY

Palatability Factors	Percentage of Complaints	
	Roasts	Steaks
Tenderness	55	62
Flavour	17	16
Juiciness	10	8
Others	-	1

can affect tenderness, and is the one important factor over which the homemaker has direct control. Traditional recommendations for "moist" and "dry-heat" methods have been questioned. Some alteration may be required in cooking practices to bring them into line with new concepts in meat tenderness.

REVIEW OF LITERATURE

Meat is composed of three main substances, muscle tissue, connective tissue, and fat. Muscle tissue is, for the most part, voluntary cross-striated muscle. Individual muscle fibres are long and slender with cross-banding. Each fibre is enclosed in a sheath called the sarcolemma. Individual muscle tissues are grouped into bundles called fasciculi.

Because of its design and composition, the muscle fibre has remarkable ability to contract and relax, bringing about bodily motion. The contractile substance of the muscle is made up of two proteins, actin and L-myosin, which combine to form actomyosin. Much remains to be learned about the mechanism of contraction, but it is believed that changes occur in the actomyosin as a result of energy supplied by the nucleotide, adenosine triphosphate or ATP. Muscle fibres that are fine in diameter seem to be related to tender meat, while coarser fibres seem to be associated with meat that is not as tender.

Connective tissue binds together muscle fibres. The casing for individual muscle fibres is thin and filmy in nature and is called the endomysium. A sheet of connective tissue, known as the perimysium, surrounds groups of fibres to form a bundle. Groups of bundles form the muscle and are further surrounded by epimysium. Varying from thin, filmy sheaths to tough bonds and heavy membranes, connective tissue is found in skin, tendons, ligaments, aponeurosis and bone. Two types of fibres make up the connective tissue, the white and the yellow fibres. White collagenous fibres are coarse, strong, inelastic, and will hydrolyze to gelatin in moist heat. Softening of collagen during cooking decreases toughness in meat. In structure, collagen consists of bundles of individual, non-branching fibrils. The fibrils are very thin, arranged in random order, and are imbedded in a large amount of extra-cellular matrix called ground substance. Chemically, the basic collagen molecule is made up of polypeptide chains high in glycine, proline and hydroxyproline residues. Yellow fibres are not found in large amounts in muscle cuts and are fine, elastic, branched in structure, and resistant to moist heat.

Fat is deposited in the connective tissue around organs, around and between muscles, and under the skin. It is thought to contribute to the apparent juiciness of meat and does influence tenderness. Each fat cell is a large single vacuole of fat. It may be arranged in groups or globules with delicate connective tissue and blood capillaries. During cooking, fat is released from the cells by heat, and contributes to the richness and flavour of cooked meat.

Meat varies greatly in composition because of differing physical, structural and chemical characteristics. It is a heterogeneous substance showing variation within the same cut, in different cuts from the same carcass, and from animal to animal. Tenderness is influenced by the relative amount and distribution of each constituent. Estimation of tenderness is made, in the final analysis, by the eating of cooked meat. But to study tenderness with scientific precision, a number of methods of measurement have been developed.

Subjective Measurement of Meat Tenderness by Taste Panel Scores

Sensations of tenderness are highly complex because they are related to chewing motions, as well as impressions of texture, softness, and moistness on the tongue, mouth, teeth, lips and cheeks (12). Taste panel scores can be used as a subjective measure of tenderness, competent judges having the ability to merge the diverse sensations into a unified tenderness impression. Lowe (52), in describing subjective tests generally, stated that they "measure, in the expression of opinion, the qualities of food as they make their impression, individually and collectively on the sensory organs." Tests of this type are subjective because they involve judgment of the qualitative and quantitative aspects of the characteristic being considered.

The usefulness and validity of taste panel scores has sometimes been questioned. Since the method is entirely subjective, it is susceptible to inaccuracy as a result of erratic tendencies in human judgment. But Peryam and Swartz (71) point out that stability as well as variability should be recognized in the sensory capacity of individuals. They further state that objectivity is possible in sensory testing when tests are set up in such a way that they depend more on discrimination than judgment. Deatherage (34) in a comparative study of sensory panel and shear strength measurements for tenderness in broiled steaks from thirty-two matched pairs of short loins, reported that panel testing gave reproducible results. Even though he found low correlation between panel and shear scores, he claimed that the sensory panel method is the preferred method for guiding research. Correlations as high as -.9 have been reported between panel scores and shear tenderness of meat by Ramsbottom and Strandine (74). Other studies on the reproducibility of taste panel test data have shown standard deviations of average panel scores of 0.46 - 0.73 (73). Deatherage in his study, reported a correlation coefficient of only -.369 between panel scores and shear strength, but nevertheless recognized the existence of a relationship between panel scores for tenderness and shear values.

Three types of tests have been used (31) to detect sensory differences in palatability, 1) consumer preference tests, 2) flavour acceptance tests, 3) difference tests. In the latter, the only concern is whether a detectable difference exists between two or more treatments. This is the method of special interest in this study.

Panel members, then, serve essentially as a laboratory instrument (32) with precision depending on (a) control of environmental conditions, (b) method, and (c) selection of panel members. The conditions under which scoring takes place should be carefully controlled and be free from interruptions and distractions. Privacy should be provided so that judges are not unduly influenced by each other and unrelated outside factors.

The test method should be appropriate to the problem. In some studies, it is only necessary to establish that a difference exists, while in others the direction and extent of the difference must be known, and a more complete analysis and description may be required. Panel members should be selected for intelligence, concentration, motivation, ability to detect fine differences in specific attributes, and the ability to give reproducible judgments. A panel ranging in size from three to ten is usually adequate. Training is important as it helps to increase sensory acuity, and ensure uniform understanding of the properties to be evaluated.

Various types of rating scales have been developed to evaluate beef tenderness organoleptically. Raffensperger, Peryam and Wood (73) at the Quartermasters Food and Container Institute for United States Armed Forces, worked on several scales in 1956, in which tenderness was considered as a single quality of varying intensity. Considerable work was done with a nine-point scale with a toughness-tenderness continuum. A structured scale describing various degrees of toughness and tenderness provided some guidance for judges. However, an unstructured scale was found to be no less effective with well-trained judges, because they apparently structured a scale mentally, relating descriptive qualities of specific intensities to the numerical scale. By eliminating a neutral category of "neither tough nor tender," a nine-point structured scale was improved and error was reduced from 50 per cent to 20 per cent.

A different approach to sensory tenderness testing has been suggested by Cover and her co-workers. Cover first proposed the method of using paired identical cuts from the right and left sides of the same carcass in 1936 (15). This method is now almost standard in meat tenderness research. In order to better analyze tenderness, Cover suggested that this complex quality should be broken down into various components (22,24). At first, two components (1957) and then three (1959-60) were described as comprising tenderness. The three components that contributed to tenderness were softness, friability and amount and quality of connective tissue. The method of partitioning tenderness into several components made it easier to relate chemical and physical changes to certain kinds and degrees of tenderness. Tenderness of the connective tissue components is not identical with tenderness and softness of the muscle fibres, and for the first time, they were separated and measured individually. In work reported in 1962 (26), the tenderness components were further partitioned into six components including juciness, softness to tongue and cheek, softness to tooth pressure, ease of fragmentation and mealiness, adhesion between fibres, and tenderness of connective tissue. This latest approach is claimed to increase precision in analyzing the multiple components of tenderness.

Aldrich and Deans (1), when comparing the single quality components versus composite factors, state that selected descriptive components increase discrimination by the composite tenderness method. Sections of longissimus dorsi muscles of Choice and Good grade beef were cooked to internal temperatures of 70°C. When tenderness was determined, the use of three selected tenderness characteristics did not appear to have any advantage over the traditional tenderness composite. However, the tenderness components seemed to reinforce and substantiate each other as well as the conventional single factor tenderness composite.

A more objective approach to measuring tenderness by sensory methods which has some reproducibility is the chew count. Harrington and Pearson (43) found that the number of chews required to masticate halves of one inch cores could be measured. The mean chew counts of six tasters for thirty-six loins ranged from 25.3 to 47.0. This technique, while not as refined as Cover's tenderness components, does provide a means of gauging gross variations in tenderness, and may be very useful where comparative information is required.

Thus, a variety of sensory methods are in use. Each method represents an attempt to measure the important but elusive and complex property of tenderness in meat.

Evaluating Meat Tenderness by Objective Means

Methods for evaluating quality that do not involve the human senses are classed as objective. According to Griswold (42), objective methods are an advantage because they are less subject to error and human variability than sensory methods, and also they are reproducible. The disadvantages of some objective methods is that they are expensive or too time-consuming. If the same quality can be measured by both sensory and objective methods, the findings are more meaningful. Sensory and objective methods should supplement and reinforce each other by correlating highly with one another. Types of objective methods used for determining meat tenderness are: (1) mechanical, (2) chemical, and (3) histological.

Mechanical Methods

Mechanical methods have been widely used because of their simplicity and high objectivity. The Warner-Bratzler shear, a motor-driven, cutting gauge that shears a core of meat inserted in a triangular opening, is perhaps the most commonly used device for measuring tenderness. The force required to shear a sample is recorded in pounds on a scale by a pointer. The advantage of the shear is that it is simple to operate and gives reproducible results. Deatherage and Garnatz (34) suggested that although tenderness and shear values may not be identical qualities, some relationship does exist between them.

Hurwicz and Tischer (49), in working with a homogeneous material, parowax, studied the variation in shear force measurements. A high experimental error was found to be inherent in the machine. The use of a slope-of-shear force versus time curve, instead of just a maximum shear force was suggested as an improved criterion for tenderness.

Comparisons between shear force value and other measurements of tenderness have revealed a range of values, as summarized in Table III.

TABLE III

CORRELATION COEFFICIENTS BETWEEN SHEAR AND PANEL SCORES FOR BEEF TENDERNESS

Workers	Year	Description of Cut	Correlation Coefficient
Ramsbottom *et al.* (74)	1945	25 representative muscles from 3 U.S. Good carcasses	- .9
Deatherage (34)	1952	32 matched pairs of short loins	- .369
Burrill, Deathardt and Saffle (11)	1962	82 cooked beef muscles with range in tenderness	- .69
Fielder, *et al.*(37)	1963	32 beef carcasses	- .32
Bratzler and Smith (10)	1963	15 beef short loins	- .75

Burrill *et al.* (11), in a comparison of type of shears with taste panel scores and panel chews, have stated that the choice of shear would depend on cost, ease, and versatility, the time involved in making measurements as well as accuracy. The Warner-Bratzler shear showed reasonably good agreement between panel score and shear force, and was easier to use than the other type of shear tested (Kramer shear).

Many other devices for estimating tenderness have been developed and include the Child-Sartorius shear, Kramer shear press and a variety of cutting gauges, motorized grinders, penetrometers, as well as a unique moveable set of dentures which simulate chewing action. With some, the cost, complexity or error introduced limits their usefulness. Others give accurate results, but either time or further development is necessary for their general acceptance.

Chemical Methods

Chemical methods have developed along two main lines, in the attempt to relate structural components present in meat to tenderness. Tests have been developed for collagen and hydroxyproline, but questions remain as to the usefulness of these in rating meat tenderness. Both methods are based on the assumption that connective tissue in meat makes the major contribution to toughness. On heating, in a moist medium, connective tissue, present mainly in the form of white fibrous collagen tissue is converted to soluble gelatin. Collagen, is supposedly the only protein in meat which is capable of complete hydrolysis to gelatin by autoclaving. Elastin is the yellow, elastic, chemically-resistant material found in smaller amount in connective tissue. The degree of softening and gelatinization of collagen is largely dependent on the conditions of heating or cooking. Conversion of collagen to gelatin produces a tenderizing effect, but collagen and connective tissue are not the only factors which determine tenderness. The amount that is not converted (residual collagen) contributes to the overall toughness of meat.

Collagen in the meat sample is removed by extraction, commonly with an alkali. The method of Lowry, Gilligan and Katersky (54), or some modification of this procedure is frequently employed. Collagen may be found by weight as in the original procedure or the nitrogen present in the gelatin after autoclaving may be used as a measure of collagen. Hydroxyproline is used also as an index of connective tissue because it is an amino acid found in unusually large amounts in collagen (61).

In 1952 Winegarden et al. (94) carried out a study that related the effects of heating connective tissue in water to the cooking of meat. Strips of connective tissue were heated at varying temperatures (60° - 95°C) for time intervals ranging from 1 to 64 minutes. Little change occurred at 60°C and the critical temperature appeared to be around 65°C. The strips shortened and thickened, and in general, the changes were greater as time, temperature and collagen content in tissues increased. Hiner, Anderson and Fellers (46), in 1955, after studying histological sections of beef from nine beef samples varying widely in age and tenderness, indicated that collagen and elastin fibres were the major determiners of tenderness.

A comparison of the collagen nitrogen and hydroxyproline methods as a measure of connective tissue was made by Ritchey and Cover (79). Average collagen nitrogen values were determined for 10 steers and 4 bulls by both nitrogen and hydroxyproline from two muscles, the biceps femoris and longissimus dorsi, cooked rare (61°C) and well done (100°C). A conversion factor of 13 per cent was used to change hydroxyproline to units of collagen nitrogen, because hydroxyproline originally was assayed in micrograms of amino acid. The collagen nitrogen values as measured by Kjeldahl method were found to be lower than those calculated from hydroxyproline, due either to extraction procedure or conversion factor. Hydroxyproline was recommended as the most reliable indicator of connective tissue in raw and cooked meat. The cooked meat showed collagen hydrolysis at both low and high temperatures, with some variation at the low (rare) temperature. The greatest hydrolysis of collagen occurred at the high (well done) temperature.

An association between collagen, as determined by collagen nitrogen, and the ability of judges to score for toughness or tenderness of connective tissue was shown by Irwin and Cover in 1959 (50). Steaks from 2 muscles of 26 animals were analyzed raw and boiled for collagen nitrogen, using a more exhaustive alkali extraction procedure. A correlation coefficient of -.492, significant at the 1 per cent level, was reported for collagen nitrogen content versus panel scores for connective tissue. The biceps femoris, a muscle known to contain moderately large amounts of connective tissue, was used.

Histological Methods

Histological methods are fairly recent in the study of muscle tenderness. Skill has to be acquired in using staining and heating methods and more work is required to confirm some observations. In relating tenderness to the physical structure of either muscle fibres or connective tissue, changes produced during heating and detected by sensory or mechanical methods can be more easily explained and interpreted.

Wang *et al.* (90) reported evidence of emulsification of fat by degraded collagen. Fat droplets and collagen appeared to be dispersed and intermingled, rather than existing in a continuous liquid state. The role of fat as a separating or diluting agent for connective tissue was suggested.

Hiner, Anderson and Fellers (46) studied the distribution of connective tissue in nine samples of muscle from animals varying in age from 10 weeks to 9 years, and noted larger amounts of collagenous fibres in the portions of the animal that had had more exercise. A loose network was seen between muscle bundles with fatty deposits, while bunching was noted where less fat was present. Paul (66,67) studying the effect of aging, observed cracks, breaks and granulated areas in the muscle fibres. Heating had the same effect, and even increased the disintegration. Doty and Pierce (36) described the changes in muscle fibres on cooking as "erosion" and noticed increased granulation with longer heating. Collagen, with heating, also appears to change from a fibrous to a granular stage.

Factors Influencing Tenderness in Meat

Tenderness is a complex property, resulting from the interaction of many factors. Some of the contributing factors mentioned by Boyd (12) include breed, age, sex, feed, aging, resolution of rigor, fat content, muscle activity, solubility of collagen, enzyme action and cooking method. The relative effect of each factor on tenderness can be understood better by looking at them separately.

<u>Breed, Sex and Feed</u>

An interaction of genetic influences and environmental conditions is always involved in the growth of animals. Genetic improvement will be the result of using mating systems that make use of hereditary variation (55). Most traits related to growth and feed efficiency, as well as conformation, are inherited and will respond to selection pressure. Animals that are short and stocky with short legs and shallow bodies have been found to have more edible meat with less bone than those that are tall, long-legged and deep-bodied.

The effect of breed on tenderness has been established by studies that indicate that beef tenderness is heritable to some degree. With one type of breed, in particular, the effect on tenderness is marked. As soon as Zebu breeding is introduced, there is a decrease in tenderness. When breeds are compared, Brahmans, a type of Zebu, are tough, while the British breeds, Herefords, Jersey, Angus and Guernsey are more tender. Intermediate in tenderness are crossbreeds of Brahman and Hereford or Angus ancestry.

Several recent studies (2, 65, 77) give some indication of the relationship between breed and tenderness. Two hundred and eighty-one animals of known genetic background were studied at the Range Cattle Station in Florida. Breeding was predominantly Brahman and Shorthorn, with some crossbred bulls. After slaughter, animals were graded. Tenderness was evaluated by shear and taste panel. Sixty per cent of the Brahman progeny were less than the average values for tenderness, while sixty-one per cent of Shorthorn progeny were average or above. Differences within progeny due to sires, breed of sire, and sires within breeds, as measured by panel scores, were all highly significant.

Between breeds, sire differences were highly significant for only Brahman bulls. An estimate of heritability was made to measure the extent to which differences in heredity influence tenderness among animals. Brahman sires were found to have heritability estimates of 71 per cent for panel and 54 per cent for shear values. Shorthorns used in the study were of similar stock, and sizeable difference within the breed were not shown (65).

A later study of 538 cattle was made at the Florida Agricultural Experiment Station with the major beef breeds and crossbreeds (2). Age ranged from 5 to 99 months. Tenderness was evaluated by a taste panel and shear readings. Angus, Hereford and Shorthorn progeny were found to be significantly more tender than progeny of Brahman and Brahman x Shorthorn sires. When progeny within a breed were grouped according to tenderness, the percentage progeny found to be average or better than average in tenderness values were as follows (2):

Angus	86.7
Hereford.	87.4
Shorthorn	56.8
Brahman	36.3

As a comparison of relative significance of breeding, animal age, conformation, finish and marbling, Alsmeyer, et al. (2) partitioned the variance factors, and expressed them as a proportion of total tenderness variability. Brahman breeding accounted for the greatest variability in tenderness by taste panel evaluation. The respective values are shown in Table IV.

TABLE IV

PERCENTAGE OF TENDERNESS VARIABILITY ACCOUNTED FOR BY BREED, AGE, GRADE AND FAT CONTENT

Factor	Per Cent of Tenderness Variability
Per cent of Brahman breeding	12.1
Carcass grade	9.2
Animal slaughter age	5.0
Carcass outside finish	3.1
Carcass conformation	2.6
Marbling	1.1

Alsmeyer, et al. (2).

Ramsey, et al. (77) determined tenderness and palatability differences among breeds of British, Zebu and dairy type cattle. One hundred and fifty-one steers were full-fed a high concentrate ration under similar environmental conditions. Results of the five year study showed that eating quality differed among samples from various breeds. Steaks from Brahman steers rated lowest in tenderness, while those from Jersey steers were most tender. Means for shear values and taste panel scores were significantly less tender for Zebu breeds at 5.89 and 6.06 respectively. Average values for British breeds were 5.24 and 6.49, while those for dairy breeds were 5.13 and 6.71.

Sex of the animal is not considered to have much effect on tenderness (65). Recent interest has been shown in bull beef and boar pork to find out whether quality and tenderness would be acceptable. A comparison of steers, stilbestrol implanted bulls and untreated bulls showed no significant differences in tenderness that could be attributed to sex.

No single nutrient has, in itself, been shown to influence beef tenderness. Even with extremes, such as borderline deficiencies and nutrient fortification, it has been difficult to directly demonstrate any clear-cut influences. Much remains to be learned about the effect of feed additives such as hormones, antibiotics and tranquilizers. A relatively high plane of nutrition during growth and development does result in weight gain, followed by marbling as finishing progresses.

The effects of a specific type of feed management have been studied. Meyer et al. (60) provided some evidence in favour of grain-finishing in preference to grass-finishing. Meat came from 8 pairs of steers, divided into 2 lots with one lot grain-fed, while the other was grass-fed. Significant differences in tenderness were measured by a taste panel, at 21 days ripening, in favour of the grain-finished beef. Shear values were not significantly different.

Age at Time of Slaughter

The relationship of age at the time of slaughter to tenderness has been recognized. Meat from a young animal with tender muscle fibres, and less extensive development of connective tissue is tender. Hankins and Hiner (44, 45) provided some evidence linking animal age with tenderness. Fifty-two carcasses varying in age from 10 week veal calves to aged cows, and including steer calves, 1000 pound steers and barren heifers, were rated by shear and panel tests, and showed a trend toward decreasing tenderness with increasing age. Other investigators studying age as the single factor have found similar results. However, other associated factors may also have had an influence on tenderness.

Alsmeyer, et al. (in a study referred to previously)(2), considered age of animal in relation to other factors, because they questioned the explanation of tenderness variation on the basis of age perse. Experiments were designed to evaluate the tenderness effects of animal age, breed, marbling and carcass grade. Five hundred and two carcasses, ranging in age from 18 to 48 months, were studied. A highly significant, though small correlation of .15 was obtained between tenderness and age of slaughter without respect to degree of marbling. Within degrees of marbling classes as slight or devoid, the relationships were small, but not significant. In a further study of 538 carcasses (65), age explained only a minor part of the variability in tenderness (6 per cent of total variability) as determined by a taste panel. Simple correlation between age at time of slaughter and tenderness was significant though small, with -.25 for panel and .27 by Warner Bratzler shear.

More information is needed, but in general, while there is some relationship between age and tenderness, the effects of age, perse, on tenderness are not completely understood.

Aging of Carcass

After slaughter the carcass goes into a state of rigor mortis. The stiffening of the dying muscle can be explained in terms of physiology and chemistry of the muscle (7). During the course of rigor, adenosine-triphosphate (ATP) begins to disappear and lactic acid results from the process of glycolysis as the muscle becomes anaerobic.

As stiffness diminishes, tenderness increases, with both physical and chemical changes produced largely by the action of enzymes.

Paul, et al. (67) compared steaks and roasts from six animals cooked after 0, 5, 12, 24, 48 to 53 and 144 to 149 hours cold storage. Roasts were found to be least tender immediately after slaughter and became increasingly tender as storage time lengthened. Steaks, tender immediately after slaughter, became less tender with cold storage up to 24 hours, and then returned approximately to their original tenderness with storage of 144 to 149 hours. Physical changes brought about by tension in the muscle were revealed by histological examination. Areas in a state of rigor mortis were wavy and contracted, while areas between the contraction nodes appeared stretched at 24 hours storage. Several days later, as some relaxation in the muscle took place, the fibres straightened somewhat, and breaks appeared, either as fractures or disintegrated areas.

In a further study on storage time and conditions, Paul and Bratzler (68) found that increased length of cold storage increased tenderness as measured by shear values. Any handling of the muscle, such as removal from the carcass or cutting into the muscle, interfered with the tenderizing process. After three days aging, additional cold storage of 0, 1 and 2 days increased tenderness, as did freezing and thawing.

When eight pairs of steers were aged for 2, 7, 21 and 42 days in a longer range study by Meyer, et al., highly significant increases in tenderness were found for both shear and panel scores (60). Table V shows the effect of aging on shear and panel tenderness.

TABLE V

EFFECT OF AGING ON TENDERNESS

Number of Days Ripening	Tenderness of Grain-Finished Beef	
	Panel Scores (10 point scale)	Shear (pounds)
2	6.6	19.8
7	7.7	14.6
21	8.2	13.3
41	8.4	14.0

J. Meyer, J. Thomas, R. Buckley and J. W. Cole (60)

Doty and Pierce (36) were able to show that aging for two weeks, in a study of 153 beef carcasses, caused a substantial reduction in the shear strength of cooked meat. Mean differences for shear values were significant, with values of 11.30 for unaged and 8.72 for the samples after 2 weeks of aging.

Deatherage and Hersham, on the other hand, in trying to speed up post-mortem tenderization, concluded that tenderness did not increase uniformly with aging times (33). Tenderization appeared to increase up to 44 hours storage, but 12 additional hours showed no further effect. Aging may not be strictly a function of time, and there may be a limit to the length of time that produces the maximum effect. High temperature aging and the use of antibiotics to inhibit growth of organisms have been studied as a modification of the aging process (93).

pH of Meat

Once the blood supply to the muscle is cut off after death, the anaerobic respiration results in lactic acid production and a fall in pH (7, 76). Glycolysis is carried on at a slow rate, until the glycogen in the muscle is completely exhausted. At a pH of 5.4 or below, the glycogen enzyme system becomes inactivated. Stress, fatigue or exercise before slaughter reduces the glycogen and consequently the lactic acid levels. Lewis, Brown and Heck (51) reported that electrical stimulation and feeding increased glycogen concentration.

A higher pH of meat is related to low glycogen levels, and has an effect on colour (13). At a pH of 6.6 and above, the meat is dark in colour, with an unpleasant, slimy quality. A pH of 5.6 is associated with a bright colour and firm tissue. The effects of pH on tenderness, if any, are not marked.

Fat Content and Grade

The relationship between fatness in meat and tenderness is not direct. Fat content is related to the impression of tenderness because it contributes to juiciness, and is important in determining flavour. Fat is present in two forms in meat, as the finish or outer covering of the carcass, and as marbling dispersed between muscle fibres.

Marbling is assumed to be as an indicator of tenderness in the meat trade, and has considerable influence as a determiner of grade. Grade is assessed by considering age, conformation, finish and marbling. The reliability of this approach is currently being questioned. Zinn, *et al.* (95), in an evaluation of beef grading methods, calculated a correlation coefficient of -.08 between marbling score and shear values. Their data suggested that 99 per cent of the variation in tenderness was due to factors other than marbling, but 80 per cent of the variation in grade was determined by marbling.

However, fat does offer less resistance to shearing than the lean, and by mechanical advantage alone, its presence does contribute to tenderness (60). Cover (20, 22) has found low but positive correlations between amount of fat and tenderness evaluations.

Doty and Pierce (36) determined the composition of 102 carcasses with respect to marbling (rated subjectively on a five point scale) and intramuscular fat which was determined chemically. By American grading standards the highest grade Prime ribeye was significantly more highly marbled than Good grade ribeye. There was some suggestion that heavy carcasses in each grade were more highly marbled than light carcasses. Differences in intramuscular fat in the raw ribeye occurred due to carcass grade, carcass weight, and the time of sampling. High intramuscular fat values were not necessarily correlated with fatness of the carcass, indicating that finish and marbling were not always related in a specific carcass.

Lowe and Kastelic (53), in studying characteristics of eight beef carcasses, analyzed fat content by alcohol-ether extraction, and found considerable variation from animal to animal, as well as between cuts. Some muscles like the psoas major that are designated "tender," consistently had a higher fat content than those cuts considered "less tender." A pattern relating fat content to tenderness did appear to exist but some deviation was shown by cuts with low fat content and acceptable tenderness, and cuts with high fat content but lower tenderness ratings.

A regression (for dependency of all tenderness scores upon fat content) gave a correlation coefficient of .46, significant at the 1 per cent level.

In the study mentioned previously, by Alsmeyer *et al.* (2), in which age, breed, grade and marbling were compared, fat content was found to have a minor effect on tenderness as compared to the other factors. Simple correlations between marbling and federal grade were highly significant for both shear and panel measures. Carcass grade accounted for only 11.5 per cent variation by panel, and 20.2 per cent by shear. Of the total tenderness variability studied, percentage variability in panel tenderness evaluation was found to be 9.2 for carcass grade, 3.1 for finish, 2.6 for carcass conformation and only 1.1 for marbling.

Research studies have mainly used "linear fat" as a measure of finish, or ether extract as a chemical measure of marbling. Neither approach has resulted in high positive correlations with tenderness. More experimentation appears to be required.

The influence of fat on tenderness has been clarified to some extent by Wang *et al.* who were able to give an explanation for the effect of fat on tenderness. After cooking of meat, fat probably plays a role as a separating or diluting agent for connective tissue. A mingling of fat and hydrolyzed collagen droplets was observed under the microscope, and led to the interpretation that an emulsification process takes place in which degraded collagen functioned as a dispersing agent. Further study will be needed in this area (90).

Juiciness and Tenderness

Juiciness is related to tenderness, but it is still not clear whether it is an associated or a directly related factor. Part of the tenderness sensations produced when eating a steak, broiled rare, is due to the juiciness. Moisture content or juiciness is greater in the rare steak than in a cut roasted to the well-done stage. Juiciness relates not only to the amount of juice present in a piece of meat, but part of its effect may also be due to a stimulation to the flow of saliva. Juiciness has been defined as "the relative quantity of juice judged in the act of chewing or measured by mechanical means" (38). The relative smoothness and richness of the meat juices may depend on the concentration, within the juice, of meat solids including fat. Attempts have been made to relate fluid extracted by pressure to juiciness. Some relationship does exist but results are not consistent. According to Bratzler and Smith (10) "there is very little difference between press or shear as a predictor of tenderness as determined by a sensory panel. Lack of significant correlations between raw-press readings and panel scores for cooked meat indicate it has limited application when raw samples are used." A variety of methods have been used including a screw press for raw meat, a "pressometer" and a hydraulic press for raw meat. Centrifugal force methods have been used for determining moisture in heated meat. The Carver Laboratory Press is one of the most recent devices in use (5).

Press fluid is the amount of water released by pressure either before or after cooking. Bound water is the amount not released by pressure, and inextricably bound with the protein constituents of the meat. Some indication of the amount of bound water is given by drying in a vacuum oven to determine the amount of moisture left in meat after all the press fluid is released. Total fluid content then would be press fluid plus bound water (84).

Bratzler and Smith (10) have reported a significant correlation between press and shear values for short loins. Press fluid from raw samples, however, showed little relationship to panel ratings. Cover, Ritchey and Hostetler (27) noted that meat became drier and harder with increases in temperature. Juiciness was not found by these workers to be closely related to any panel score tenderness components.

Connective Tissue and Tenderness in Meat

Considerable study has been directed towards connective tissue, and the extent to which it contributes to toughness in meat. Believed for a long time to be the major factor causing toughness, it is now considered more in relation to other structures in meat. The characteristics of connective tissue were described as follows by Hiner, Anderson, and Fellers (46):

> The collagenous fibres are soft and flexible and offer considerable resistance to a pulling force; however, they lack elasticity. Collagenous fibres are long, straight or wavy, fine fibrils that run in all directions. It is almost impossible to find where they terminate. These fibres or fibrils generally appear in bundles, connected together, which branch into smaller bundles. The small bundles often branch out into single fibrils and appear between muscle fibres.

Collagen is a protein, exhibiting typical protein reactions. Due to its characteristics it is classified as an albuminoid. When collagen is boiled in water it dissolves and forms a colloidal solution of gelatin which becomes jellylike when cooled. The collagenous fibres swell when placed in dilute acids and strong alkalies.

They are also easily digested by pepsin in acid solution but resist trypsin in alkaline solution. Hinrichs and Whitaker (47) compared the action of ficin on collagen with that of bromelin, pepsin, trypsin, and fungal protease, and reported that native collagen was not affected. Only after heat denaturation, or in high salt concentrations, or at a low pH, did ficin, bromelin, pepsin or trypsin have any hydrolyzing effect on collagen. Quite rapid degradation occurs at 60° to 70°C.

Elastin has been well described by Hiner, Anderson, and Fellers (46) as "yellow fibres [that] occur in connective tissue as a loose network of fine fibres that branch and anastomose in various directions." Elastic fibres are homogenous and not fibrillar as are collagenous fibres. As a rule, elastic fibres appear as straight branching fibres. Upon stretching, they yield readily but return to their normal length when released. If the fibres appear in large numbers, as in the ligamentum nuchae, they are yellowish in color.

Elastin, an albuminoid, is the principal constituent of elastic fibres. Elastin is very resistant to boiling water, acids, and alkalies, but it can be digested slowly with pepsin and trypsin. Elastic fibres differ from collagenous fibres in that they will stain differently with orcein and resorcin fuchsin (46). Either acid or basic dyes will stain elastin.

Much about the distribution of connective tissue was revealed by Hiner, Anderson, and Fellers (46) in a study of fifty-two animals ranging in age from three month veal calves to five year old cows. Muscles assumed to be used more actively by the animal were shown by histological study to have more highly developed connective tissue because of the greater activity and exertion they have undergone with time. Chemical analysis has shown that younger animals have a lower proportion of connective tissue (46). Collagenous fibres were shown to be bunched between large muscle bundles and scattered between individual muscle fibres.

Further evidence of a varying distribution of connective tissue was given by Cover, Ritchey and Hostetler (26) in which collagen changes after cooking to temperatures of rare (61°C) and well done (80°C) by dry heat, and 100°C by moist heat were compared in steaks from two cuts, the biceps femoris and longissimus dorsi. The biceps femoris, considered initially less tender and found to be higher in connective tissue content, became more tender with cooking and resulting collagen hydrolysis, even though it had scored tough at 61°C. The longissimus dorsi with a lower initial connective tissue content scored tender at 61°C and became only slightly more tender with increased temperatures. A difference in response to cooking conditions due to different amounts of connective tissue in various muscles has been suggested (79). The same investigators later reported (80) that chemical tests of the longissimus dorsi showed it contained less collagen nitrogen in both raw and cooked states than did the biceps femoris. Rates of conversion of collagen to gelatin, measured as percentage loss, during cooking to 61°C and 80°C, were similar for the two muscles.

Winegarden _et al._ (94) described the effect of heat, such as would be encountered during cooking, on connective tissue. Aponeurotic sheets of beef, mainly collagen with a little elastin, and tendon which is almost exclusively collagen, as well as ligamentum nuchae (principally elastin) were heated at temperatures ranging from 60° to 95°C, for intervals of 1, 2, 4, 16, and 64 minutes. Most of the tests were made on aponeurotic strips which served as the collagen model, on the assumption that connective tissue actually found in this material would be similar enough to permit inferences about muscle connective tissue. The critical temperature at which greatest softening and thickening took place was found to be near 65°C. As time and temperature of heating increased, more collagen conversion occurred. Elastin was found to be more resistant to heat than collagen, but since it is found only in small amounts, this fact has little significance in influencing tenderness in meat. The interpretation of the findings as applied to meat cookery was that short cooking of steaks or roasts would not bring about much softening of connective tissue (94). But further study with collagen in a number of forms has indicated that the change takes place fairly rapidly once heat is applied. Irwin and Cover (50) have shown that some conversion of collagen to gelatin takes place even with broiling to rare (61°C) and that collagen is readily affected by heat.

Ritchey, Cover, and Hostetler (79, 80) have questioned whether the collagen models from animal skins and connective tissue would be identical with that actually found between muscle fibres in meat. Cover, Ritchey, and Hostetler (26, 27), Irwin and Cover (50) and Griswold (41) have all reported tendering trends in meat with increasing temperatures due to collagen conversion.

The curling of steaks and plumpness of roasts produced by cooking may be least partly explained as a tightening and squeezing effect caused by contraction and shrinkage of tissue surrounding muscle fibres (50). Machlik and Draudt (56), in studying the effect of time and temperature on tenderness, have noted a marked decrease in shear of beef semitendinosus within eleven minutes at 58°C. The first part of the reaction, which took place very quickly, was interpreted as a manifestation of collagen shrinkage. There appeared to be a high dependence on temperature for this part of the reaction. Further changes were attributed to effects on muscle fibre coagulation. Minimum shear values were obtained in the range of 60° to 64°C, after heating 30 to 60 minutes. This time and temperature range was recommended because the collagen shrinkage reaction would be completed quickly, while at the same time, the hardening due to protein denaturation at higher temperatures would be avoided.

Muscle Fibres and Tenderness in Meat

The part that muscle fibres play in tenderness was at first obscured because research centered mainly around connective tissue. With the realization that tenderness could not be entirely explained by the connective tissue component, attention was turned to the muscle fibres. Many studies point out that muscle is not a homogeneous tissue which undoubtedly accounts for variation in tenderness.

Ramsbottom, Strandine, and Koons (74) made a comprehensive study on the tenderness of beef muscles by studying a large number of muscles, first as wholesale cuts and then as twenty-five individual muscles representative of the beef carcass. Tenderness was measured by shear and taste panel. Both chemical analysis and histological study showed that muscles varied widely in fat content as well as in collagen and elastic tissue. A muscle near the front shank, the superficial pectoral, was found to have a coarse texture with relatively large fibre bundles, and large amounts of connective tissue surrounding the muscle, giving high shear values. In contrast, the psoas major or tenderloin, had a smooth, fine texture and low shear readings. Between the two extremes, there were intermediate variations in bundle size and amount of connective tissue.

Besides tenderness variations between muscles, some variation was found within muscles. The psoas major was fairly uniformly tender, but the biceps femoris, a "moderately tough" muscle from the round, became more tender from the end of insertion to the origin as shown in Table VI.

TABLE VI

CHANGES IN SHEAR WITH MUSCLE POSITION

Region of Biceps Femoris	Shear Values (1/2" Core)
Origin	7.5 ± 1.1
Middle	9.1 ± 0.7
Insertion	10.8 ± 1.0

Taylor *et al.* (88) were able to show that with certain relatively homogeneous muscles the central portion of the semitendinosus and the posterior of the semimembranosus were similar in composition and properties. The anterior parts of both muscles showed marked differences. The semimembranosus was found to be variable, while the adductor seemed uniform as judged by shear values in a study by Paul and Bratzler (68). Doty and Pierce, in a study of 153 carcasses, noted differences between muscles, as well as within the same muscle at different positions (36).

The tenderness of cooked meat is determined by changes in muscle fibres as well as in connective tissue. Meat will be tough or tender according to the dominant effect. Cover (24), as a result of the new scoring method partitioning tenderness into connective tissue and muscle fibre effects, has studied two different muscles, the biceps femoris and longissimus dorsi. With increasing temperatures during cooking, it seemed that the muscles responded differently to heat as revealed by ease of fragmentation and adhesion between fibres. Rising temperature caused a marked toughening in the "tender" longissimus dorsi, while a tendering effect was dominant in the "moderately tough" biceps femoris. The varying response to cooking reflects the predominant tendering effect in one muscle, as compared with the toughening in the other.

Fielder et al. (37) describe a new processing method in which carcasses are boned and trimmed, and grouped according to tenderness of muscles. A single cut, whether it be roast or steak, would be more uniform in tenderness and could be cooked accordingly. Grade differences appeared to be minimized by "prefabricating" meat in this way.

Another property of muscle fibres that has been investigated is extensibility. Wang et al. (91) were able to show correlations of -.43 and -.65 for extensibility and tenderness. Extensibility was expressed in mm. per 5 mm. initial length of a single fibre stretched to its breaking point. Cover, Hostetler and Ritchey (26)(80) were able to support findings on extensibility which were significant in the longissimus dorsi, but not the biceps femoris. Aging was found to decrease extensibility while cooking increased it. More experimentation is needed to confirm the significance of these findings.

Effect of Enzymes on Tenderness

Enzymes occur naturally within meat, and have a slight effect on tenderness. Proteolytic activity takes place during natural aging, but much remains to be understood about the exact effect on tenderness.

The direct application of enzyme preparations to meat has been suggested by the presence of natural enzymes in meat. Salt mixtures or a liquid dip are the usual forms available for home use. Action is confined mainly to the surface, and is most suitable for thin pieces of meat. There may be some surface mushiness if amount is not controlled carefully enough. Temperature has been suggested to have a greater effect than time. Tappel et al. (87) suggest 60°C is the optimum temperature for papain action. Types of enzymes that have been used include pancreatic, bacterial and fungal enzymes.

Enzyme preparations act on the muscle fibre and break down the endomysial collagen. Weir et al. (92) have shown that bromelin, rhyzyme, ficin and papain increase tenderness in rib eye steaks. Muscle fibres decreased in extensibility, and this suggested a modification of the actomyosin molecule (81, 92). After the sarcolemma at the surface of the meat was destroyed, a marked separation of fibres was noted (81). Ficin, bromelin and papain are effective in changing connective tissue (47).

Recently a new method of tenderizing meat by injecting an enzyme preparation was developed and is known as the Proten process. Papain, injected into the blood stream of animals before slaughter, is well distributed by the circulatory system of the animal. Tenderizing action then begins at cooking temperature. The degree of tenderizing depends on the amount of injection and the length of cooking time (72, 81).

Effect of Cooking Method on Tenderness

Of all factors contributing to tenderness, the one that can be most directly controlled by the homemaker is the cooking method. As indicated, tenderness is to some extent predetermined and inherent within a specific raw cut of meat. However, the cooking procedure can bring about modifications. Tenderness after cooking will depend not only on the nature of the meat itself, but also on the temperature and length of cooking, as well as the cooking medium, whether it be air, steam or fat.

The art of cookery has been formulated largely by experience and observation. Traditional methods have been developed, classified generally as "moist" and "dry" heat methods. Roasting and broiling are common dry heat methods, appropriate only for "tender" cuts, while stewing, braising and pot roasting by long, slow cooking with added moisture, are moist heat methods for "less tender" cuts. Moist heat methods have been considered essential for cuts of meat with more extensive connective tissue development. It has been theorized that the added moisture was necessary to bring about hydrolysis of connective tissue to gelatin. This may appear to ignore the fact that meat contains up to 70 per cent moisture. Dry heat is supposedly more appropriate for cuts of meat that are initially low in connective tissue. Changes taking place in meat during cooking have been described by Doty and Pierce (36) in this way:

(a) Muscle fibres are changed (denatured) so that their resistance to shear and their extensibility are increased.

(b) Collagen is hydrolyzed or denatured.

(c) Soluble proteins are denatured or condensed to more insoluble complexes.

(d) Creatine is changed to creatinine.

(e) Perimysial and endomysial fat is dispersed.

(f) The surface of the muscle fibres is sometimes slightly "eroded" . . .

It may be seen that some of these complex changes in cooking increase tenderness while others decrease it. The final change after cooking a specific cut of meat depends upon the relative proportions of muscle fibre, connective tissue and fat. In cuts where there is little connective tissue, the toughening of muscle fibres would be predominant.

When the amount of connective tissue is large, tenderness may increase as a result of conversion of collagen to gelatin. In this case, toughening of muscle fibre due to protein coagulation may be minor in comparison with the softening produced in connective tissue. Tenderness after cooking, for a specific cut, depends, then on the extent to which both muscle fibre and connective tissue have been changed. To achieve optimum tenderness is a problem because of the opposing effects that heat produces on the components of meat.

Cover (23) has pointed out the need for critical evaluation of traditional cooking practices, and a scientific investigation of the factors involved. She has questioned procedures such as the effect of added liquid in softening collagen, the extent to which a temperature was sufficiently high to toughen protein, and the effect of rate of heat penetration on tenderness.

Research has taken various directions as questions have been raised and investigated. In the following review, some of the topics studied have been grouped as follows:

(1) "Moist heat" versus "dry heat" cookery.

(2) Low heat, long time interval cooking.

(3) Dry heat for "less tender" cuts.

(4) Effect of cooking time and temperature on tenderness.

(5) Electronic cookery.

"Moist" Versus "Dry" Heat Cooking

Cover (21,25) questioned the value of adding water or other liquid to "less tender" cuts of meat for the purpose of softening connective tissue. She pointed out that meat in the raw state is high in moisture, and additional liquid would only contribute a minor effect in the conversion of collagen to gelatin. In an early study in 1941, (17), Cover cooked paired roasts from 8 carcasses at a controlled temperature of 90°C, with one being submerged in water in a large water bath, while the pairmate was roasted in an uncovered pan in the oven. Roasts were cooked to a similar degree of doneness to internal temperatures of 85°C for the water-cooked, and 80°C for the oven-cooked meat. (Previous work had shown that meat cooked by dry and moist heat to the same internal temperature did not exhibit the same degree of doneness.) There was a vast difference in time required for cooking. The water-cooked meat required only 3 hours, compared with 23 hours for the oven-cooked roasts. The explanation advanced for this difference was that water, being a good conductor of heat, permitted more rapid heat penetration and cooking than air. Shear and taste panel ratings for tenderness were in favour of the oven-cooked roasts.

Cover and Shrode (19) in 1955 compared moist and dry heat methods, cooking roasts and steaks from four steers. One cut was cooked by a moist heat method while the pair-mate was done by a dry heat method. The response of all cuts to moist and dry heat methods was not alike, but ratings for tenderness were in favour of the moist heat methods. The biceps femoris from bottom round steaks were significantly more tender by braising than by broiling.

A comparison of fourteen cooking methods made by Griswold (40, 41) included braising, pressure cookery and roasting. Results after cooking round steak showed that braising was a suitable method for cooking round. Though shear values for the pressure-cooked meat were lower, judges expressed a preference for the flavour and other qualities of the braised meat. However, roasted meat was even more highly rated than the braised.

Clark et al. (14) in cooking top and bottom round steaks from 3 carcasses by braising and pressure cookery found that steaks cooked to a temperature of 112°C at 15 p.s.i. were significantly more tender than those cooked at lower temperatures in the pressure saucepan or by braising. A lower internal temperature of 80°C gave better aroma, flavour and juiciness.

Cover, Bannister and Kehlenbrink (22) noted a significant difference in shear and tenderness scores for muscle fibres when braising and oven broiling were compared in the loin and bottom round of 2 steers. Shear force values indicated the loin was most tender when broiled rare, but the round was most tender when it was braised well done. Cover and Hostetler (25) and Cover, Hostetler and Ritchey (29) showed moist heat methods brought about increased tendering in the round steaks (18).

Long, Slow Cooking

The effects of low temperatures and long cooking times have resulted in unusual tenderness and a characteristic dryness, mealiness and crumbliness in the fibre. Cooking takes place so slowly that toughening which ordinarily occurs in muscle fibre does not result (18).

Bramblett et al. (8) in 1959 reported 5 muscles from 6 pairs of round cooked at temperatures of 63°C or 145°F for 30 hours, while the pair-mates were cooked at 68°C or 155°F for 18 hours. Cooking losses were less at the lower temperature. Shear values and panel scores showed meat was more tender at the lower temperature. The biceps femoris required 12.35 lbs. to shear the sample at 63°C and 18.77 lbs. at 68°C. Panel scores were 3.83 or more tender at 63°C and 2.72 at 68°C.

Eight top round roasts were cooked at low oven temperatures of 200°F, 225°F and 250°F to internal temperatures of 60°C or 140°F, 70°C or 158°F, 80°C or 176°F by Marshall, Wood and Patton (58) in 1960. They noted considerable variation in cooking time and cooking losses, but reported the largest yield at an oven temperature of 225°F and an internal temperature of 140°F or 60°C. Conclusions were that the long cooking time necessary (30 to 40 hours) would make the method impractical.

Using five oven temperatures, 275°, 300°, 325°, 350° and 375°F, and cooking to three different internal temperatures of rare (60°C or 176°F), medium (70°C or 158°F), and well done (80°C or 176°F), 75 top round beef roasts were compared by Hunt, Seidler and Wood (48) in 1963. No significant differences in tenderness by shear were noted, but there was considerable variation from roast to roast. Internal temperature was found to affect yield and cooking losses more than oven temperature.

In a recent study Bramblett and Vail (9) roasted 60 paired round cuts from 12 carcasses to internal temperatures of 65°C or 149°F at oven temperatures of 155°F and 200°F. Muscles cooked at 155°F showed greater cooking losses but were better in appearance and flavour than those cooked at 200°F. Meat cooked at 155°F was rated more tender by shear and taste panel. Average panel scores were 4.34 at 155°F and 3.67 at 200°F, while shear values were 4.81 and 7.14 lbs. at the temperatures of 155°F and 200°F respectively.

Dry Heat and High Temperature Cookery

High heat is said to produce toughening of the protein constituents of meat. Questions have been raised as to the temperatures and cooking times most likely to cause toughening. If tenderness changes produced during cooking are thought of as resulting from both temperature and time, high temperatures and rapid cooking could possibly be used with good results.

Rodgers, Mangel and Baldwin (82) have pointed out that long cooking results in meat that is dry and lacking in flavour. A 1963 study led to the statement that variations of the traditional cooking procedures are possible, and that these different methods may be applied to meat ordinarily cooked by moist heat methods. A broiling and a new method called the prebrown-plus-oven method were used for top round of beef. Meat was prebrowned on a surface unit and then cooked rapidly until done in a 500°F oven. Taste panel scores showed a preference for the prebrown-plus-oven method. Lower cooking losses also were recorded. Differences in shear value or panel scores were not significant.

The "Roasteak" method is yet another innovation in dry heat cookery, proposed by Rodgers et al. (83). Large cuts of meat were preroasted to an internal temperature of 110°F, cooled, sliced and then broiled. A comparison of the prebrown-plus-oven and "Roasteak" methods showed top beef rounds were judged significantly more tender and higher in acceptability when cooked by the "Roasteak" method. More work needs to be done to confirm the possibilities of these new methods.

Effect of Cooking Time and Temperature on Tenderness

Tenderness changes produced by cooking can be better explained by the interaction of both time and temperature. Low roasting temperatures and long cooking periods result in meat that is very tender. But high temperatures and short cooking intervals, as in the case of broiling or the Rodgers prebrown-plus-oven method, also produce acceptable tenderness. The interaction between time and temperature helps to explain the wide variation in tenderness resulting from different cooking methods.

Bard and Tischer (6) in studying canned beef found that tenderness was proportional to processing temperature. The time to reach minimum shear at each temperature appeared to be related to the temperature used.

Variations in cooking rate and temperature are greater in large cuts of meat such as roasts. Marshall et al. (58) in using 10 pound roasts, noted temperature differences within the same roast that were as high as 60°F at different positions. Hunt et al. (48) also noted variations in heat penetration. In order to minimize temperature fluctuations within a piece of meat Tuomy, Lechnir and Miller (89) used cylinders that were 1 1/2 inches square and 8 inches long, and found that rapid temperature changes occurred throughout the mass. A wide range of cooking intervals up to 7 hours and temperatures of 140°, 160°, 180°, 190°, 200°, and 210°F were used. Toughening increased as temperatures increased. When meat was held below 180°F or 82°C, tenderness of the cooked meat depended on temperature with time having little or no effect. At temperatures of 180°F or above the meat became tender at a rate and to a degree dependent on both time and temperature. Tenderness at any given temperature and time was influenced by the inherent tenderness due to biological differences.

Machlik and Draudt (56), using smaller cylinders (1.2 inch in diameter and 2 inches long) from beef semitendinosus muscle, heated samples for intervals up to several hours at temperatures ranging from 50° to 90°C. A marked decrease in shear was noticed, and after 11 minutes at 58°C half the change was completed. Change in shear was found to be related to both time and temperature. The first part of the reaction was considered a manifestation of collagen shrinkage because it occurred quickly and was highly dependent on temperature. Other changes would be due to protein denaturation of the muscle fibres. Because proteins differ in composition and reaction the hardening reaction also would take place at different temperatures as different proteins were precipitated. The effect of changes due to hardening of the proteins were not marked because temperatures were not very high. The tenderness changes and temperature range over which they took place are shown in Table VII.

TABLE VII

CHANGE IN SHEAR TENDERNESS WITH TIME AND TEMPERATURE

	Temperature Range	Shear Values
	50 - 54°C	High shear values.
Collagen shrinkage reaction	55 - 56°C	Change in shear due to collagen shrinkage.
	57 - 59°C	Shrinkage reaction essentially complete in one hour.
	60 - 65°C	Shrinkage reaction substantially completed after 15 minutes or less. Little evidence of hardening in shear pattern even after 5 hours heating.
	66 - 70°C	Hardening substantial in 1 1/2 to 1 hour.
	71 - 75°C	Hardening reaction rapid and complete in 30 minutes.
Hardening associated with muscle fibre proteins	76 - 79°C	Trend to decrease in shear after extended heating.
	80 - 90°C	Collagen shrinkage and protein hardening completed in a few minutes of heating. Shear values decline at substantial rate during heating.

Machlik and Draudt (56)

Electronic Cookery

Effects of electronic cookery on meat tenderness are not completely understood. Only a limited number of reports are available and results are not always consistent. The great speed of cooking in this method may provide further information about the time-temperature effect. The manner in which heat penetrates by microwave is largely dependent on mass, and it is suggested that portions should be compact and as square as possible (4).

Temperature fluctuations during cooking were reported by Noble and Gomez (62). A standing period seemed necessary after cooking to equalize heat. Removal time was found to be difficult to estimate. Lamb roasts cooked evenly to a uniform grey colour. Apgar et al. (3), however, reported slight differences in surface colour between pork roasts cooked conventionally and electronically. No significant differences in palatability including tenderness were noted. But Marshall (57) in a comparison of conventionally and electronically cooked beef roasts reported less tenderness in the electronically cooked roasts.

In summary, to group research findings into specific recommendations about cooking for the best degree of tenderness is difficult because no clear-cut answer is available. Only a few of the many research articles have been mentioned, but even on this basis it can be seen that results are not always consistent. Because of differences in test methods for evaluating tenderness and in the type of animal, as well as cut of meat, some variation will be noted. Cooking methods as well require further standardization.

Explanations of tenderness on the basis of amount of exercise undergone by the animal and the amount of connective tissue present no longer completely explain the situation. The old rules about moist heat applied strictly for less tender cuts and dry heat for tender cuts are oversimplified and much too general.

EXPERIMENTAL METHOD

Meat was obtained from eight steers raised under similar feedlot conditions by the Department of Animal Science at the University of Manitoba. The animals were eighteen month old Hereford steers that had been on a finishing diet for 130 days. After slaughter and processing grading was done by a government inspector. All carcasses were classified as Canada Choice.

The femoris rounds were dissected to remove the biceps femoris (see Figure 1). After storing overnight in a refrigerator at 10°C, the muscles were divided into two similar lengthwise portions to ensure identical muscle conformation in both halves. The thirty-two roasts ranging in weight from four to five pounds were wrapped in heavy aluminum foil, frozen and maintained at approximately -15°C for three months.

The roasting was begun at three different initial temperatures:

(a) room temperature (internal temperature of 20°C)

(b) refrigerator temperature (internal temperature of 10°C)

(c) frozen (internal temperature of o°C)

Roasts started at room temperature were thawed out of the refrigerator for 24 hours; the roasts started at refrigerator temperature were held for 18 hours at room and 6 hours at refrigerator temperature; while the frozen roasts were removed one hour prior to cooking. Portions of raw meat ranging in weight from 20 to 80 grams were removed and ground for determination of pH with a Beckman pH meter and water imbibition by the modified J.H. Hall method, described by Doty and Pierce (see Appendix A).

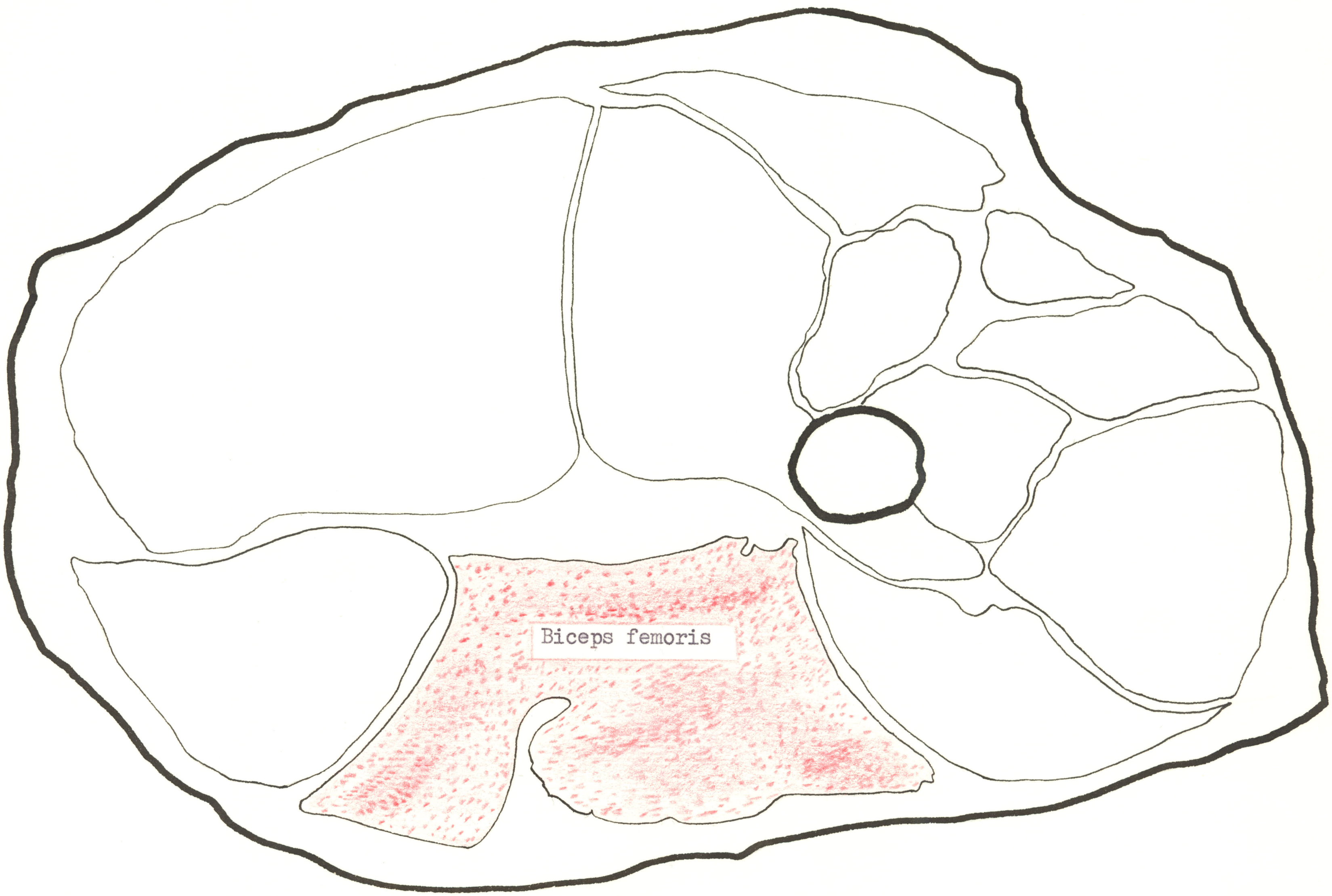


FIGURE 1.   LOCATION OF BICEPS FEMORIS WITHIN BOTTOM ROUND

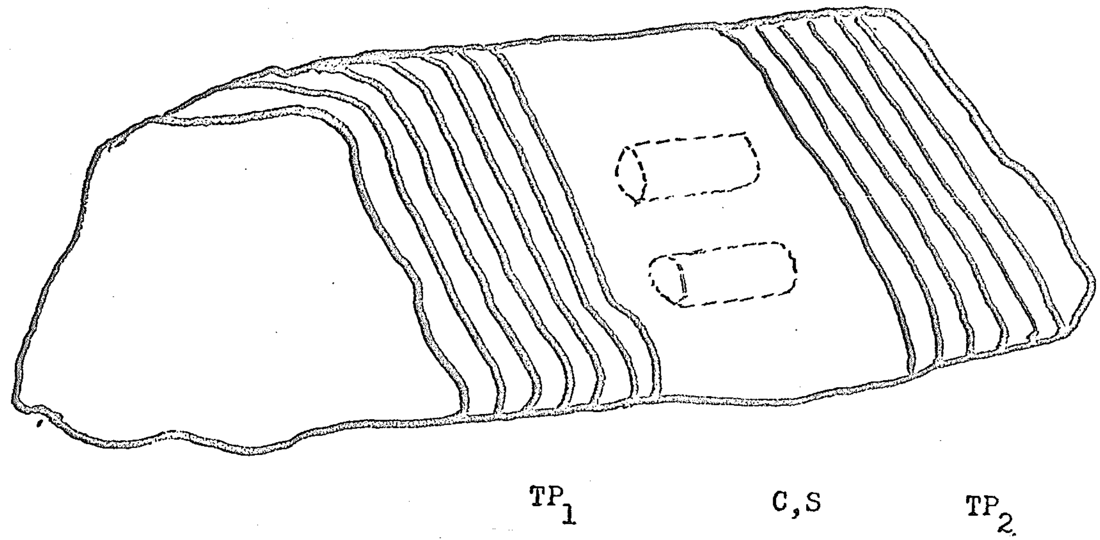
Two types of ovens were used. Conventional gas ovens were maintained at constant temperatures of 300°F, until the desired internal temperature was reached. An electronic oven was also used for cooking of a smaller number of roasts. A "low" setting was used without the browning unit.

The roasts were cooked to two different internal temperatures approximating rare and well done, by a dry heat and a moist heat method. Roasting by dry heat was done to internal temperatures of 60°C (140°F) and 80°C (176°F). Pot roasting in a foil-covered pan with added moisture (236 grams of water) was done to internal temperatures of 80°C (176°F) and 100°C (212°F). Each roast was placed fat side up on a rack in an enamel roasting pan and cooked until the specified internal temperature was reached. Thermometers were inserted in the middle of the roast and 1 1/2" from each end, to one-half the depth of the roast. Temperatures were recorded at ten minutes intervals except for the portion of the experiment where cooking was done in the electronic oven and temperatures were recorded at one minute intervals.

The roasts were weighed before and after cooking. Cooking losses in terms of drip, evaporation, and shrinkage were calculated.

Meat was cooled and stored overnight (for 16 hours) before being judged by a taste panel of five members of the Foods and Nutrition Department. After trimming away 1 1/2" slices from both ends, opposite ends of the roast were sliced by a hand-operated meat slicer to a thickness of 3/8". Meat samples were presented in random order, each judge always receiving portions from the same section of each roast. Samples were scored for tenderness on a seven-point scale, ranging from very tough to very tender, and including muscle fibre and connective tissue components as well as a tenderness composite and a chew count rating. See Figure 2 for division of the roast for taste panel and chemical and physical tests.

The central section of the roast was removed for cores used in shear tests. Two cores, 1 inch in diameter and 1 1/2 inches long were removed from each roast for testing by a Warner-Bratzler shear. The remaining portion of the meat was frozen for collagen and moisture determinations. Collagen levels after cooking were measured by chemical analysis according to the Lowry, Gilligan and Katersky method (see Appendix B). Samples were dried to constant weight by the A.O.A.C. method (64).



TP_1 - portions for taste panel rating.

TP_2 - portions for taste panel rating.

C,S - portions used for collegen and shear tests.

FIGURE 2. DIVISION OF ROAST FOR TASTE PANEL AND PHYSICAL AND CHEMICAL TESTS.

DISCUSSION OF RESULTS

The biceps femoris muscle was chosen for this study because it is one of the less tender cuts. Although it may be cooked by both "dry" and "moist" heat methods, the addition of moisture is usually recommended because of the large amount of connective tissue present. Changes in tenderness resulting from degradation of collagen as a result of cooking method should be readily noted in this muscle.

The raw weight of the biceps femoris roasts varied from 5.6 to 2.8 pounds. Although the meat was obtained from steers of similar genetic background and raised under identical conditions, some degree of variability between muscles from different animals was noted. This difference included some variation in size and shape, and slight dissimilarity in the fineness of the muscle fibres and extent and distribution of connective tissue.

Moisture Losses During Freezing

Some moisture losses occurred during freezer storage and preparation for cooking. Weight losses ranged from 0.06 per cent to 8.77 per cent of the original weight. Weighing of the meat was done immediately before cooking, and some loss recorded as a moisture loss in freezing and thawing may actually have been due to drip losses, although attempts were made to keep these to a minimum. The roasts were kept wrapped during thawing to lessen evaporation losses. Variations in moisture loss were probably due to differences in the size and shape of the roasts, in the length of freezer storage time, and/or in the effectiveness of the foil wrap.

Moisture losses that occurred previous to roasting are shown in Table VIII. Mean values for moisture loss were very similar at 4.13, 3.05 and 3.60 per cent for roasts in the frozen state, thawed to refrigerator temperature and thawed to room temperature before cooking, respectively. There appeared to be no relationship between weight of the roast and evaporation losses.

TABLE VIII

MOISTURE LOSS DURING FREEZER STORAGE AND PREPARATION FOR COOKING

Temperature of Meat before Cooking	Number of Samples	Percentage Moisture Loss		
		High	Low	Mean
Frozen	10	7.50	1.32	4.13
Refrigerator	12	5.38	0.06	3.05
Room	10	8.77	0.44	3.60

Cooking Losses

Average losses in the form of evaporation and drippings are shown in Table IX. Both evaporation and dripping losses increased with longer cooking. Total losses ranged from 49.68 to 7.57 per cent. When roasts cooked by moist and dry heat methods to the same internal

TABLE IX

MEAN VALUES FOR PERCENTAGE EVAPORATION AND DRIP LOSSES IN FOUR COOKING METHODS

Temperature of Meat before Cooking	Dry Heat						Moist Heat					
	60°C			80°C			80°C			100°C		
	Evap.	Drip	Total	Evap.	Drip	Total	Evap.	Drip	Total	Evap.	Drip	Total
Room	15.3	3.6	18.8	21.6	5.2	26.8	25.8	17.9	43.7	27.1	19.7	46.8
Refrigerator	13.2	2.9	16.1	26.1	6.3	32.4	28.0	18.8	46.8	29.9	18.7	48.6
Frozen	6.8	0.8	7.6	15.1	7.5	22.6	23.2	20.0	43.2	24.5	21.2	45.7

temperature were compared, both drippings and evaporation losses were noticeably higher for moist heat. The added moisture could account for part of the increase in the total and dripping losses, but evaporation losses were also somewhat greater in spite of the covering used on the roasting pan.

Figure 3 gives a graphic illustration of differences in cooking losses due to method and initial temperature. Total cooking losses for room and refrigerator roasts were fairly similar with mean values at 34.0 and 35.9 per cent. The cuts roasted in the frozen state had slightly lower cooking losses of 29.1 per cent. The major part of the difference in cooking losses was due to smaller evaporation losses in the frozen roasts.

Moisture content in the cooked meat was related to cooking method and length of cooking time. Moisture losses, calculated as a percentage of the original cooked weight, ranged from 66.83 to 53.58 per cent. Mean values according to cooking method were as follows: 64.35 per cent for dry heat to an internal temperature of 60°C, 62.54 per cent for dry heat to 80°C, 60.52 per cent for moist heat to 80°C and 57.63 for moist heat to 100°C.

The percentage shrinkage or weight losses of the meat after cooking is found in Table X. In all cases shrinkage increased with longer cooking. For example, refrigerator roasts lost 11.4 per cent roasted to 60°C, and 28.5 per cent roasted to 80°C. There was approximately twice as much shrinkage in roasts cooked by dry heat to 80°C as in those cooked to 60°C.

Shrinkage losses by the moist heat method were similar, ranging from 27.8 to 34.3 per cent, regardless of degree of cooking or initial

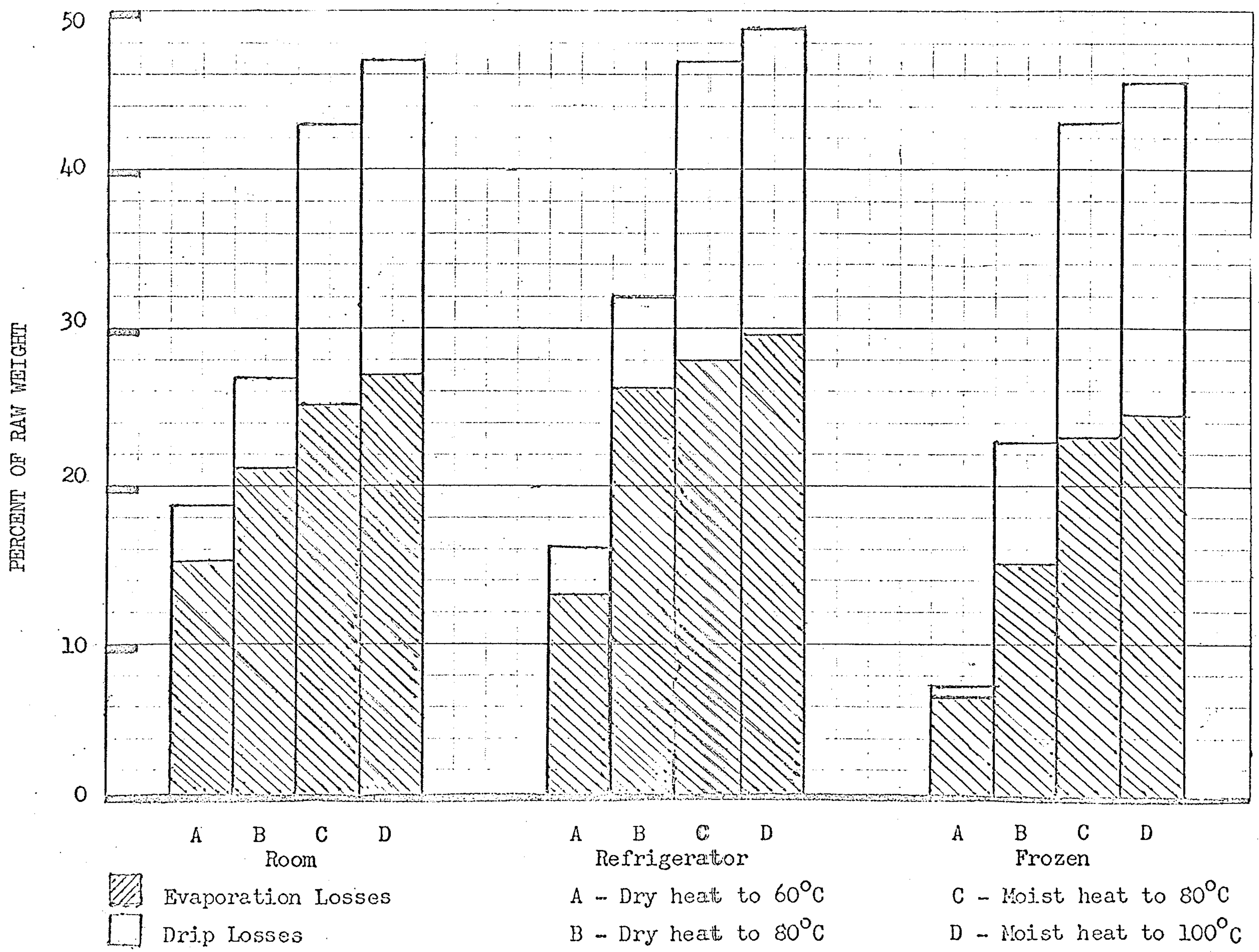


FIGURE 3. PERCENTAGE COOKING LOSSES DUE TO EVAPORATION AND DRIP AT THREE INITIAL TEMPERATURES AND FOUR METHODS OF COOKING.

TABLE X

MEAN VALUES FOR PERCENTAGE SHRINKAGE

OF MEAT DURING COOKING

Temperature of Meat before Cooking	Dry Heat Method		Moist Heat Method	
	60°C	80°C	80°C	100°C
Room	24.4	47.9	29.4	33.3
Refrigerator	11.4	28.5	32.7	34.3
Frozen	4.5	18.7	27.8	28.7

temperature. By dry heat methods there was greater variation in the amount of shrinkage (4.5 to 47.9 per cent). The initial temperature influenced percentage shrinkage for the meat cooked without added moisture, and was least for frozen and highest for room temperature roasts.

Lowe and Kastelic (53) reported average weight losses for the biceps femoris of 32.8 per cent and 24.4 per cent for roasts cooked to internal temperatures of 90°C and 70°C respectively. Temperatures of 60°C and 80°C in this study resulted in weight losses of 11.38 per cent and 28.50 per cent. Estimating shrinkage for a temperature midway between those used by Lowe and Kastelic gives a figure of 28.6 per cent at 80°C, which is close to the figure of 28.5 per cent for the present study. Hunt, Seidler and Wood (48) report higher total cooking losses of 38.5 and 50.9 per cent for ten pound roasts cooked to internal temperatures of 60°C and 80°C, compared with 11.4 and 28.5 per cent for smaller roasts in the present study. The temperature of the meat before cooking was found to influence cooking time. Frozen roasts required longer cooking in all cases. Where the internal temperature was highest initially (the room temperature roasts) cooking time was shortest. Frozen roasts required 163 minutes to reach 60°C, while refrigerator roasts reached that temperature in 103 minutes, and only 76 minutes were required by those started at room temperature. Cooking rates in these instances were 35.4, 25.2, and 16.7 minutes per pound for frozen, refrigerator, and room temperature roasts respectively. This difference, due to initial temperature of the meat, occurred with each of the cooking methods.

When different internal temperatures within a cooking method were compared, a longer time was required to reach the higher temperature. Refrigerator-thawed roasts cooked to 60°C in 103 minutes (25.2 minutes per pound) but required 193 minutes (40.3 minutes per pound) to reach 80°C.

Cooking was more rapid when moisture was present. Heat was conducted more quickly in a moist medium and the rate of heat penetration was faster. Refrigerator-thawed roasts reached 80°C at a rate of 40.3 minutes per pound when roasted uncovered, but when covered with added moisture the rate decreased to 26.8 minutes per pound.

Paul, Bratzler and Knight (66) reported biceps femoris roasts cooked at 325°F to 63°C at a rate of 37.4 minutes per pound. Hunt, Seidler and Wood (48) found that 10 pound top round roasts cooked at 23.8 minutes per pound to an internal temperature of 60°C, and at 43.1 minutes per pound to 80°C. Comparable cooking rates of 25.2 minutes per pound, and 40.3 minutes per pound were obtained in the present study for temperatures of 60°C and 80°C respectively.

Time and Rate of Cooking

Mean values for total cooking time in minutes, and rate of cooking in minutes per pound for twenty-six roasts are summarized in Table XI.

TABLE XI

TOTAL COOKING TIME AND RATE OF COOKING BY DRY AND MOIST HEAT METHODS AS AFFECTED BY INITIAL TEMPERATURE

Temperature of Meat before Cooking	Total Cooking Time (Min)				Cooking Rate (Min/Pound)			
	Dry Heat		Moist Heat		Dry Heat		Moist Heat	
	60°C	80°C	80°C	100°C	60°C	80°C	80°C	100°C
Room	76	160	108	170	16.7	37.3	24.7	38.6
Refrigerator	103	193	105	168	25.2	40.3	26.8	43.2
Frozen	163	214	156	214	35.4	49.7	38.3	50.4

The rate of heat penetration within roasts cooked by dry and moist heat is illustrated in Figures 4, 5 and 6. Figure 7 shows mean values for heat penetration as influenced by initial temperature and cooking method. Heat penetration took place at a much faster rate in a moist medium than in a dry medium. Heat penetration curves by moist heat rise more sharply than do those for dry heat.

The degree of thawing before cooking also affected heat transfer. Roasts in the frozen state required much longer to heat up, and only after 60 minutes did the temperature curves begin to rise. The level of the heat penetration in frozen roasts cooked by dry heat never did reach that of the refrigerator or room temperature roasts, and cooking

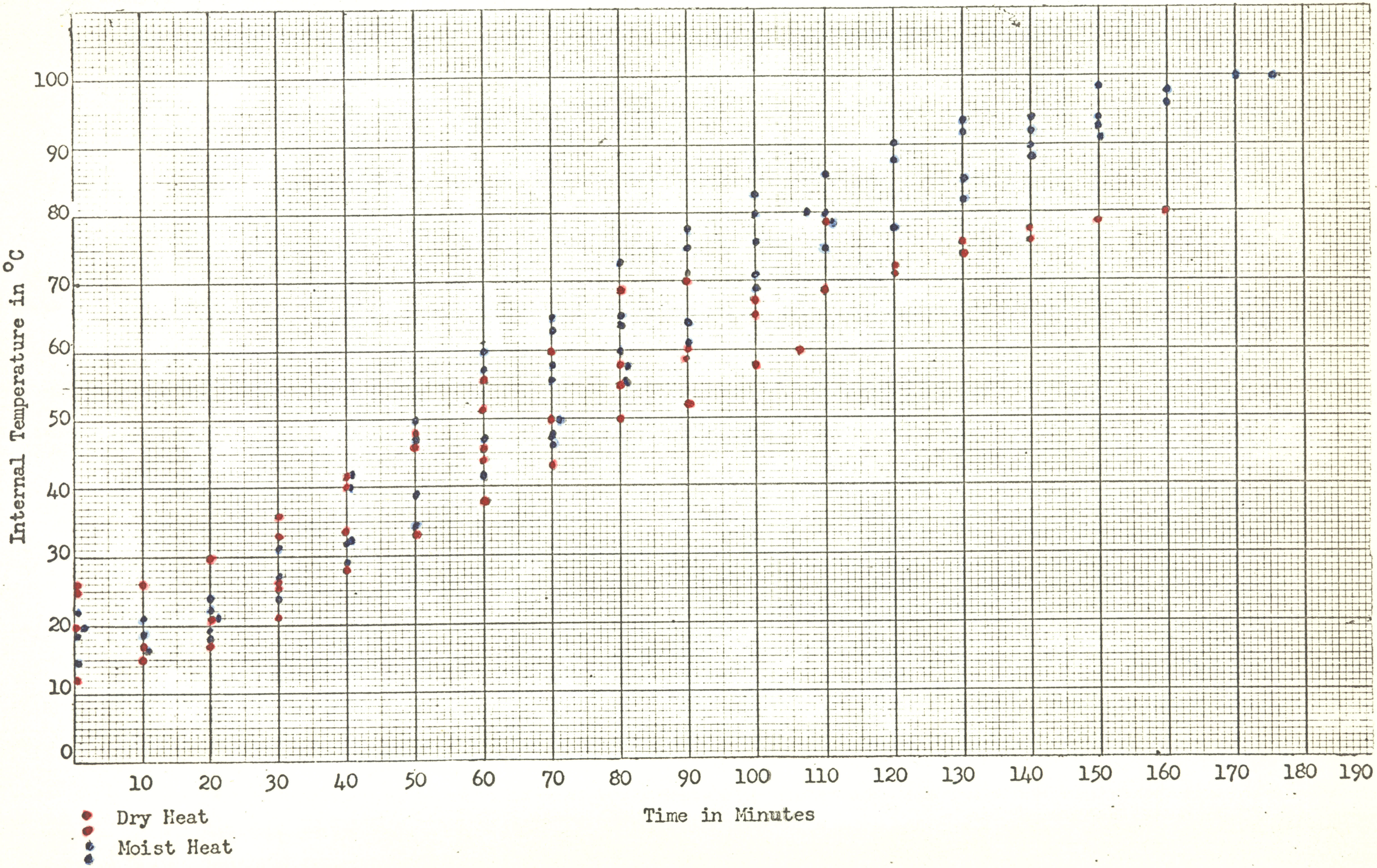


FIGURE 4. SCATTER GRAPH FOR RATE OF HEAT PENETRATION OF INDIVIDUAL ROASTS STARTED AT ROOM TEMPERATURE DURING COOKING BY MOIST AND DRY HEAT

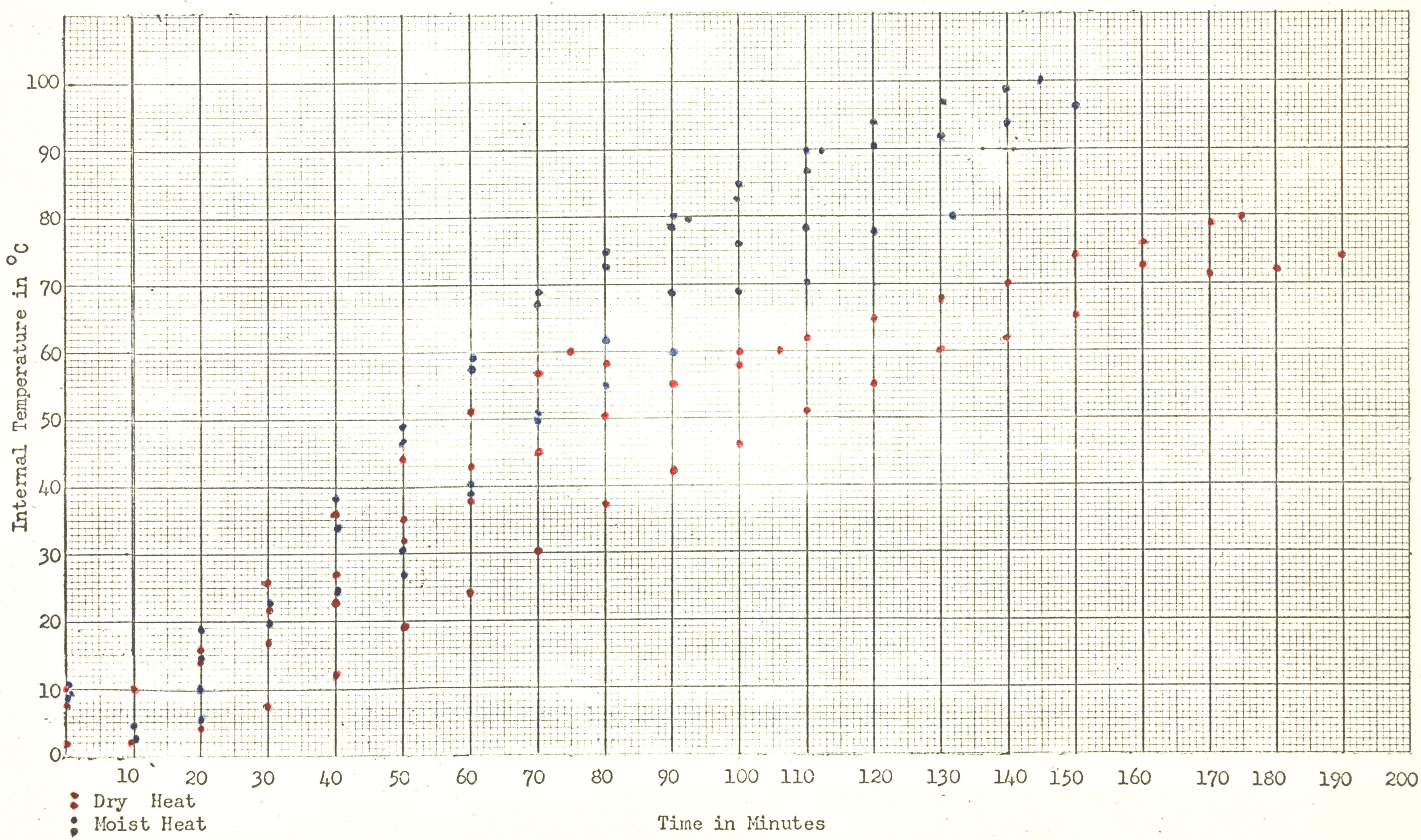


FIGURE 5. SCATTER GRAPH FOR RATE OF HEAT PENETRATION OF INDIVIDUAL ROASTS STARTED AT REFRIGERATOR TEMPERATURE DURING COOKING BY MOIST AND DRY HEAT.

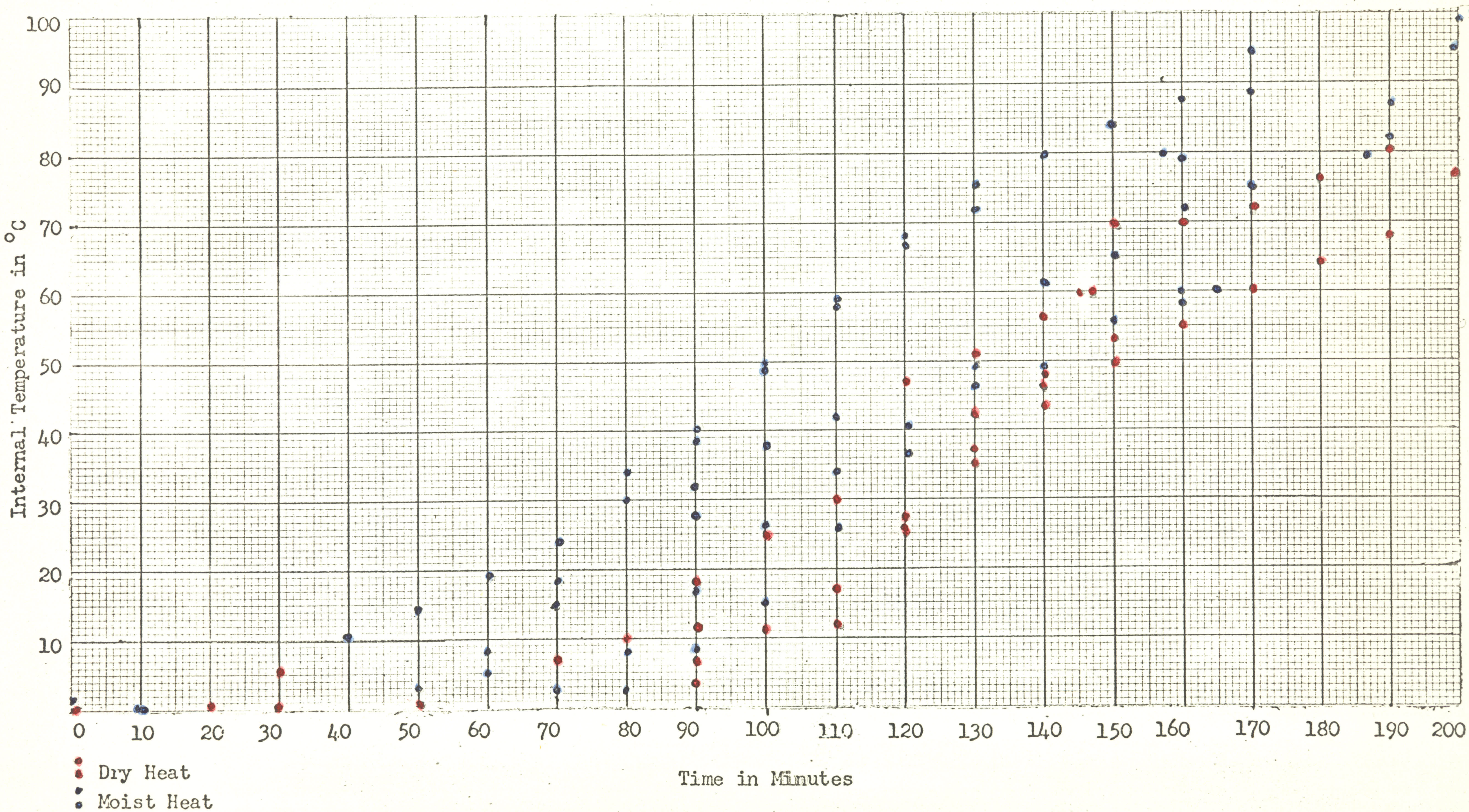


FIGURE 6. SCATTER GRAPH FOR RATE OF HEAT PENETRATION OF INDIVIDUAL ROASTS STARTED FROZEN DURING COOKING BY MOIST AND DRY HEAT.

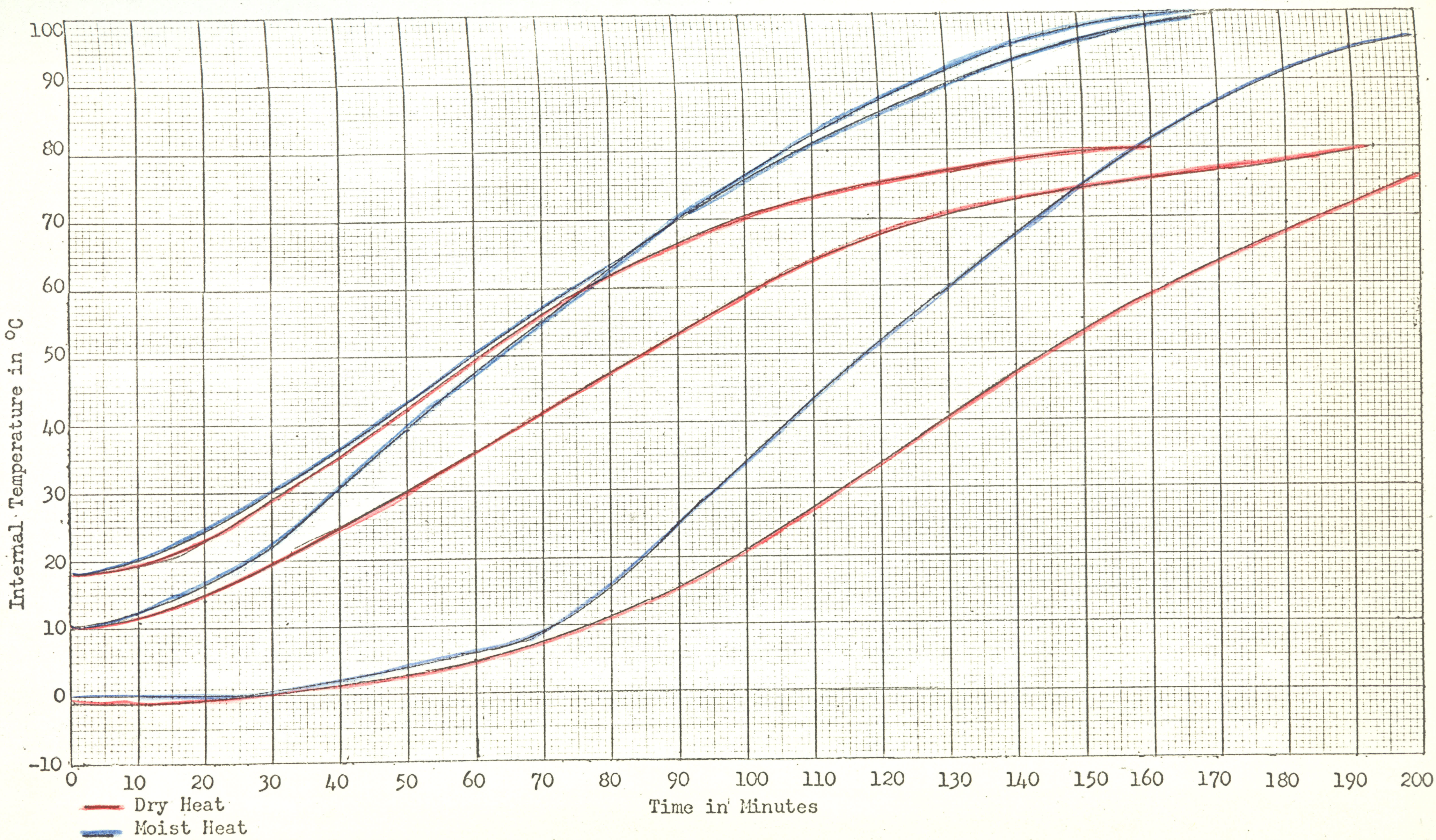


FIGURE 7. MEAN VALUES FOR RATE OF HEAT PENETRATION IN ROASTS STARTED AT THREE INITIAL TEMPERATURES DURING COOKING BY MOIST AND DRY HEAT.

time to reach the desired internal temperature was, as pointed out earlier, considerably longer. Differences in heat transfer were not as great between room and refrigerator temperature roasts. While heat penetration for the refrigerator-thawed roasts was lower to begin with, temperature soon rose and heat penetration was almost at the same level as by moist heat methods. The dry heat methods for room and refrigerator temperatures showed almost parallel increases, although the room temperature roasts were always at a higher level in this study.

Cover (22) has stated that a marked flattening of the heat penetration curve is accompanied by greater tenderness of the meat. For broiled steaks cooked to the well-done stage she found that the greatest flattening of the curve took place between 65°C and 80°C. In this study there appears to be a similar flattening for roasts cooked by dry heat between 60°C and 80°C.

pH and Moisture

The pH values for the raw meat varied only slightly and did not appear to be related to any tenderness factor. The range of values was 5.5 to 6.6 with a mean of 5.6.

The amount of water imbibed by raw meat varied from 1 to 8 ml. per 5 grams of meat, with a mean value of 3.6 ml. There appeared to be little relationship between water imbibition of raw meat and tenderness or juiciness after cooking.

Shear Strength Measurements

Shear strength values register the number of pounds required to shear through a cylinder of meat. Tough meat offers greater resistance to shear, and therefore high shear values are associated with less tender meat, while low shears are an indication of tender meat. In this study one inch cylinders of cooked meat were used for shear strength measurements.

Means for shear values obtained in this study are shown in Table XII.

TABLE XII

MEAN SHEAR STRENGTH VALUES OBTAINED FOR FOUR COOKING METHODS AND THREE INITIAL COOKING TEMPERATURES

Temperature of Meat before Cooking	Dry Heat		Moist Heat	
	60°C	80°C	80°C	100°C
Room	17.88	17.44	15.50	9.76
Refrigerator	22.19	17.57	14.19	11.19
Frozen	26.50	19.94	20.00	15.32
Mean for all conditions	22.18	18.31	16.56	12.08

Tenderness shown by decreasing shear strength values progressively increased with longer cooking (higher internal temperature) and was greater for meat cooked by moist heat than that done by dry heat methods. Mean values for dry to 60°C, dry to 80°C, moist to 80°C, and moist to 100°C were 22.18, 18.31, 16.56, and 12.08 respectively. Though not significantly different, the means gave some indication of a tenderness trend, particularly between dry and moist heat methods. Cuts roasted to 60°C gave shear values of 22.18 pounds, but meat was more tender roasted to 80°C with a shear of 18.31 pounds. Cooking to 80°C with added moisture resulted in a mean shear of 16.56 pounds with a range of 21.75 to 12.88. Roasting to 80°C by dry heat gave a mean shear of 18.31 pounds with a range of 20.63 to 16.13.

The analysis of variance of shear strength values can be seen in Table XIII. Both temperature condition of the meat before cooking,

TABLE XIII

ANALYSIS OF VARIANCE OF SHEAR VALUES RELATED TO COOKING METHOD AND TEMPERATURE CONDITION OF MEAT BEFORE COOKING

Source	d.f.	s.s.	m.s.	F
Conditions	2	124.331	62.165	4.06*
Methods	3	315.986	105.329	6.878**
Interaction	6	28.488	4.748	
Duplicates	12	183.757	15.313	
TOTAL	23	652.562		

** Significant at 1% level.
* Significant at 5% level.

and cooking method produced differences in tenderness that can be considered significant. The degree of thawing of the meat before cooking produced differences in tenderness which were significant at the 5 per cent level. Highly significant at the 1 per cent level and accounting for the major part of the variation were differences due to cooking method. Some shear variation occurred between duplicates due to lack of homogeneity in the meat and mechanical error in the shear.

Comparison of the shear strength results with those of other workers show reasonably close agreement, as can be seen in Table XIV. The meat in each case came from the round of beef, but since some workers used steaks while others used roasts, variation may be expected and could account for some difference in shear.

Taste Panel Ratings

Tenderness differences were detected by taste panel. The score card used was a seven point bipolar scale ranging from very tender to very tough (Appendix C). Higher figures approaching seven indicates a more desirable characteristic or degree of tenderness. Qualities rated were muscle fibre characteristics, connective tissue components and juiciness. A general score for tenderness as a composite effect was obtained. In addition the number of chews required to masticate a portion of meat, half an inch in diameter, was recorded. The taste panel ratings to be discussed are average scores of five judges. For greater uniformity in judging, individual panel members were always given samples from the same portion of each roast. Composition of the meat varied slightly between judges since a slice near the end of the roast was not identical in all respects with that closer to the centre.

The cooking method produced highly significant differences in tenderness (Table XV). There was some indication of interaction effect. The taste panel scores did not show any significant tenderness differences for temperature condition of the meat before cooking. A close agreement between paired samples indicated good reproducibility of taste panel judgments.

TABLE XIV

COMPARISON OF SHEAR VALUES FOR DRY AND MOIST HEAT COOKING METHODS

Researchers	Cut of Meat	Shear Value in Pounds*			
		Dry Heat		Moist Heat	
		60°C	80°C	80°C	100°C
Griswold, 1955 (40)	Round Steaks	-	21.2(85°C)	18.0(85°C)	-
Cover and Shrode, 1955 (19)	Bottom Round Pot Roasts	-	19.8	-	13.1
Bramblett, Hostetler, Vail and Draut, 1955 (8)	Biceps Femoris Roasts	12.4	18.88	-	-
Cover, Bannister and Kehlenbrink, 1957 (22)	Steaks Biceps Femoris	19.4	18.4	18.8	12.8
Cover and Hostetler, 1960 (25)	Bottom Round Steaks	17.8	18.0	18.0	14.8
Present Study	Biceps Femoris Roasts	22.2	18.3	16.56	12.1

* Shear force required to cut one inch cores with Warner-Bratzler shear.

TABLE XV

ANALYSIS OF VARIANCE OF TASTE PANEL SCORES FOR TENDERNESS COMPOSITE RELATED TO COOKING METHOD AND TEMPERATURE OF MEAT BEFORE COOKING

Source	d.f.	s.s.	M.S.	F
Conditions	2	0.72	0.36	3.71 N.S.
Methods	3	4.39	1.46	15.05**
Interaction	6	2.04	0.34	3.51*
Duplicates	12	1.16	0.097	
TOTAL	23	8.31		

** Significant at 1 per cent level.
* Significant at 5 per cent level.

LSD revealed values of .4 and .5 for 5 per cent and 1 per cent level of significance, respectively.

Some characteristics are largely inherent within the animal and not readily altered by cooking conditions or initial temperature. Such a characteristic is the fineness of the muscle fibre. The same muscle was used throughout the experiment and differences which were seen in muscle fibre diameter were considered to be more likely due to biological variation than to cooking effect. Scores for muscle fibre fineness ranged from 3.6 (moderately coarse) to 5.0 (moderately fine). Similarly, the amount of connective tissue present was characteristic of the individual animal, as well as the specific muscle. The biceps femoris has more connective tissue than a muscle like the longissimus dorsi in the loin.

Mean values for panel ratings of the five judges are shown in Table XVI. It appeared that fragmentation increased with cooking. The effects of moist heat to 100°C were particularly noticeable. Cover (28) has described this characteristic as a greater case of fragmentation into distinct dry particles and lessened adhesions between muscle fibres. This is particularly noticeable in the biceps femoris cooked by moist heat to temperatures of 80°C and 100°C. At temperatures of 61°C fragmentation and mealiness was not apparent, according to Cover. Longer cooking and higher temperatures would presumably result in more extensive coagulation and denaturation of muscle proteins, as well as a greater breakdown of connective tissue. Mean values for fragmentation in this study were 5.4 (moderately easily fragmented), for moist heat to 100°C, 3.9 (fragmented with slight difficulty) for moist heat to 80°C, 3.1 (slightly difficult to fragment) for dry heat to 80°C, and 2.9 (moderately difficult to fragment) for dry heat to 60°C. With the exception of the difference between dry heat roasts cooked to 60°C and 80°C, the difference in fragmentation scores were large.

Differences in the softness of muscle fibre as a result of treatment were not very great according to panel ratings. The range for individual values of 24 roasts were from 6.4 (soft) to 3.6 (slightly soft) with an average of 5.2 (moderately soft). According to four cooking methods, with six roasts in each group, mean scores were 5.2 (soft) for dry heat to 60°C, 4.2 (moderately soft) for dry heat to 80°C, 4.2 for moist heat to 80°C, and 5.2 for moist heat to 100°C.

Connective tissue was considerably softened by the cooking method. Moist heat methods are particularly effective in bringing about hydrolysis of collagen. Heat penetration takes place quickly and high temperatures

TABLE XVI

MEAN TASTE PANEL RATINGS OF FIVE JUDGES FOR PALATABILITY CHARACTERISTICS OF MEAT PREPARED BY FOUR COOKING METHODS

Score Card Component	Dry Heat		Moist Heat	
	60°C	80°C	80°C	100°C
Fragmentation of Muscle Fibre				
Room	4.0	3.7	4.0	5.9
Refrigerator	2.3	2.9	4.2	5.6
Frozen	2.4	2.8	3.5	4.7
Mean	2.9	3.1	3.9	5.4
Softness of Muscle Fibre				
Room	5.3	4.6	4.2	5.6
Refrigerator	4.8	4.4	4.3	5.2
Frozen	5.5	3.7	4.2	4.5
Mean	5.2	4.2	4.2	5.1
State or Softness of Connective Tissue				
Room	3.7	3.8	3.4	5.7
Refrigerator	3.7	3.6	4.3	5.7
Frozen	3.4	2.9	4.1	4.8
Mean	3.6	3.4	3.9	5.5
Juiciness				
Room	5.6	4.2	2.8	2.8
Refrigerator	6.7	4.2	2.6	2.6
Frozen	7.0	4.4	4.1	2.5
Mean	6.4	4.3	3.2	2.6
Tenderness Composite				
Room	5.3	5.0	4.6	6.5
Refrigerator	5.7	5.1	5.3	5.8
Frozen	5.3	4.6	5.0	5.4
Mean	5.4	4.9	4.9	5.9
Chew Count				
Room	21.0	22.1	18.0	15.3
Refrigerator	15.0	16.3	17.3	15.4
Frozen	15.4	18.7	17.0	17.5
Mean	17.1	19.6	17.4	16.3

are maintained in a moist medium. The longer cooking at moist heat brought about the greatest change of collagen to gelatin. The mean values for softness of connective tissue by four cooking methods and internal temperatures (six roasts in each category) were 3.6 (slightly soft) for dry heat to 60°C, 3.4 (moderately hard) for dry heat to 80°C, 3.9 (slightly soft) for moist heat to 80°C, and 5.5 (soft) for moist heat to 100°C.

Greater juiciness was retained with low cooking temperatures and is characteristic of meat cooked to the rare stage of doneness. Roasting to an internal temperature of 60°C required a shorter time than roasting to 80°C. Meat cooked by dry heat to 60°C had a mean score of 6.4 (juicy) while that done by dry heat to 80°C had a lower juiciness score of 4.3 (moderately juicy). Moist heat methods produced greater dryness. Panel scores were 3.2 (moderately dry) at 80°C by moist heat and 4.3 (slightly juicy) by dry heat at the same temperature. Moist heat cooking to 100°C resulted in the greatest degree of dryness, as shown by a score of 2.6 (moderately dry). Moisture losses for cooked meat dried to constant weight gave similar results.

The tenderness composite was the score related to the general, or overall impression of tenderness. Cooking by moist heat to 100°C resulted in the highest tenderness rating, significant at the 1 per cent level with a mean score of 5.9 (tender); next in tenderness was the roast cooked by dry heat to an internal temperature of 60°C, with a score of 5.4. Scores for dry and moist heat methods at the same internal temperature (80°C) were not significantly different with 4.9 and 5.0 (moderately tender) respectively. An LSD value of 0.5 at the 1 per cent level and 0.4 at the 5 per cent level was obtained.

Cover's approach to tenderness scoring by partitioning it into numerous components appears to have value. Subtle variations in tenderness can be revealed in scores for individual components. The general tenderness impression is influenced by both muscle fibre and connective tissue factors. With a single score the general impression is registered, but there is no way of distinguishing the effect produced by muscle fibre hardening from connective tissue softening. In most cases, changes occur in both constituents, but one effect will usually be dominant. The attempt to relate tenderness change to a specific constituent helps to increase understanding of the complex nature of tenderness.

The chew count score is considered to be a fairly objective type of measurement using taste panel judges. Analysis of variance of the chew count (Table XVII) revealed no significant differences as a result

TABLE XVII

ANALYSIS OF VARIANCE OF CHEW COUNTS RELATED TO COOKING METHOD AND INITIAL TEMPERATURE OF THE MEAT

Source	d.f.	s.s.	m.s.	F
Conditions	2	43.10	21.55	2.63 N.S.
Methods	3	24.28	8.09	.98 N.S.
Interaction	6	41.83	6.97	.85 N.S.
Duplicates	12	98.15	8.18	
TOTAL	23	207.36		

of cooking method or initial temperature. It was noted that there was large individual variation among panel members in chews required to completely masticate a sample. It appears that the chew count does not distinguish tenderness differences which were revealed by other methods.

Intramuscular Variation

The biceps femoris is known to have some within-muscle variation. It has larger deposits of connective tissue at the origin than the insertion end of the muscle. During the experiment the roasts were observed to have consistently larger amounts of connective tissue in the form of heavy strands at one end. The most suitable samples for taste panel judging were obtained from the other end of the muscle, and the resulting scores were used for analysis of variance of taste panel scores and for the mean comparisons made in Table XVI. Since the size of the roasts permitted a duplication of test samples, it was decided to rate samples from the sinewy end of the roast. Average scores for the amount of connective tissue at opposite ends of the roasts did not reveal any differences. The mean value for amount of connective tissue in the meaty end of 24 roasts was 4.23 compared with 4.28 at the sinewy end. The judges were perhaps more concerned with the nature of the connective tissue surrounding muscle fibres and may have paid less attention to the large strands that were present.

Table XVIII gives a comparison of panel ratings for different parts of the muscle, and shows very close agreement between the two judgments. Similar trends can be seen throughout the characteristics rated for the two ends of the muscle. A "t" test calculated for those means where the differences were large revealed no significant differences.

TABLE XVIII

MEAN TASTE PANEL RATING FOR VARIOUS TENDERNESS COMPONENTS OBTAINED FROM OPPOSITE ENDS OF BICEPS FEMORIS ROASTS

Score Card Component	Dry		Moist	
	60°C	80°C	80°C	100°C
Fragmentation				
End A	2.9	3.1	3.9	5.4
End B	3.2	4.3	4.2	5.2
Mean	3.1	3.7	4.0	5.3
Softness				
End A	3.6	3.4	3.9	5.5
End B	4.6	4.8	5.0	5.3
Mean	4.1	4.1	4.5	5.4
State of Connective Tissue				
End A	3.6	3.4	3.9	5.5
End B	4.6	4.8	5.0	5.3
Mean	4.1	4.1	4.5	5.4
Juiciness				
End A	6.4	4.3	3.2	2.6
End B	6.0	4.7	3.3	3.0
Mean	6.2	4.5	3.2	2.8
Tenderness Composite				
End A	5.4	4.9	4.9	5.9
End B	5.8	5.3	5.2	5.8
Mean	5.6	5.1	5.0	5.9
Chew Count				
End A	17.1	19.0	17.4	16.3
End B	17.6	18.6	17.7	17.0
Mean	17.4	18.8	17.6	16.7

Scores for the tenderness composite from both the meaty and sinewy ends of the roasts were correlated. The resulting correlation coefficient was +.61 indicating some positive relationship. A muscle that was more uniform in composition would undoubtedly have shown a higher degree of correlation.

Roasts Cooked in the Electronic Oven

When an electronic oven became available toward the latter part of the study the experimental design was modified to include this method of cooking. A total of six roasts were cooked by microwave energy at two initial temperatures, refrigerator and frozen, and by moist and dry heat methods.

Noble and Gomez (62) in roasting lamb reported difficulty in estimating doneness. In the present study the same difficulty was encountered and there was some trouble estimating the degree of doneness and removal time. Since a specially designed thermometer for the electronic range was not available, the type of Centigrade glass thermometer used was the same as for the other part of the study. Preliminary experimentation revealed that the small amount of metal at the top of the thermometer did not produce arcing or interfere with operation of the oven. Attempts were made to cook the roasts to the same internal temperatures as previously reported. Even though the thermometer recorded the correct internal temperature the meat in all cases was underdone. Cooking took place unevenly, the surface was not browned and a central core of meat remained completely raw. These results then are not comparable with roasts cooked to the same internal temperature in the conventional gas oven. Noble and Gomez reported that lamb roasts cooked evenly and were uniformly grey inside with a lightly browned surface. Longer cooking time would have resulted in a greater degree of doneness in the present study.

Cooking losses ranged from 6.47 to 42.99 per cent of the raw weight before cooking. The same general trends as noted for conventional cookery were observed in electronic cooking. Losses tended to be higher with moist heat and the roasts started in the frozen state had lower cooking losses than those started at refrigerator temperatures. Cooking losses increased with longer cooking time. Four roasts started at refrigerator temperatures showed cooking losses of 7.93 per cent with roasting by dry heat to 60°C, 17.59 per cent with roasting by dry heat to 80°C and 42.99 per cent by moist heat to 100°C. Two frozen roasts cooked by dry heat to 60°C and by moist heat to 80°C lost 6.47 and 22.99 per cent in the form of evaporation and drip losses. On the whole electronically cooked roasts appeared to have slightly lower cooking losses than conventional cookery, but this was probably related to the extent of cooking which hardly progressed beyond the rare stage.

A comparison of refrigerator-temperature roasts cooked in gas and electronic ovens is shown in Table XIX. Cooking time was less in the electronic oven but, as mentioned before, the degree of doneness was not comparable with that of the conventionally cooked roasts. Total cooking times required for refrigerator roasts, according to cooking method, were 7 minutes by dry heat to 60°C, 13 minutes by dry heat to 80°C, 11 minutes by moist heat to 80°C and 19 minutes for moist heat to 100°C. Two frozen roasts cooked in 13 minutes by dry heat to 60°C and 16 minutes by moist heat to 80°C. Noble and Gomez reported varying cooking times with different roasts with an average rate of 6 minutes per pound.

TABLE XIX

COMPARISON OF ELECTRONICALLY AND CONVENTIONALLY ROASTED MEAT*

Characteristic	Dry Heat		Moist Heat	
	60°C	80°C	80°C	100°C
Cooking Rate (min/lb.)				
Gas	25.50	40.30	26.80	43.20
Electronic	.62	.35	.38	.21
Shear Force (lbs.)				
Gas	15.0	16.3	17.3	15.4
Electronic	20.6	19.6	20.8	18.4
Panel Scores				
(a) Tenderness Composite				
Gas	5.0	5.6	5.2	5.2
Electronic	5.7	5.1	5.3	5.8
(b) Chew Count				
Gas	20.5	19.6	20.8	19.4
Electronic	15.0	16.3	17.3	15.4

* Stages of doneness are not strictly comparable since there were undercooked sections in the meat cooked in the electronic oven.

Shear force values were higher for meat cooked electronically because the meat was not done as well and offered more resistance to shear. The difference is probably due more to stage of doneness and less to the effect of type of oven. Refrigerator-thawed roasts cooked in gas and electronic ovens by four cooking methods had shear values of 15 to 17.3 in gas oven and 18.4 to 20.8 in electronic oven.

Panel members found it unpleasant to score the electronically cooked samples because of the underdone areas. Tenderness composite and chew count scores for refrigerator-thawed roasts indicated lower tenderness values for the electronically cooked roasts.

Much remains to be learned about roasting meat in the electronic oven. The advantages of great speed of cooking are minimized with large masses of meat like the five pound roasts used in this study. Meat cookery in the electronic oven has not advanced much beyond the trial and error stage, although acceptable results for electronically cooked roasts have been reported by some workers (3, 57, 62). Cooking time for small amounts of meat, like hamburger patties, can be closely regulated to obtain the desired degree of doneness.

Chemical Test for Collagen

Table XX shows the percentage collagen determined in the cooked meat. Within each cooking method considerable variability was found,

TABLE XX

COLLAGEN CONTENT OF MEAT SAMPLES COOKED BY FOUR METHODS

Cooking Method	Number of Samples	Percentage Collagen Dry Weight Basis*	
		Mean*	Range of Values
Dry heat to 60°C	10	2.77	1.6 - 3.9
Dry heat to 80°C	8	1.13	0.4 - 3.1
Moist heat to 80°C	5	0.48	0.1 - 1.4
Moist heat to 100°C	8	2.79	0.9 - 4.7

* Some evaporation loss on standing was not accounted for in total moisture loss, so that relative values may be somewhat high.

due in part to muscle variations and to differences between animals. Greater similarity was noted between paired samples than between animals.

Mean values appeared to show a trend toward lowered collagen with increased cooking and added moisture for dry heat to 60°C and 80°C, and for moist heat to 80°C. Mean collagen level of moist heat roasts cooked to 100°C was high. These samples were cooked the longest time and the proteins present presumably would be denatured to a greater extent affecting their solubility. Ritchey and Cover (79) point out that some proteins other than collagen which are insoluble in alkali may become soluble during autoclaving altering collagen values. Griswold and Leffler (39) state that apparent gains in collagen on cooking may be due to the decomposition of non-collagen proteins during autoclaving.

A comparison of results obtained by the gravimetric method used in this study with those of other workers is shown in Table XXI. The results obtained in this study, 1.68 per cent dry weight basis, compare quite closely with those of Griswold and Leffler's (39) who obtained a value of 1.39 per cent. Smith and Cover (20) reported 1.56 per cent collagen content in the longissimus dorsi muscle of the round.

While the method used had been chosen because of its simplicity, separation of the alkaline extract presented some difficulty because it became murky and very viscous. Irwin and Cover (50) suggested a longer extraction period to ensure that all proteins other than collagen were dissolved in alkali. Ritchey and Cover (79) in a comparison of the alkali-insoluble, autoclave soluble nitrogen procedure and the hydroxyproline method recommended the latter as a more accurate indicator of collagen in raw and cooked meat. The exact nature and composition of collagen is not completely understood, and more information about the changes occurring during extraction and cooking is needed.

TABLE XXI

COMPARISON OF COLLAGEN LEVELS IN BEEF ROUND
EXTRACTED BY ALKALI AND AUTOCLAVING

Griswold and Leffler (39) 1952 Sample	Moisture	% Collagen	Present Study Sample	Moisture	% Collagen
RAW			COOKED DRY HEAT TO 60°C 9 SAMPLES	64.1	0.91
A	71.8	0.87			
B	71.5	1.11			
C	68.8	1.17			
COOKED					
Method 1*	56.9	0.61	COOKED DRY HEAT to 80°C 7 SAMPLES	63.6	0.37
Method 2	64.4	0.79			
Method 3	56.9	0.33	COOKED MOIST HEAT to 80°C 5 SAMPLES	60.2	0.18
Method 4	56.7	0.93			
Method 5	59.7	0.70	COOKED MOIST HEAT to 100°C 8 SAMPLES	57.9	1.17
Method 6	58.1	0.56			
Method 7	58.4	0.58			
Method 8	53.5	0.61			
Method 9	53.9	0.40			
Method 10	57.4	0.48			
Cooked meat, moist weight basis	57.6	0.59		61.5	0.65
Cooked meat, dry weight basis**		1.39			1.68

* Cooking Methods not identified.
**Conversion to dry weight basis made by using formula $\frac{\text{collagen moist wt.x100}}{\text{dry weight sample}}$

Correlation of Shear, Panel and Collagen

Results of tenderness measurements by three methods were correlated. Shear and panel ratings for the tenderness composite had a correlation coefficient of -.60. Burrill, Beethardt and Saffle (11) reported a similar though slightly higher correlation of -.69. In the present study the correlation coefficient for collagen level and taste panel scores was .53 while collagen and shear values had a coefficient of .35. Tenderness measurements, to some extent, rate different aspects of the quality which may account for the failure to obtain a higher degree of correlation.

Meat cookery studied scientifically leads to further understanding so that applications can be made for practical use. The cooking of meat has been, for a long time, essentially an art, and no matter how skillful the treatment the results have often shown considerable variation. It is only recently that procedures have been standardized and reproducible results obtained. As knowledge is accumulated there is increased awareness of cooking conditions that must be controlled. Of all factors which make meat acceptable and enjoyable , tenderness is the most important. The gourmet may look for succelence and the pleasant texture of fine muscle filaments in a tender piece of meat. Those with scientific leanings would be more impressed by low shear values, low residual collagen and a correlation coefficient of .97 such as that calculated by Rodgers *et al.* (83) between general acceptability and panel tenderness ratings.

SUMMARY AND CONCLUSIONS

Tenderness was compared in thirty roasts of the biceps femoris obtained from eight steers raised under controlled conditions. The muscles were cooked under four conditions by moist and dry heat to two internal temperatures approximating rare (60°C for dry heat and 80°C for moist heat) and well done (80°C for dry heat and 100°C for moist heat). The degree of thawing before cooking was varied with meat being started at room and refrigerator temperatures and in the frozen state. Tenderness was affected more by cooking method than initial temperature of the meat under the conditions of the experiment. Conventional gas ovens were used for the major part of the experiment. Six roasts were cooked in an electronic oven. Tenderness was evaluated by shear and taste panel, while collagen level was determined by chemical analysis.

Cooking losses including both evaporation and drippings increased with longer cooking and were higher at 46.8 per cent by moist heat and 32.4 per cent by dry heat. Roasts started in the frozen state had lower cooking losses of 29.1 per cent compared with 34.0 and 35.9 per cent at room and refrigerator temperatures respectively. Moist heat cooking methods brought about greater moisture losses in the cooked meat. At an internal temperature of 80°C meat roasted by dry heat was juicier and lost 62.54 per cent moisture when dried to constant weight. Moisture losses with moist heat methods were 60.52 per cent. Shrinkage losses by moist heat methods ranged from 27.8 to 34.3 per cent, while dry heat methods showed greater variation and ranged from 4.5 to 47.9 per cent.

Rate of cooking varied with the temperature of the meat before roasting. Frozen roasts cooked to 80°C by dry heat in 214 minutes, while refrigerator roasts required only 193 minutes and room temperature roasts were done in 160 minutes. The presence of moisture increased the rate of heat penetration. Refrigerator roasts cooked to an internal temperature of 80°C by dry heat at a rate of 40.3 minutes per pound, and almost twice as rapidly or 26.8 minutes per pound by moist heat.

Shear force values revealed significant differences in tenderness due mainly to cooking method, but initial temperature of the meat before cooking had some effect. Moist heat methods to the well done stage resulted in the greatest shear tenderness at 12.2 pounds. Meat cooked by dry heat to the rare stage was less tender with a shear value of 22.2 pounds. At the same internal temperature of 80°C meat cooked by moist heat had a shear value of 16.6 pounds, lower than the dry heat method with a shear of 18.3 pounds.

Taste panel scores showed that meat cooked to the well done stage was significantly more tender than that done by other methods. Scores for a tenderness composite were 5.9 for moist heat to 100°C, 5.4 for dry heat to 60°C and 4.9 for moist and dry heat to 80°C. Individual scores for muscle fibre and connective tissue components showed that moist heat to the well done stage increased fragmentation of the muscle fibres, and considerably softened connective tissue. Good reproducibility of judgments between duplicates was shown by the panel. Correlation for panel scores from opposite ends of the biceps femoris was .61 indicating some variation in composition. A chew count measurement was not effective in distinguishing tenderness differences between cooking methods.

Chemical analysis for collagen in cooked meat did not reveal large differences due to the influence of cooking method, but the mean level for cooked meat on a dry weight basis was 1.68 per cent. Correlations of .53 were found between collagen and panel scores while collagen and shear had a value of .35. A notable relationship was found between shear and taste panel with a correlation coefficient of -.60.

Electronically cooked meat was not strictly comparable in degree of doneness. Although cooking rate was rapid with the method, the meat did not cook uniformly.

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A P P E N D I X

APPENDIX A

WATER IMBIBITION DETERMINATION

Method adapted from that of J. H. Hall, as described by Doty and Pierce in U.S.D.A. Bulletin No. 1231.

1. 5 grams ground meat were blended with 30 ml. distilled water at high speed in Warning Blender for 15 seconds.

2. The mixture was transferred to centrifuge tubes.

3. The tubes were refrigerated and stored overnight at 35°C.

4. Tubes were centrifuged for 5 minutes at 3,500 rpm.

5. Liquid was decanted and measured.

6. Amount of water in the decant was subtracted from the original 30 ml. to obtain "imbibed" water.

APPENDIX B

COLLAGEN DETERMINATION

Lowry, Gilligan and Katersky Method (54)

Reagents:

0.1N NaOH

0.1% Phenol Red

0.1N HCL

Ether Alcohol Mixture

Ether

Method:

1. Weight 2 to 4 (A) grams ground meat in 50 c.c. Pyrex centrifuge tube. Transfer to small porcelain mortar and grind until paste like. Rinse back into centrifuge tube with 2 to 4 c.c. water followed by 0.1 NaOH until total volume is 40 c.c. Stir and let stand overnight.

2. Stir vigorously, centrifuge and remove supernatant by suction. Add 40 c.c. 0.1 N NaOH and stir. Let stand 2 hours, centrifuge and again remove supernatant fluid.

3. Add 40 c.c. water and a drop 0.1% phenol red. Adjust color to faint pink (pH7) with 0.1N NCL. Centrifuge and remove supernatant fluid.

4. Add 40 c.c. of 95% alcohol, 1 part ether mixture, and stir. Allow to stand 10 minutes, stir and centrifuge. Remove supernatant.

5. Add 40 c.c. ether, stir, and allow to settle or centrifuge and remove supernatant. Wipe outside of tube with warm water.

6. Dry in an oven at 108° for 2 to 4 hours to constant weight. Cool to room temperature.

7. Weigh tube (B) and contents.

8. Add 20 c.c. water. Plug tubes with non-absorbent cotton. Autoclave at 50 lbs. pressure for 4 hours.

9. Centrifuge and remove supernatant. Dry at 100° overnight, cool and weigh (C).

10. Calculate the percentage collagen on a dry weight basis as $\frac{B-C}{A} \times 100$.

Autoclaving was done for three hours at 15 lbs. pressure according to the Doty and Pierce modification of the method (36).

APPENDIX C

INSTRUCTIONS FOR SCORING BEEF TENDERNESS

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1. Score the sample considering six components of tenderness, which can be grouped into three main categories:

   (a) Muscle fiber - Texture
Fragmentation or crumbliness
Softness

   (b) Connective tissue - Amount
State

   (c) Tenderness, composite and chew count - according to a 7 point scale.

2. Mark with an x, the adjective and numerical rating that best describes each factor.

3. A description of each tenderness and palatability factor is outlined below to aid you in judging.

I. TEXTURE should be judged by the appearance, distribution and organization of muscle fibres and connective tissue. Fine muscle fibres that are uniform in size and densely packed are associated with high quality; irregular and coarse fibres, loosely distributed are usually an indication of lower quality.

II. FRAGMENTATION OR CRUMBLINESS
The ease or difficulty with which fibres of a one-half inch thickness fragment or crumble when a thin portion cut across the grain by the side of a fork, is considered under this factor. Mealiness is associated with meat that can be easily fragmented or crumbled forming tiny fragments that are dry and hard.

III. SOFTNESS should be judged by:
1. the sensation produced on the tongue and the side of the cheek during chewing, and

2. the muscular force or tooth pressure exerted in chewing.

IV. AMOUNT AND STATE OF CONNECTIVE TISSUE can be judged by examining and pulling apart muscle fibres to see the nature of the connective tissue binding muscle fibres together. Is the amount of connective tissue present small or large? Is it present as a fine network enmeshing the muscle fibres, or is it found in the form of firm and thick strands, or as clusters or lumps? Sensory impressions produced by chewing and swallowing also aid in rating this characteristic.

V. JUICINESS should be judged according to the initial impression of wetness produced during the first few chews as a result of the rapid release of meat fluids. Judges should use their first impression. A secondary impression of juiciness will be given from the slow release of meat juices and the stimulating effect of fat on the salivary flow.

VI. TENDERNESS COMPOSITE AND CHEW COUNT
The sensation of tenderness is a composite effect. The general impression as a result of chewing is influenced by both muscle fibre and connective tissue. Record the number of chews for complete mastication of a piece one-half inch in diameter.

Date ____________
Judge ____________

Sample No.

BEEF TENDERNESS SCORE CARD

FACTORS	7	6	5	4	3	2	1
I. MUSCLE FIBRES TEXTURE	Very fine, uniform fibres	Fine grain	Moderately fine grain	Slightly fine	Moderately coarse	Coarse, stringy	Very coarse fibres, very stringy
II. FRAGMENTATION or CRUMBLINESS	Very easily fragmented	Easily fragmented	Moderately easy	Slight difficulty	Moderately difficult	Difficult to fragment	Very difficult to fragment
III. SOFTNESS of MUSCLE FIBRE	Very soft	soft	Moderately soft	Slightly soft	Moderately hard	hard	Very hard
IV. CONNECTIVE TISSUE A. Amount	Very small amt. conn. tissue	Small amount conn. tissue	Moderately small amount	Medium amount	Moderately large amount	Large amount conn. tissue	Very large amt. conn. tissue
B. State	Very soft	Soft	Moderately soft	Slightly soft	Moderately hard	Hard	Very hard
V. JUICINESS	Very juicy	Juicy	Moderately juicy	Slightly juicy	Moderately dry	Dry	Very dry
VI. TENDERNESS COMPOSITE and CHEW COUNT	Very tender	Tender	Moderately tender	Slightly tender	Moderately tough	Tough	Very tough

COMMENTS: