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Histological, physical, and organoleptic changes in three grades of beef during aging

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(HISTOLOGICAL, PHYSICAL, AND ORGANOLEPTIC) CHANGES IN THREE GRADES OF BEEF DURING AGING

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INTRODUCTION

The factors that affect the tenderness of beef have been investigated by many workers, but only a few of these studies have been concerned with the effect of aging on tenderness or with the variation in tenderness among the different muscles of the carcass. The more recent papers in the literature which have dealt with these factors have been limited to one muscle from several animals or to certain muscles from one animal. Aging has long been considered a process which improves the tenderness and flavor of beef; thus, it was deemed worth while to study the histological, physical, and organoleptic changes during the aging of several muscles from three grades of animals. There is variation in tenderness among the muscles from a given carcass, therefore, the muscles were chosen to represent different degrees of tenderness within the carcass.

The desirability of aroma, flavor, juiciness and tenderness of the cooked meat was determined by judges' scores. In addition juiciness and tenderness were determined by press fluid and shear force, respectively. Physical changes upon which data were recorded were changes in length, width, thickness, and weight of the beef during cooking; and changes in weight during storage. Histological sections of both raw and cooked

meat were used to observe the changes in the structure of the muscle fibers and the proportion of collagen and elastin in the various muscles.

Connective tissue has been reported as a factor contributing to the tenderness of meat. Collagenous connective tissue is said to contract, swell, and soften when cooked, but elastic connective tissue is considered to be little affected by cooking. Strips of tendons (which were mainly collagen) and ligaments (which consisted chiefly of elastin) from each of the carcasses used in the study were treated in hot water at given temperatures for definite periods of time and changes in length, width, thickness, and softening of these tissues were recorded. It is probable that such information might be helpful in explaining some of the physical changes of meat during cooking.

The specific objectives of this study were to study: (1) the histological, physical, and organoleptic changes which occur during the aging of beef; (2) the proportion of connective tissue in certain muscles of beef; and (3) the effect of moist heat on collagen and elastin. Chemical determinations of the collagen and elastin content of the muscles used in this study are being determined by Inez Prudent and the results will be reported in her thesis.

REVIEW OF LITERATURE

Structure and Composition of Beef Muscles

General structure

Skeletal muscle is an organ made up of fibers held together by connective tissue and surrounded by a sheath of heavier connective tissue. The fibers are arranged parallel to each other in bundles called fasciculi. Each fiber is elongated, cylindrical, and multinucleated with elliptical shaped nuclei; some fiber ends are tapered, others rounded, The fiber may run the length of the muscle with both ends terminating in a tendon; one end of the fiber may terminate in a tendon and the other within a muscle; or both ends of the fiber may terminate in the muscle. Each fiber is encased in a thin colorless, elastic membrane, the sarcolemma. The connective tissue around the fasciculi is called the perimysium and the sheath of connective tissue around the entire muscle is the epimysium (18).

The proportion of connective tissue

The connective tissues consist mainly of two proteins, elastin and collagen. Mitchell et al. (20) determined chemically the amount of these two substances in several cuts of beef. No constant or significant differences in connective

tissue content were found between heifer and steer beef. Eye muscle of rib and the tenderloin in calves gave the lowest percent of collagen, whereas next in order and distinguishable from each other were round, porterhouse, and sirloin. Foreshanks, chuck ribs, and navel showed the highest percentages of collagen. The percentage of elastin in muscle was reported to be small and usually insignificant when compared to the percentage of collagen. Inconclusive results indicated that age of the animal does not greatly influence the content of connective tissue in muscle. Smith (30) stated that in most of the muscles of the body, connective tissue, in which collagen predominates, makes up 12 to 15 percent of their dry weight.

Proteins of muscles fibers

Szent-Györgyi (34, 35) summarized the biochemical studies on muscle proteins. He stated that striated muscle contains about 20 percent protein. If the muscle is minced and extracted with water, half of this protein goes into solution. The soluble muscle protein is called myogen. The insoluble fraction contains several enzymes involved in oxidation and the contractile substance of the fibril, actomyosin. Actomyosin is composed of two proteins, actin and myosin which are hydrophilic colloids.

The Aging of Beef

The term "aging" as applied to fresh beef refers to the practice of holding the meat at temperatures just above freezing, usually 34° to 36° F., for various periods of time. The purpose is to improve the quality of the meat, particularly the tenderness. The published studies have reported physical, organoleptic, chemical, and histological changes in meat held for different periods of time.

Physical changes

One of the early investigations on the aging of beef was carried out at the United States Department of Agriculture (12). The principal effects of storage on the physical characteristics of beef were loss of weight and a hardening and darkening of the exposed muscular and fatty tissues. These changes were great enough to lower the market value of the meat when the storage time was 177 days, but the physical changes which took place in 2 to 4 weeks were not marked and did not lower the market value of the product.

Paul, Lowe, and McClurg (23) found that the external fat on roasts cooked without storage was soft and oily, whereas that on roasts refrigerated 1 day or longer was firm and brittle. The muscles were cut from the carcass, after chilling 24 hours, cut into roasts, and wrapped in cellophane

for aging. Roasts stored 0 and 1 days were quite dry on the surface; those with 2 and 4 days storage were quite moist. By the 9th day the surface of the meat was again fairly dry, but the moisture had collected in the paper in which the roasts were wrapped, and with 18 days of aging the roasts were sticky.

Organoleptic changes

Aroma, flavor, juiciness, and tenderness are the factors which contribute to the palatability of a piece of meat. Judges scores for aroma and flavor usually follow much the same pattern. In the work of Paul et al. (23) aroma and flavor scores improved up to 9 days but with further storage the roasts were graded lower on these factors. The less desirable scores were attributed to development of "gaminess" in the lean and rancidity in the fat. Hoagland et al. (12) stated the opinion that storage did not improve the flavor of the meat used in their study. There was a gradual change in flavor to the extent that beef stored over long periods was described as "old" and was less appetizing than fresh meat. Similar changes were noted in the odor of the freshly cut surfaces of the stored meat.

The juiciness scores given by Paul et al. (23) show a gradual increase in juiciness with increased aging, but the press fluid values first decreased then increased sharply.

In general, the moisture content of the beef aged by Hoagland et al. (12) decreased as storage increased. This was in keeping with the loss of weight in the meat during storage. Paul's roasts were wrapped for aging, whereas the beef in Hoagland's study was not wrapped.

The principal effect of aging on the organoleptic properties of beef is usually considered to be a marked increase in tenderness. Paul et al. (23) found a decided increase in tenderness with storage up to 9 days as indicated by both scores and shear readings. The data of Hoagland et al. (12) showed a similar change in the meat but the extent of this change did not bear a direct relation to the length of the storage period. Beef stored 2 to 4 weeks was almost as tender as beef stored for a much longer time.

Deatherage and Harsham (10) were puzzled by the fact that they had obtained what seemed to be paradoxial results in various studies on tenderization of beef. Such results could be duplicated and were beyond the errors expected by the testing technique used. The discrepancies were contrary to the idea that tenderness increases linearly with postmortem age of meat. The heterogeneous structure of meat probably contributes to the fact that beef does not tenderize regularly with increased aging time. In a recent study conducted by these men tenderization curves of the loins from 14 carcasses indicated variation in the animals

used. At a given time steaks cut from the loin of some carcasses were more tender than those cut from other carcasses. In addition the meat from some of the animals became less tender at certain times during the aging period, whereas some of the meat progressively increased in tenderness throughout the aging period. In general, tenderness increased until 17 days. At 24 days there was no improvement or a slight drop in tenderness, and finally at 31 days there was some improvement beyond the 17 day tenderness measurement. It was concluded that unless beef is to be aged at 33° to 35° F. beyond approximately 4 weeks it need be aged only 2 1/2 weeks.

These same authors (10) discuss some interesting speculations underlying the results of the investigation reported. A summary of these speculations follows:

1. Cooked meat consists of coagulated muscle plasma and connective tissue.

2. Before cooking and during aging the precursors to coagulated muscle plasma seem to disintegrate at a faster rate than the connective tissue. Therefore, from the taster's point of view toughness contributed to connective tissue is changed only a small degree as aging progress, whereas that owing to coagulated muscle plasma may approach zero. If this condition continued for a period of time, the taster observes no tenderization during this period. Still further aging might disintegrate the connective tissue to the point that the connective tissue fibers lose their strength, and toughness owing to connective tissue diminishes. This could account for a plateau.

3. To explain toughening during certain periods of the aging process it was stated that connective tissues may maintain their strength for some time during aging whereas muscle plasma autolyzes so that on cooking it is weaker. Thus if connective tissues maintain their elasticity and muscle plasma loses tensile strength but remains firm or brittle, the muscle plasma gives the taster a mechanical advantage in chewing the connective tissue by shearing. With such mechanical advantage the connective tissue may be effectively masticated by the taster, thus to him the meat is tender. If aging proceeds further to the point where the connective tissue is not yet effectively reduced but where the plasma is autolyzed to give still less firmness, then the connective tissue has lost the supporting substance. Since the mechanical advantage is lost to the taster the meat seems tough and chewy to him. With still further aging the connective tissue finally loses strength and the meat again becomes more tender.

Moran and Smith (21) attributed an increase in tenderness during the aging of beef to chemical changes in the proteins of the muscle fibers and connective tissue. The alteration of the proteins of the muscle fibers was considered most important during the first few days of storage, but with a longer time of storage the increased tenderness was attributed to a softening and swelling of the collagen.

Steiner (33) stored beef muscles at 0° C. and above for definite lengths of time, and measured tenderness changes by a mechanical device. He was interested in determining the lowest storage temperature above freezing which would give the least growth of microorganisms and still not retard the maturation processes. He concluded that muscles stored at 0° C. were superior to those stored at higher temperatures.

He also found that the rate at which ripening took place at a given temperature depended on age, sex, and other individual characteristics of the animals. Muscle of old animals ripened more slowly than that of younger animals and steer muscle ripened more slowly than cow muscle.

Histological changes

Most of the investigations on the aging of meat have not dealt with the histological picture. However, Paul et al. (23) reported histological observations. Paul et al. (23) found that in freshly killed beef the fibers were poorly differentiated and were straight to slightly wavy. After one day storage the fibers were much more distinct with contracture nodes, kinks, and crinkles. The nodes persisted through 18 days storage but the kinks and crinkles disappeared after 4 to 9 days storage. Breaks or disappearance of the cross striae in the fibers appeared on the second day and became more numerous as storage time progressed. The semitendinosus muscle behaved differently from the other muscles studied. In the semitendinosus, after one day of storage the fibers were thrown into pronounced waves which were observed microscopically. These waves were present for 4 days but had disappeared by the ninth day of storage. It was speculated that since the semitendinosus muscle

showed appreciable amounts of elastin when examined microscopically, the elastin content of the muscle may have had a role in the formation of the microscopic waves.

Chemical changes

Richardson (25) gave a good review of the chemical and biochemical deterioration of flesh foods. The biochemical reactions were considered as those reactions brought about by microorganisms while hydrolysis and oxidation were given as chemical reactions. The chemical changes were accelerated by enzymes naturally present in the food, by acids and salts, and by chemical causes under the influence of microorganisms. Richardson believed chemical methods should be relied upon for the main evidence of change in stored foods, and that any change of histological sort should be confirmed and supported by chemical analysis. He also stated that taste, odor, texture, and appearance of the meat are important, but he cautioned that the senses detecting odor and flavor are far less developed in the average individual than he supposes them to be. The result of this is apt to be false observations and deductions.

The chemical changes that took place in the muscular tissue of beef held in cold storage at temperatures above freezing for periods ranging from 14 to 177 days were reported by Hoagland and co-workers (12) to consist chiefly

of increases (1) in acidity, (2) in proteose, noncoagulable, amino, and ammoniacal nitrogen, and (3) in soluble inorganic phosphorus; whereas decreases occurred in coaguable nitrogen and in soluble organic phosphorus. These changes were progressive in nature, and had no appreciable effect upon the nutritive value or the wholesomeness of the edible portions. They were regarded as largely due to enzyme action because bacteriological studies showed no appreciable penetration of bacteria into the meat during storage.

Variation in Tenderness of Beef Muscles

The factors that contribute to the tenderness of beef have been reported by many authors. The age and grade of the animals, the size of muscle fibers, the amount of connective tissue, and the amount of fat have all been studied in relation to the tenderness of beef. The literature on these subjects has been reviewed by Ramsbottom et al. (24) and by Paul et al. (23).

Very little work has been published on the relative tenderness of different muscles in beef carcasses. Paul (22) used paired psoas major muscles and several muscles from a pair of rounds. The tenderness varied significantly according to the muscle being judged. The psoas major was

more tender than the other muscles. The gastrocnemius was more tender than the vasti, semimembranosus, and the biceps femoris, the differences being significant for the first two and highly significant for the last one. The adductor was significantly more tender than the semimembranosus and the biceps femoris. The semitendinosus was more tender than the vasti, semimembranosus, and biceps femoris, but less tender than the psoas major and gastrocnemius. These results were obtained by analysis of judges scores for tenderness. When the muscles were ranked according to shear force they rated in tenderness as follows: psoas major > adductor > gastrocnemius > vasti > biceps femoris > semimembranosus > semitendinusus.

Ramsbottom et al. (24) compared the tenderness of 25 muscles from each of three heifer carcasses. The comparisons were based on shear readings of the cooked muscle, judges scores, and a subjective histological rating. They ranked the muscles studied according to decreasing tenderness. Abundant connective tissue tended to increase the shear readings, but there appeared to be other important factors affecting tenderness because the histological ratings of some muscles were widely divergent from the shear values.

The Effect of Cooking on the Tenderness of Beef

Tenderness in cooked meat is the total effect of aging the meat before cooking, heat coagulation of the muscle fiber proteins, and the changes which take place in the connective tissues. The connective tissue is composed chiefly of the fibrous protein, collagen, which is partially converted to gelatin during cooking. Elastic connective tissue may be slightly softened when meat is cooked. Bell, Morgan, and Dorman (3) pointed out that the degree to which tenderness is affected by these two influences is very different in different cuts. Tender cuts such as sirloin steaks and prime rib roasts contain little connective tissue and are probably little improved by the collagen to gelatin transformation, but instead may be toughened by the heat coagulation of the muscle fiber proteins. Less tender cuts such as shoulder, sirloin butt or rump which are usually cooked for a long time by moist heat contain a great deal more connective tissue and are made tender by the hydrolysis of collagen to gelatin.

Ramsbottom et al. (24) determined tenderness by shear tests before and after cooking the 25 muscles studied. The muscles were cooked to an internal temperature of 76.7° C. in deep fat held at 121.1° C. Most of the muscles became

less tender upon cooking, some did not change significantly, and others became more tender. The tenderness of the internal oblique muscle decreased 168 percent by cooking. The shear readings for the deep pectoral muscle were about the same before and after cooking and the cutaneous muscle was an example of improved tenderness by the given method of cooking. This same study included observations on the effect of cooking on white collagenous connective tissue and on yellow elastic connective tissue. The yellow connective tissue improved relatively less on cooking than did the collagenous tissue. This is in accord with the work of Mitchell et al. (20) who found that in the raw condition white fibrous connective tissue was almost twice as tough as yellow elastic connective tissue, but when cooked the former lost most of its toughness, whereas the latter remains practically unchanged in this respect.

Satorius and Child (26) noted that the semitendinosus muscle of beef increased in tenderness during cooking until an interior temperature of 67° C. was obtained, beyond that temperature the muscle became less tender. The longissimus dorsi became more tender by heating to an internal temperature of 58° C. but the triceps brachii and adductor muscles did not change in tenderness when heated to 58° C. In another paper (8) these same authors presented data which

showed a greater shear force was required for roasts cooked at 200° C. than for those cooked at 150° C.

Work of Cover (9) indicated that it was the length of the cooking time rather than the oven temperature that affected the tenderness of less tender cuts of meat; the longer cooking time produced a more tender roast. Her investigations also showed that the use of skewers or any other means for shortening cooking time for the less tender cuts of beef may be of doubtful value when tenderness is important.

The Connective Tissues of Meat

Structure and composition

The connective tissues form a soft skeleton which support the other tissues and the organs of the body. In meat they are most evident as tendon or gristle but they are also distributed in a finer state of subdivision throughout muscle.

There are variations in the forms and microscopic appearance of connective tissue. Some is loose like that between organs; some is compact as that visible to the eye; and some is dense such as that in tendons. The loose collagenous tissues have fibers which run in all directions.

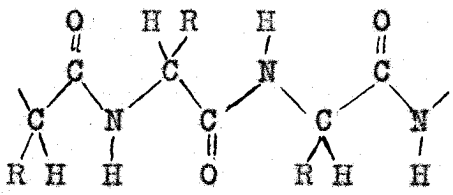
The fibers are straight or wavy and are grouped parallel to each other in bundles. In tendons the collagenous fibers are collected into dense, longitudinally striated bundles, united into a thick compact network. Because the tissue appears white in large masses it is called white fibrous connective tissue. Elastic tissues contain non-striated fibers which may branch and which are very elastic. When massed together they have a yellow color, hence they are called yellow elastic connective tissue (18).

At the present time the available information on the chemical composition and structure of most proteins is limited, and collagen and elastin are no exceptions even though there are many papers in the literature which deal with collagen from this standpoint. Comparatively speaking elastin has not fared nearly as well as collagen.

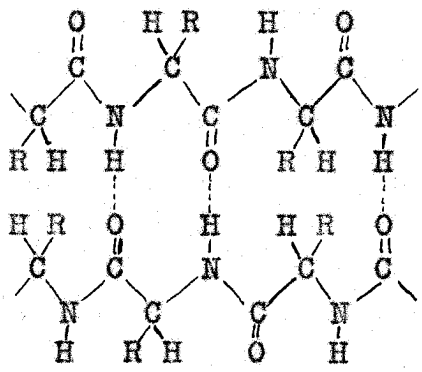
There is some knowledge of the amino acid composition of collagen (1, 7), but complete data cannot be expected until more precise analytical methods are developed. Chibnall (7) is confident, even though there is much work ahead for the analyst, that the difficulties will be overcome in the next few years and then it will be possible to apply an accepted routine procedure to a few grams of protein.

Chemical and X-ray data have strongly indicated that

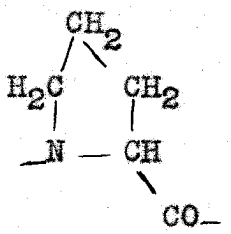
for the most part proteins are made up of amino acid residues bound to each other through carbonyl-imino union. Thus the formula of a polypeptide chain making up any protein might be illustrated:



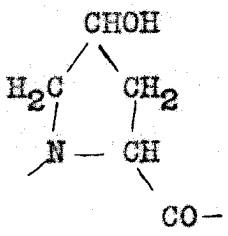
If the side chains or R-groups are short such as hydrogen atoms or methyl groups the polypeptide chains may be pictured as being linked by the so-called "hydrogen bond" as follows:



Using data obtained by Bergmann, Astbury (1) showed that about one third of all amino acid residues of gelatin are either proline or hydroxy proline:

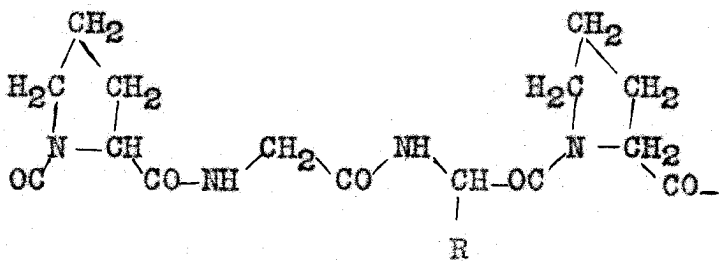


proline



hydroxy proline

He believes that the chemical composition of collagen is similar to that of gelatin and that it must be the preponderance of these amine acid residues which accounts for the construction of the backbone chains of collagen. He pictured the general sequence of amino acid residues as:

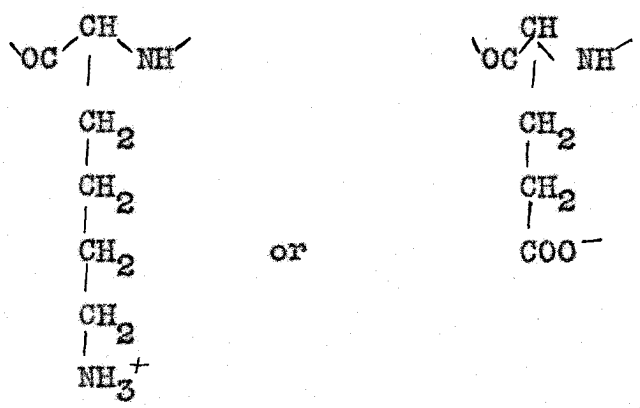


fiber axis

It was suggested the chains run in essentially straight lines parallel to the fiber axis, but the length of the average residue is less than that in other fully extended protein chains because the high concentration of proline and hydroxy proline residues constricts the chains. The

glycine, proline, and hydroxyproline residues lie on one side of the chains, whereas all other residues lie on the other side of the chains (1). Huggins (13) disagreed with this view and suggested that the main chains are spirally coiled which he attributed to NHO bridges between the chains.

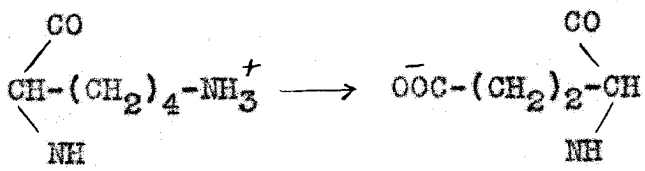
According to Theis and Steinhardt (36), upon hydrolysis and subsequent analysis, collagen or gelatin show quite large quantities of both basic and acid amino acid residues. Thus, these particular amino acids may be bound in the polypeptide chain by the α-amino and α-carboxyl groups but with rather long extending side chains:



lysine residue or glutamic acid residue

Such side chains terminating in an amino or carboxyl group, especially if existing as dipoles, would create certain charged centers. If a charged amino group of one side chain stood opposite a charged carboxyl group of

another side chain, an attraction would result and give an electro-valent linkage or the so called "salt linkage" as demonstrated by the glutamic acid residue of one chain and the epsilon amino lysine group of another chain:



With strong dehydration or other drastic chemical effects this salt linkage may change to give a carbonylimino link:

X-ray studies indicated the fibrous proteins fall into two main groups of diffraction patterns (1). These groups were called the keratin-myosin group and the collagen group. The keratin-myosin group gave an X-ray photograph that corresponded to a system of regularly folded polypeptide chains running the direction of the fiber axis. This was observed as the equilibrium form of keratin and was called α-keratin. When such a fiber was stretched the molecules changed to a form about twice as long in which the polypeptide chains were fully extended. The stretched form was called β-keratin. X-rays on collagen revealed amino acid residues that were shorter than those of the fully extended polypeptide chains of β-keratin, but longer than

those of the folded chains of α-keratin. This suggested that in some way the collagen chains are folded, but to a smaller degree than those in α-keratin. It was not possible to stretch collagen into a fully extended form like β-keratin.

Through the use of the electron microscope Hall, Jakus, and Schmitt (11) found single collagen fibers showed a cross striated appearance. The relatively opaque and transparent bands extend uniformly across the fiber. The interband distance is independent of the fiber width and varies considerably from one fiber to another. Extremes measured were 902 and 552 Å units (accuracy 3 percent). A statistical study showed that the most frequently occuring spacings lie between 620 and 660 Å units; the average was 644 Å.

Bear (2) used X-ray diffraction investigations to show the presence of a fiber axis periodicity of 640 Å units which seemed to be characteristic of collagen in intact tissues. The coincidence of this value with that of the electron microscope indicated that both methods show the same regularity of structure. Bear also studied single collagen fibers which had been treated with water, 5 percent tannic acid, 5 percent chromic acid, and 10 percent formalin. In such cases there was a variation in the fiber

axis periodicity from 675 to 550 Å units, depending on the treatment of the collagen.

Schmitt (27) pointed out that if reliable data were available for all amino acids from pure collagen a periodicity theory based on stoichiometric relations might suggest but could not directly show a specific sequence of amino acids in the protein chains. It is not certain that the amino acids follow an exclusively linear course. However, the 640 Å unit periodic axial structure is characteristic of all types of collagen, from vertebrates and invertebrates, thus far examined. Some 30 X-ray orders were observed, thus, such regularity must reflect some specific molecular structure and amino acid pattern. Before such a pattern can be related to the chemical composition of collagen it will be necessary to have more knowledge on both subjects.

The Contraction, Swelling, and Gelatinization of Collagen

The contraction, swelling, and gelatinization of collagen are important in meat cookery research from the standpoint of their effect on the tenderness and shrinkage of the meat. These characteristics of collagen seem to be related to the fundamental structure of collagen. Therefore,

until there is more available information on structure the processes of swelling and contraction will not be entirely clear. The effect of heat, acids, alkalies, salts, and organic compounds on the swelling and contraction of collagen have been studied and the results obtained were explained on the basis of the knowledge of structure. The factors heat, acid, alkali, and salts are of interest in meat cookery.

Dorothy Jordon Lloyd (16) divided her general explanation of the swelling of structural tissue such as collagen into two types of swelling: the first is brought about by the drawing in of water by osmotic or other forces against the restraining forces of structure. The second type is contributed to a weakening of the structure, allowing water to pass in simply from its own diffusion pressure. The osmotic swelling leads to a shortening of the swollen fiber, a turgid condition and a glossy appearance, while swelling attributed to weakened structure gives an increase in diameter, a flaccid condition, and an opaque appearance.

The water imbibed under the second condition is closely associated with or "bound" to the protein molecule. The "bound" water is thought to be linked to positions in the molecule by a coordinate link or hydrogen bond, but it may be merely held in dynamic equilibrium around the charged

centers of the protein zwitterion. In closely packed structures, such as tendon, the centers of hydration in two molecules may be linked to each other with the reduction in the amount of water which may be held in this way. The rest of the water in the system is held by the osmotic equilibrium.

The effect of heat

Bendall (4) considered the swelling and contraction of collagen as part of the process of conversion of collagen to gelatin. He stated the conversion takes place in three stages: (1) the conversion of collagen A to collagen B which occurs at 56° to 60° C., and results in shortening of the collagen fiber; (2) the uptake of water by collagen B and the consequent swelling and softening of the connective tissue; and (3) the dissolution of collagen B to form a gelatin sol. The latter occurred during cooking at 100° C. only if the cooking was abnormally prolonged, but during pressure cooking at 115° to 126° C. dissolution was complete.

Cherbuliez et al. (6) described a reversible and an irreversible process which occurred during the treatment of collagen fibers with warm water. The reversible process consisted of loosening the parts of the crystal lattice of

collagen by a two dimensional solution of the chains in the water absorbed during swelling. This gave the fibers elastic properties, but cold water reversed the process. The irreversible process was actually hydrolysis resulting in a decrease in mechanical strength, appearance of plasticity, and finally solution into gelatin.

Hall, Jakus, and Schmitt (11) reported beef tendons to contract to 20 percent of their original length when heated. Under the contracted condition the X-ray spacings disappeared, which suggested considerable disorientation of the fibrils. The phenomenon was assumed to indicate a super-folding of the polypeptide chains when the hydrogen bonds of the chain backbone was disrupted by heat.

Astbury (1) explained the X-ray interpretation of the thermal contraction of collagen shows the contraction to be spontaneous at rather specific temperatures, generally in the neighborhood of 60° C. The X-ray photograph is an amorphous pattern which led Astbury to agree with Hall et al. that the thermal contraction of collagen is a super-contraction or folding. He explained that the shortening of the fibers is a result of a shortening of the chain molecules. When the thermal agitation is sufficient to overcome the inter-chain attractions, the chain bundles were said to "melt" and the chains collapse upon themselves.

The effect of acid, alkalies, and salts

Acids and alkalies form salt linkages with the protein zwitterion and lead to the setting up of a Donnan equilibrium. The swelling in acid solutions begins when the pH is below the iso-electric point of collagen and reaches a maximum at pH 1.7 to 1.9. There is no sharp minimum swelling at the iso-electric point of collagen but there is a zone from pH 5.5 to 9.0 in which swelling is uniformly small. In alkaline solutions swelling begins at pH 9.5 and reaches a maximum at pH 10.0 to 10.5. Destruction of the fibers occurs at higher pH values (15).

Bendall (4) found that one of the changes accompanying the coagulation of proteins when meat was cooked was a shift in pH to the alkaline side. It affected the texture of the meat by its effect on the colloidal swelling of the system. To an exaggerated degree this effect was demonstrated by cooking meat in a slightly alkaline medium (pH 7.0 to 7.5); the cooked meat was bulkier and softer than meat cooked at the natural pH (pH 5.5 to 6.0). Bendall also reported that hydrogen ions and phosphate ions have a marked accelerating effect on the rate of conversion of collagen to gelatin.

Lloyd (15) stated that salts will not weaken a direct

carbonyl-imino linkage between the backbones of adjacent molecules. She attributed the swelling of protein in salt solutions to a solvent action, which is brought about by the influence of the salt ions on the multipolar molecule of the protein. This leads to a rearrangement of the interionic forces of the system.

The report of Smith (31) agreed with that of Bendall in that the presence of phosphate ions powerfully accelerates gelatinization. The effect was noticeable at 0.02 M concentration and in a 0.2 M phosphate solution the half conversion period was reduced by 80 percent. The arsenate ion had an analogous but less marked effect. No other ion except the hydrogen and hydroxyl ions gave similar results.

EXPERIMENTAL PROCEDURE

Grades of Animals

The carcasses of four animals of three different grades were used in this study. Animal I was a yearling steer, carcass grade, good; animal II was also a steer, carcass grade, good, but was slightly older than animal I. Animal III was a large steer, carcass grade, commercial, which dressed to only 50 percent of his weight. Animal IV was an eight year old dairy cow, carcass grade, cutter. The muscles of the cow were smaller than those of the other animals, and the fat and connective tissue were a bright yellow.

The psoas major, longissimus dorsi, semetendinosus, and biceps femoris muscles were chosen for use. Ramsbottom et al. (24) have demonstrated that these muscles vary in tenderness. The psoas major and longissimus dorsi muscles are known as the tenderloin and loin respectively and the other two muscles are in the round of the carcass. A detailed description of these muscles is given by Sisson and Grossman (28).

Paired muscles were divided so that 30 roasts were obtained from each animal. Each longissimus dorsi was

divided between the 12th and 13th rib into the rib portion and the loin portion, and each portion was cut into three roasts. All other muscles were cut into three roasts each. See Figures 1 to 10 for pictures of the muscles and diagrams of the division of the muscles. The roasts varied in weight from about 0.7 pounds to 4.5 pounds. Roasts from the biceps femoris muscles were the largest with the other muscles in the following order: longissimus dorsi > semitendinosus > psoas major.

Slaughtering, Storage Conditions, and Aging Periods

The animals were slaughtered in the Iowa State College Animal Husbandry abattoir, dressed, cut into right and left sides and hung in the cooler at 34° to 36° F. The following day the carcasses were cut between the 4th and 5th ribs and the muscles used in the study were trimmed, and cut into roasts. The roasts were labeled, placed unwrapped on enamel trays with about one inch space between them and were then stored on open shelves in the cooler for the desired aging periods. Paul (22) found that roasts wrapped in cellophane and stored at 34° to 36° F. for 18 days became slimy. In order to keep the roasts in this study for periods longer than 18 days they were stored unwrapped, even though a loss in weight through evaporation during storage was anticipated.

Fig. 1. The Semitendinosus Muscle (above) and the Psoas Major Muscle (below) Before Dividing. (Reduced approximately 8 x)

Fig. 2. The Semitendinosus Muscle (above) and the Psoas Major Muscle (below) After Dividing. (Reduced approximately 8 x)

Fig. 3. The Longissimus Dorsi Muscle Before Dividing. (Reduced Approximately 9 x)

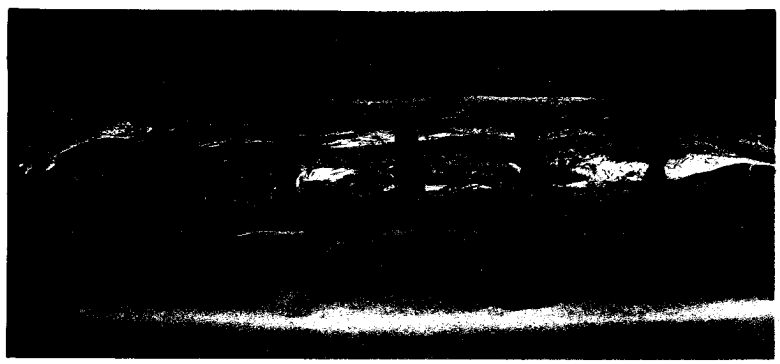
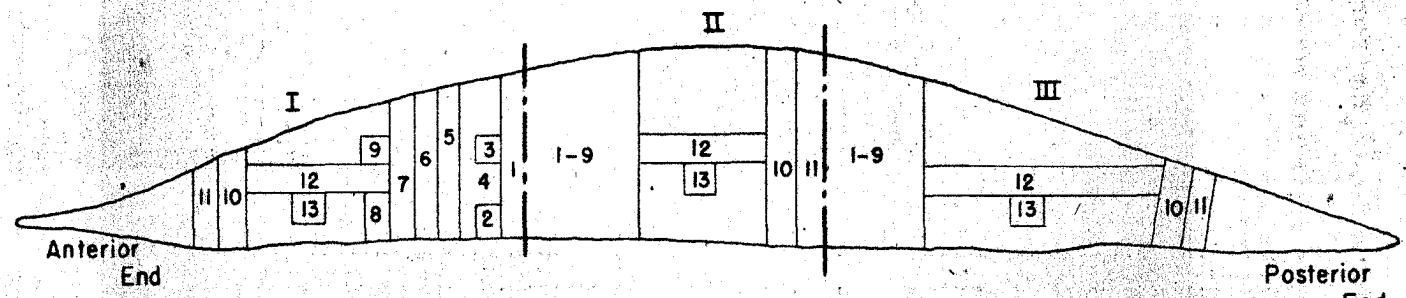


Fig. 4. The Longissimus Dorsi Muscle After Dividing. (Reduced approximately 9 x)

Fig. 5. The Biceps Femoris Muscle Before Dividing. (Reduced approximately 11 x)

Fig. 6. The Biceps Femoris Muscle After Dividing. (Reduced approximately 11 x)

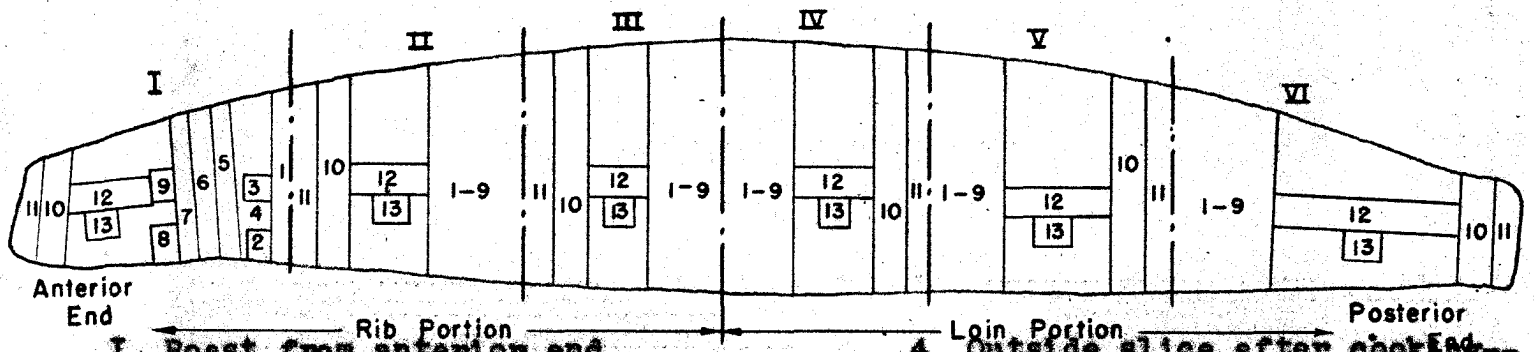
Division of the Psoas Major.



I	Roast from anterior end	7	Cooked chemical sample
II	Roast from middle portion	8	Cooked histological cross section
III	Roast from posterior end	9	Cooked histological longitudinal section
1	Uncooked chemical sample	10	Cooked sample for pH
2	Uncooked histological cross section	11	Uncooked sample for pH
3	Uncooked histological longitudinal section	12	Shear sample
4	Outside slice after cooking -- discarded	13	Press fluid sample
5 & 6	Slices for palatability tests		

Fig. 7. The Psoas Major Muscle.

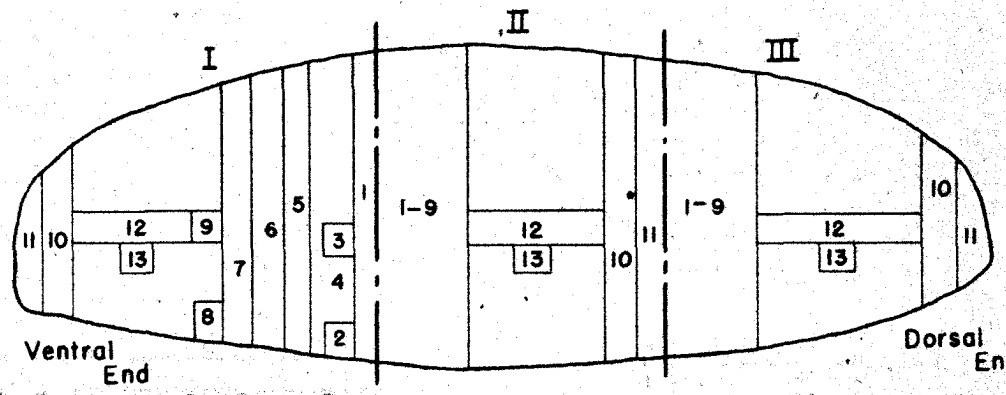
Division of the Longissimus Dorsi.



I	Roast from anterior end	4	Outside slice after cooking--discarded
II	Roast from middle rib portion.	5 & 6	Slices for palatability tests
III	Roast from portion adjoining loin	7	Cooked chemical sample
IV	Roast from portion adjoining ribs	8	Cooked histological cross section
V	Roast from middle loin portion	9	Cooked histological longitudinal section
VI	Roast from posterior end	10	Cooked sample for pH
1	Uncooked chemical sample	11	Uncooked sample for pH
2	Uncooked histological cross section	12	Shear sample
3	Uncooked histological longitudinal section	13	Press fluid sample

Fig. 8. The Longissimus Dorsi Muscle.

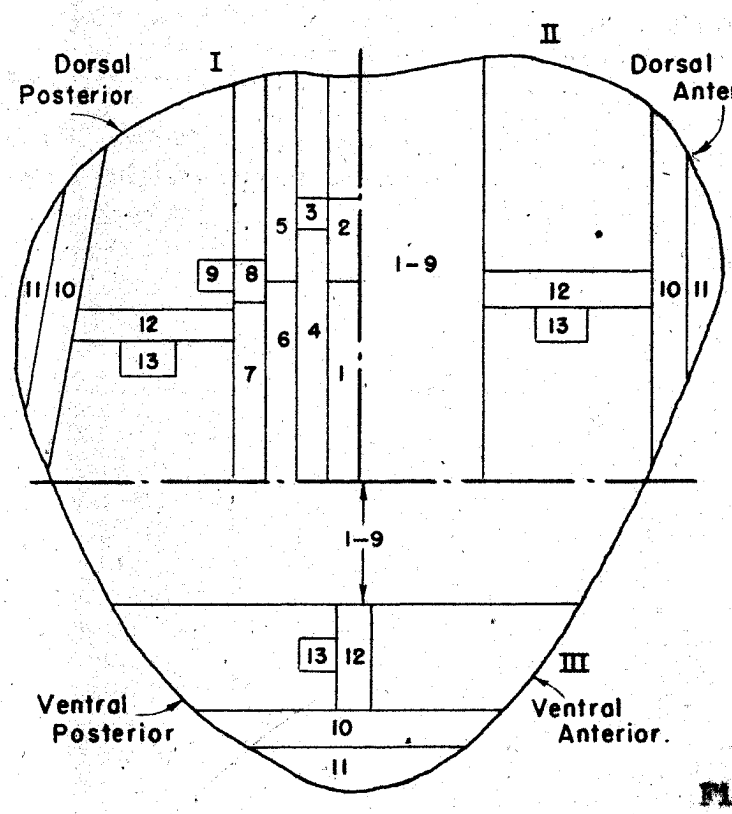
Division of the Semitendinosus



I	Roast from ventral end
II	Roast from middle portion
III	Roast from dorsal end
1	Uncooked chemical sample
2	Uncooked histological cross section
3	Uncooked histological longitudinal section
4	Outside slice after cooking--discarded
5 & 6	Slices for palatability tests
7	Cooked chemical sample
8	Cooked histological cross section
9	Cooked histological longitudinal section
10	Cooked sample for pH
11	Uncooked sample for pH
12	Shear sample
13	Press fluid sample

Fig. 9. The Semitendinosus Muscle.

The Division of the Biceps Femoris.



I Roast from dorsal posterior
II Roast from dorsal anterior
III Roast from ventral posterior and ventral anterior
1 Uncooked chemical sample
2 Uncooked histological cross section
3 Uncooked histological longitudinal section
4 Outside slice after cooking--discarded
5 & 6 Slices for palatability tests
7 Cooked chemical sample
8 Cooked histological cross section
9 Cooked histological longitudinal section
10 Cooked sample for pH
11 Uncooked sample for pH
12 Shear sample
13 Press fluid sample

Fig. 10. The Biceps Femoris Muscle.

The aging periods used were 1, 2, 5, 10, 20, and 30 days, thus the roasts in the 1 day series were taken to the foods laboratory and cooked immediately after the dissection and division of the muscles was completed. For all animals one roast from each muscle was included in every aging period. The statistical pattern for the aging periods consisted of a 5 x 6 table for each animal in which the storage periods were determined from a table of random numbers. The pattern was outlined as given in Tables 1, 2, 3, and 4.

Cooking Method and Observations Made on the Roasts

The wide variation in the weight and shape of the roasts created a problem in standardizing a cooking method. A modification of the procedure suggested by Ramsbottom et al. (24) was used. The roasts were placed on a rack in a kettle that was deep enough to cover them with bland lard which was held at a temperature of 96° to 98° C, and cooked to an internal temperature of 70° C. As the roasts were immersed into the fat the initial internal temperature of the roasts and the clock time were recorded, and the rate of heat transfer through the roasts was determined by recording the time for every 5° C. rise in internal temperature throughout the cooking period. When

1 Swifts "Bland" lard

Table 1.

Statistical Pattern for Aging Periods in Days for Roasts from Animal I.

Muscle	A*		B*		C*	
	Left	Right	Left	Right	Left	Right
Psoas Major	2	5	1	10	20	30
Longissimus dorsi (ribs)	1	30	5	10	2	20
Longissimus dorsi (loin)	10	20	2	30	1	5
Semitend-inosus	2	10	5	30	1	20
Biceps femoris	5	20	1	2	10	30

*A, B, C for the psoas major and longissimus dorsi muscles refer to roasts from the anterior end, middle portion, and posterior end of the muscles respectively. For the semitendinosus these numbers refer to the ventral end, middle portion, and dorsal end of the muscle, and for the biceps femoris to the ventral anterior and posterior (lower part), the dorsal posterior, and the dorsal anterior.

Table 2.

Statistical Pattern for Aging Periods in Days for Roasts from Animal II.

Muscle	A*		B*		C*	
	Left	Right	Left	Right	Left	Right
Psoas Major	2	10	5	30	1	20
Longissimus dorsi (ribs)	10	20	1	5	2	30
Longissimus dorsi (loin)	1	2	5	20	10	30
Semitend-inosus	2	20	1	30	5	10
Biceps femoris	2	5	1	10	20	30

* See Table 1.

Table 3.

Statistical Pattern for Aging Periods in Days for Roasts from Animal III.

Muscle	A*		B*		C*	
	Left	Right	Left	Right	Left	Right
Psoas Major	1	5	2	30	10	20
Longissimus dorsi (ribs)	1	30	5	10	2	20
Longissimus dorsi (loin)	2	5	1	10	20	30
Semitend-inosus	5	30	2	10	1	20
Biceps femoris	10	30	1	2	5	20

* See Table 1.

Table 4.

Statistical Pattern for Aging Periods in Days for Roasts from Animal IV.

Muscle	A*		B*		C*	
	Left	Right	Left	Right	Left	Right
Psoas Major	1	20	5	30	2	10
Longissimus dorsi (ribs)	1	5	2	30	10	20
Longissimus dorsi (loin)	10	30	5	20	1	2
Semitend-inosus	2	5	20	30	1	10
Biceps femoris	1	30	5	10	2	20

* See Table 1.

the roasts were removed from the fat the internal temperatures continued to rise, reaching a temperature 2° to 5° C. higher than the temperature upon removal from the fat.

Other data obtained were: (1) the percentage loss in weight during aging and cooking, (2) the percentage decrease in length and width and the percentage increases in thickness of the roasts during cooking, (3) shear force, (4) percentage of press fluid, and (5) palatability scores. The change in weight during aging and cooking were determined by weighing the roasts when first cut and at the end of each aging period and before and after cooking. Changes in length, width, and thickness were determined by taking these measurements of the roasts before and after cooking.

Shear force samples were obtained by boring through the meat in the place specified for each muscle with a sharp edged metal cylinder, one inch in diameter. Each cylinder was cut 3 times by a modified Warner-Bratzler shearing apparatus and the readings, which indicate the number of pounds force required to cut through the sample, were averaged.

Press fluid determinations were run on samples taken from given areas in the roasts. The samples, which weighed between 1 and 2 grams, were wrapped in 2 thicknesses of unsized cotton cloth with pieces of blotter

between the 2 layers of cloth. The wrapped samples were subjected to 250 pounds pressure for 5 minutes, unwrapped and weighed. From these weights the percentage of press fluid for each sample was calculated.

The meat was scored for aroma, flavor, tenderness, and juiciness by four judges. The outside slice was discarded, then the next two slices were used for palatability scores except in the case of roasts from the biceps femoris muscles where only one slice was used. Each judge was given a sample from the same position in every roast.

Histological Studies

Histological studies were made to determine the microscopic changes during the storage of beef and the proportion of connective tissues in the muscles used. Samples from the raw and cooked roasts were preserved in a physiological salt solution and formalin. Longitudinal sections were cut 15 to 25 microns thick on a freezing microtome, stained with Van Geisson's, Weigert's and hematoxylin stains to differentiate collagen, elastin, and muscle fibers, and mounted in glycerine jelly. After this treatment the collagen was a bright pink, the elastin a blue black, and the muscle fibers varied from greenish yellow to yellow orange. The following arbitrary numerical evaluations used by Ramsbottom et al. (24) were used

to compare the relative amount of connective tissues in the muscles:

Relative amount of tissue present	Elastin	Collagen
None	1	1
Small	3	3
Medium	5	5
Large	7	7

pH Measurements

The pH of a sample of muscle from the fore-part of the chuck was determined soon after each animal was slaughtered and at variable intervals after the first measurement was made. Also the pH of raw and cooked samples from each of the roasts was determined. The pH measurements were made on the samples from the fore-part of the chuck within a few minutes after the sample was removed from the carcass. Samples for pH measurements of the raw and cooked roasts were removed from the roasts just before and immediately after cooking. The samples were wrapped in waxed paper and stored in the refrigerator until the measurements were made.

A 15-gram sample of meat was ground with 1 teaspoon of washed sea sand in a mortar and pestal. Distilled water, 30 ml., was well blended with the mixture of meat

and sand. For all pH measurements on samples from animal I the mixture was filtered and the pH measurements were made on the filtrate. All other pH measurements were made on the mash immediately after it was prepared. The process of filtering was omitted to avoid any excess oxidation which might take place.

Because of mechanical difficulties with the pH meters it was necessary to use 3 different pH meters. The pH of each sample from animals I and II was measured on a Coleman pH meter, whereas the pH of each sample which was determined on the day of slaughter of animal III was measured on a MacBeth pH meter, and the pH of each sample from the roasts of animal III and from all samples from animal IV was measured on a Leads-Northrup pH meter.

Tendons and Ligaments

Strips of tendons from around the anterior end of the longissimus dorsi muscle of each animal were heated in distilled water for 15 and 30 seconds and for 1 and 2 minutes at temperatures of 60°, 65°, 70°, and 95° C. Strips from the Achilles tendons were heated at the same temperatures for 1, 2, 3, 5, 10, 15, 20, and 30 minutes. A few additional samples from animal IV were heated for 5 and 10 minutes at 95° C. In the case of the tendons

from around the anterior end of the longissimus dorsi muscle and for 1 and 2 hours at 95° C. in the case of the Achilles tendons. The treated samples were examined for change in length, width, and thickness and for the degree of softening as compared to the untreated samples.

Samples of ligamentum nuchae, which is mostly elastic connective tissue, were heated in distilled water at 70° and at 95° C. for 30 minutes and for 1 and 2 hours. The same data were recorded on these samples as were recorded on the collagenous tissues.

The samples from the two types of tendons were strips from 0.1 to 0.3 centimeters thick, 0.5 and 1.5 centimeters wide, and 10 to 20 centimeters long. The strips of ligamentum nuchae were about the same in length and width as those of the collagenous tissues but varied from 0.3 to 0.8 centimeters in thickness.

DISCUSSION OF RESULTS

Roasts

Weight lost during aging

The roasts were weighed when the muscles were divided, after 24 hours aging, and again at the end of each of the remaining storage periods. The data showing the average percentage of the initial weight lost by the roasts during aging are given in Table 5. These data were not recorded for the roasts from animal I until the 20th day of storage.

Table 5.

Average Percentage Weight Loss of Roasts During Aging (Averages of Four Roasts from Each Muscle).

Muscle	Days Aged					
	1	2	5	10	20	30
Psoas major	0	1.6	3.0	3.7	11.7	17.5
Longissimus dorsi (ribs)	0	1.1	2.2	4.6	8.1	12.2
Longissimus dorsi (loin)	0	0.9	2.2	3.1	9.6	11.5
Semitendinosus	0	0.8	1.2	2.5	9.9	11.6
Biceps femoris	0	0.7	1.5	2.8	10.2	11.5
All muscles	0	1.0	1.8	3.3	9.9	12.9

The weight of roasts from each muscle gradually decreased as storage time increased. In general, the roasts from the psoas major muscle lost the greatest amount of weight and those from the biceps femoris muscle lost the least weight at the various storage periods. Roasts from the psoas major muscles were the smallest, whereas those from the biceps femoris muscles were the largest of all the roasts. Thus, greatest weight loss occurred when the amount of surface area of the roast was large in proportion to the weight of the roast and vice versa. Since the roasts were stored, unwrapped, on enamel trays which were placed on open shelves in the cooler, the loss in weight during aging was largely caused by evaporation of moisture. Gradually the exposed surfaces of the roasts became dark and dry. By the end of the 30-day aging period these surfaces were covered with a dry crust about 1/4 inch thick and occasionally had small areas of mold on them. The surfaces of the meat which were next to the trays were moist and sticky from the 5th day through the 30th day of storage.

The more detailed data, Table 24. (Appendix), show that by the 2nd day of aging, except in the case of the biceps femoris muscle, the roasts from animal II had lost more weight than those from animal III, and those from animal III had lost more weight than the roasts from animal

IV. Since the carcasses of these animals were graded good, commercial, and cutter, respectively, it may be stated that at 2 days storage the weight loss according to grade was: good > commercial > cutter.

Weight lost during cooking

The loss of fats and fluids accounts for most of the decrease in weight of the cooked roasts; however, there is also some loss of exuded proteins and salts. The average percentage weight losses of the roasts during cooking are given in Table 6.

Table 6.

Average Percentage Weight Loss of Roasts During Cooking. (Averages of Four Roasts from Each Muscle).

Muscle	Days Aged					
	1	2	5	10	20	30
Psoas major	20.2	21.8	20.4	16.4	14.3	16.1
Longissimus dorsi (ribs)	25.8	23.2	25.6	21.8	20.9	20.2
Longissimus dorsi (loin)	25.1	25.1	23.9	21.0	20.1	20.6
Semitendinosus	27.6	20.9	23.2	24.3	19.7	23.5
Biceps femoris	27.9	25.7	23.7	20.4	23.6	20.7
All muscles	25.3	23.3	23.3	20.7	19.7	20.4

In general the weight lost during cooking decreased slightly as the aging period increased. Also at each storage period the roasts from the psoas major muscle lost a smaller percentage of weight during cooking than the roasts from other muscles.

Changes in length, width, and thickness during cooking

Averages of data on the decrease in the length of the roasts during cooking are given in Table 7.

Table 7.

Average Percentage Decrease in Length of Roasts During Cooking

Muscle	Days Aged					
	1	2	5	10	20	30
Psoas major	40.1	43.3	37.1	29.0	27.6	26.5
Longissimus dorsi (ribs)	33.0	28.0	29.6	21.9	16.2	25.1
Longissimus dorsi (loin)	28.2	30.0	25.4	31.1	19.0	22.7
Semitendinosus	18.7	31.4	14.5	22.2	18.7	22.7
Biceps femoris	21.8	26.4	20.6	20.0	20.1	19.3
All muscles	28.3	31.8	25.4	24.8	20.3	22.7

In general, the decrease in length of the roasts during cooking was not linearly related to the time of aging

the roasts before cooking. Thus, the decrease in length was greater for the roasts aged 2 days before cooking (31.8 percent) than for those aged 1 day (28.3 percent). With longer aging periods, 5, 10, and 20 days, the decrease in length of the roasts during cooking decreased with longer storage before cooking. However, the roasts aged 30 days decreased more in length (22.7 percent) than those stored 20 days (20.3 percent). The decrease in length of roasts upon cooking do not follow such a regular pattern when individual muscles are followed through the aging periods, but it is interesting that with one exception the decrease in length was always greater during cooking for roasts aged 2 days than for those aged 1 day.

The percentage changes in width and thickness of the roasts during cooking are given in Tables 27 and 28 (Appendix). The data were not averaged because the variation within the roasts from a given muscle was so large that average values would have little meaning. However, all except one of the 120 roasts decreased in width during cooking, and all but one roast increased in thickness during cooking. It is probable that these changes in width and thickness as well as the decreases in length, which occurred during cooking, are influenced by the contraction and swelling of the connective tissue which will be discussed in another section.

Palatability factors

Each roast was scored by four judges for aroma, flavor, juiciness, and tenderness. A score card (Appendix) with a range of from 1 to 10 points was used to evaluate the first three factors. This same score card was used to rate tenderness, but since the variation in tenderness was greater than the variation in the other factors, the judges were permitted to give minus values for tenderness in order to increase the scoring range. Tenderness scores were given on the basis of the number of chews it took to completely masticate a bite of meat of a certain size. The lower points in the scoring range were assigned to the roasts from animals I and II which were aged a short time before cooking. Since the roasts from animals III and IV were less tender than those from animals I and II, it was necessary to increase the scoring range in order to keep the tenderness scores for roasts from animals III and IV consistent with the tenderness scores of the roasts from animals I and II.

The averages of the means of four judges scores for each of the palatability factors are presented in Table 8. There was little variation in aroma and flavor scores of roasts between the 1st and 20th days of aging, but on the 30th day there was a decrease of about 1 point in the scores. The lower scores given for aroma and flavor on the

30th day of storage are accounted for by the musty odor and acid or "high" flavor which the roasts had developed. There was little variation among the muscles in aroma and flavor scores. The aroma and flavor scores are differentiated according to animals in figures 11 and 12. At each aging period roasts from animal IV ranked decidedly lower in aroma and flavor than the roasts from other animals. Roasts from animals I, II, III rated about the same in aroma, but those from animal III scored slightly lower in flavor than animals I and II.

In the main there was little variation in juiciness scores of the roasts up to the 20th day of storage. After 30 days aging the juiciness scores dropped slightly below those of the earlier aging periods. By this time the evaporation of the fluids in the roasts during storage was great enough to reflect in the scores of the cooked roasts. Usually the juiciness of beef cuts left in the carcass increases with storage. In Paul's (22) study the juiciness of the roasts showed a gradual increase with aging, the change being highly significant. However, the roasts in her study were wrapped for storage, thus there was less loss of moisture by evaporation.

The juiciness scores in Table 8 indicate that the roasts from the psoas major muscle were the most juicy, whereas those from the semitendinosus were the least

Table 8.

Averages of the Means of Judges' Scores for Aroma, Flavor, Juiciness, and Tenderness.

Muscle	Days Aged	Aroma	Flavor	Juici-ness	Tender-ness
Psoas Major	1	8.5	8.4	7.7	8.2
	2	8.6	7.9	7.2	8.6
	5	8.1	7.9	7.7	8.6
	10	7.9	8.3	8.7	9.5
	20	7.9	8.1	7.7	9.1
	30	6.5	7.4	6.6	8.9
Longissimus dorsi (ribs)	1	8.2	7.4	7.1	1.8
	2	7.8	7.5	7.7	2.5
	5	7.9	7.5	7.4	4.9
	10	8.2	8.1	7.2	5.7
	20	7.8	7.1	6.6	6.1
	30	6.6	6.9	6.2	7.6
Longissimus dorsi (loin)	1	7.6	6.8	6.7	-0.2
	2	7.5	7.0	7.4	0.7
	5	8.0	7.4	6.7	1.5
	10	7.9	8.0	7.5	5.1
	20	7.7	7.4	6.7	4.8
	30	6.9	6.6	7.0	6.3
Semitend-inosus	1	8.5	7.4	6.6	3.0
	2	7.7	7.9	7.4	3.0
	5	7.9	7.0	6.2	4.2
	10	8.1	7.4	5.5	4.6
	20	7.6	6.8	6.6	6.0
	30	6.8	6.7	5.5	5.4
Biceps femoris	1	8.6	7.6	7.1	-0.5
	2	7.8	7.3	7.2	2.0
	5	8.5	8.1	7.0	2.8
	10	8.8	7.8	7.7	4.1
	20	8.0	7.3	6.6	5.9
	30	7.0	7.0	5.8	5.8
Average of all muscles	1	8.3	7.5	7.0	2.4
	2	7.9	7.5	7.4	3.7
	5	8.0	7.6	7.0	4.4
	10	8.2	7.9	7.3	5.8
	20	7.8	7.3	6.8	6.4
	30	6.8	6.9	6.2	6.7

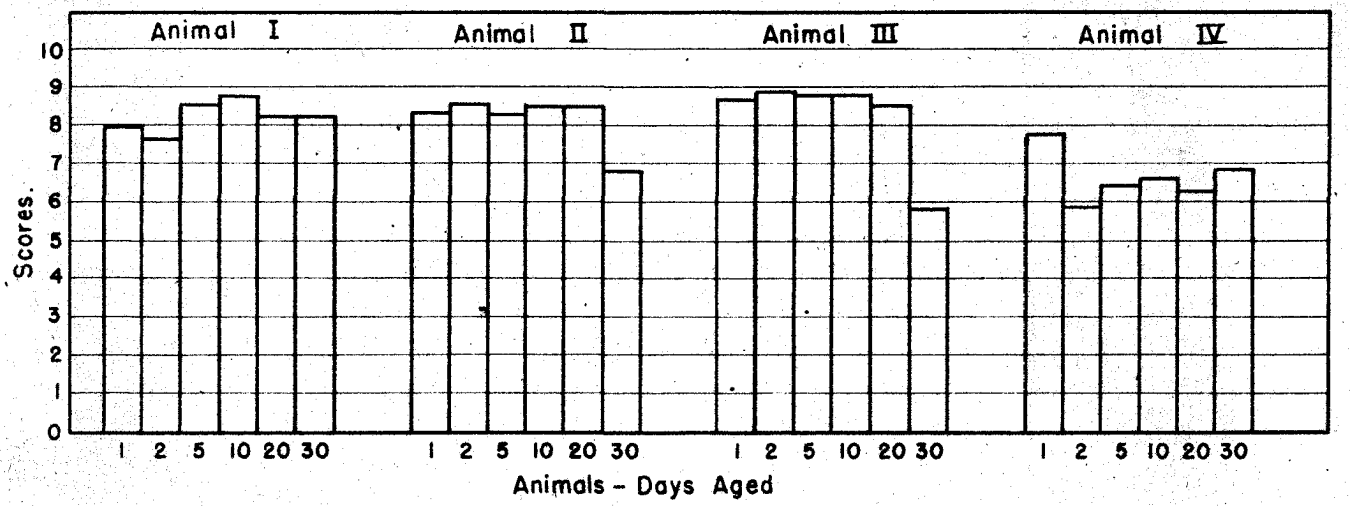


Fig. 11. Aroma Scores of Roasts from Four Animals.

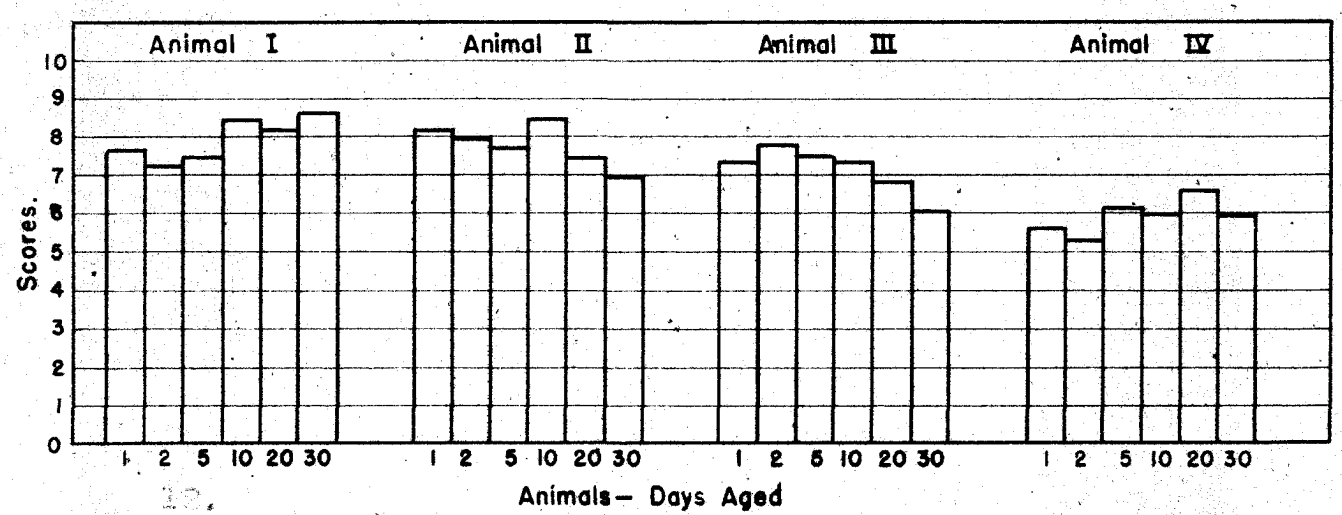


Fig. 12. Flavor Scores of Roasts from Four Animals.

juicy. Roasts from the longissimus dorsi, rib and loin portions, and those from the biceps femoris were similar in juiciness and were rated between those roasts which were scored the most juicy and those which were scored the least juicy. Paul (22) found highly significant differences in juiciness among the roasts from different muscles; the roasts from the semitendinosus, semimembranosus, and adductor muscles were the least juicy, whereas those from the psoas major were the most juicy.

Tenderness scores, which represent an average of all muscles at each aging period, show a gradual increase in tenderness as aging time progresses with greatest increase in tenderness taking place during the 1st 10 days of aging. When each muscle is considered separately, roasts from the psoas major were scored slightly less tender at 20 and 30 days of storage than roasts from the same muscle after 10 days of storage. Average scores of roasts from the semitendinosus muscle decreased only at the 30-day storage period, whereas average scores of roasts from the loin portion of the longissimus dorsi muscle were less tender after 20 days of aging. However, after 30 days of aging the average tenderness score for the roasts from this muscle increased beyond what it was at the 10-day period. The low tenderness score for the roast from animal IV accounts for the low average score for roasts

from the longissimus dorsi (loin) at 20 days of storage. These results are similar to those of Deatherage and Harsham (10). These workers explained toughening during certain periods of the aging process by speculating that connective tissues may maintain their strength for some time during aging, whereas muscle plasma autolyzes and loses tensile strength, but remains firm or brittle. Thus the muscle plasma gives the taster a mechanical advantage in chewing the connective tissue by shearing. With such mechanical advantage the connective tissue may be effectively masticated by the taster, hence to him the meat is tender. If aging proceeds further to the point where the connective tissue is not yet effectively reduced but where the plasma is autolyzed to give still less firmness, then the connective tissue has lost the supporting substance. Since the mechanical advantage is lost to the taster the meat seems tough and chewy to him. With still further aging the connective tissue finally loses strength and the meat again becomes more tender.

At each aging period the roasts from the psoas major muscle were scored from 45 to 62 percent more tender than the roasts from any of the other muscles. This is in accord with the work of Ramsbottom et al. (24). The other muscles ranked in tenderness as follows: longissimus dorsi (ribs)> semitendinosus > biceps femoris > longissimus dorsi (loin). The rank of the longissimus dorsi (loin) may be

accounted for by the scores given to the roasts from this muscle on the 1st to 5th days of storage. However, by the 10th day of aging this muscle scored higher than the semitendinosus or the biceps femoris; at the 20th day it scored less than these muscles, but after 30 days aging it again rated higher than either the semitendinosus or the biceps femoris. See Table 32 (Appendix).

The results of analysis of variance of the tenderness scores are given in Table 8a.

The F values show that change in tenderness with aging, the variation among the animals, and the variation among muscles were all great enough to be highly significant. Also when the interaction between days x animals, animals x muscles, and days x muscles is considered, the F. values were highly significant. When the effect of individual judges was added to the picture the F values show that there was a highly significant difference among judges and the interaction factors judges x days, judges x animals, judges x muscles, and judges x days x muscles.

Table 8a.

Analysis of Variance of Tenderness Scores

Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Days aged	5	1087.90	217.58	13.71**
Animals	3	969.50	323.17	10.01**
Muscles	4	2064.15	516.04	49.48**
D x A	15	223.30	14.89	2.67**
A x M	12	399.43	33.29	6.40**
D x M	20	346.20	17.31	3.33**
D x A x M	60	312.02	5.20(error)	
Judges	3	572.32	19.08	6.81**
J x D	15	202.08	13.47	4.81**
J x A	9	269.11	29.90	10.67**
J x M	12	96.36	8.03	2.86**
J x D x A	45	245.79	5.46	1.95**
J x A x M	36	103.80	2.88	1.03
J x D x M	60	152.49	2.54	1.10
J x D x M x A	180	503.55	2.80(error)	
Total	479	7548.00		

Objective tests

Shear force and press fluid values were determined on the cooked roasts. The force in pounds required to shear a cylinder of meat 1 inch in diameter is given in Table 33 (Appendix). Each figure represents the mean of 3 readings. Averages of these means are given in Table 9.

Table 9.

Averages of the Mean Shear Force Readings of Cooked Roasts

Muscle	Days Aged 1	2	5	10	20	30
Psoas major	18.7	19.7	18.0	16.7	15.5	-
Longissimus dorsi (ribs)	34.4	28.3	25.1	24.3	27.0	19.0
Longissimus dorsi (loin)	30.4	35.5	29.7	26.0	23.7	18.1
Semitendinosus	38.8	29.0	28.1	31.5	28.7	25.3
Biceps femoris	29.8	31.7	28.3	23.8	21.4	23.1
Average of all muscles	30.4	28.8	26.7	25.3	24.0	21.5

When the average shear force for all muscles is considered, the shear force, like the tenderness scores, shows a gradual increase in tenderness as the aging time progresses. The high shear force of the roasts cooked after

short aging periods checks with the low tenderness scores for these roasts, since the higher the shear force the less tender the meat. This is in accord with the work of Paul (22), who found that the shear force of roasts varied highly significantly with storage, and with the work of Mackintosh, Hall, and Vail (17), who reported a significant correlation between judges scores and shear force readings.

When each muscle is considered separately the decrease in shear force with storage was not linear, that is, at some time during the aging process each muscle decreased in tenderness. Similarly to tenderness scores, the shear force rated the roasts from the psoas major muscle the most tender. The other muscles ranked in tenderness as follows: the longissimus dorsi (ribs) > biceps femoris > longissimus dorsi (loin) > semitendinosus. This agrees with the report of Paul (22) in which shear force values rated the psoas major more tender than the biceps femoris and the biceps femoris more tender than the semitendinosus. According to shear force values reported by Ramsbottom et al. (24) the order of decreasing tenderness of these muscles is: psoas major, longissimus dorsi, biceps femoris, and semitendinosus.

A comparison of the shear force readings and the

tenderness scores at each aging period is given for the muscles from the individual animals in figures 13 to 20.

Three press fluid determinations were made on each roast. The means of these determinations are given in Table 34 (Appendix). Averages of the means of the press fluid determinations are presented in Table 10.

Table 10.

Averages of the Means of the Percentage of Press Fluid in the Cooked Roasts.

Muscle	Days Aged					
	1	2	5	10	20	30
Psoas major	38.8	40.0	39.3	36.3	36.9	35.6
Longissimus dorsi (ribs)	36.9	35.5	36.4	40.6	46.1	33.6
Longissimus dorsi (loin)	38.5	41.0	40.6	38.7	39.8	40.2
Semitendinosus	36.5	39.5	38.4	34.1	39.8	40.2
Biceps femoris	44.5	41.3	39.9	42.5	35.9	39.2
Average of all muscles	39.1	39.5	38.9	38.4	38.7	37.0

In general, there is little variation in the average percentage of press fluid of the roasts during the 1st 20 days of aging. With 30 days of aging the average percentage of press fluid in the roasts decreased slightly below that found in the roasts aged from 1 to 20 days.

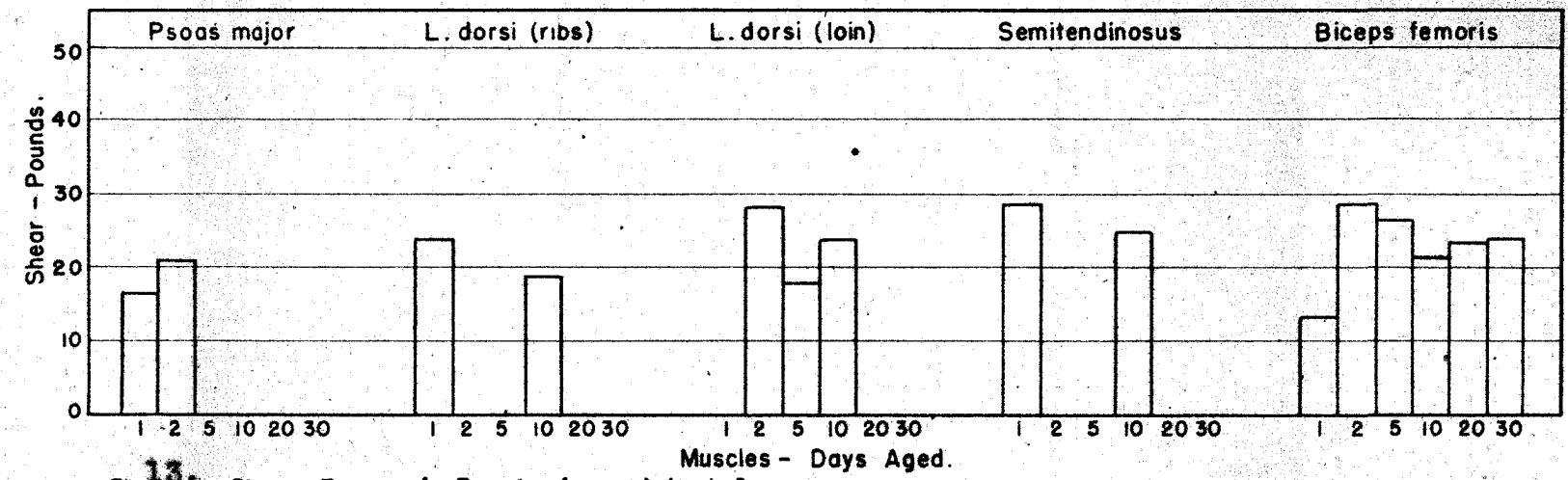


Fig. 13. Shear Force of Roasts from Animal I.

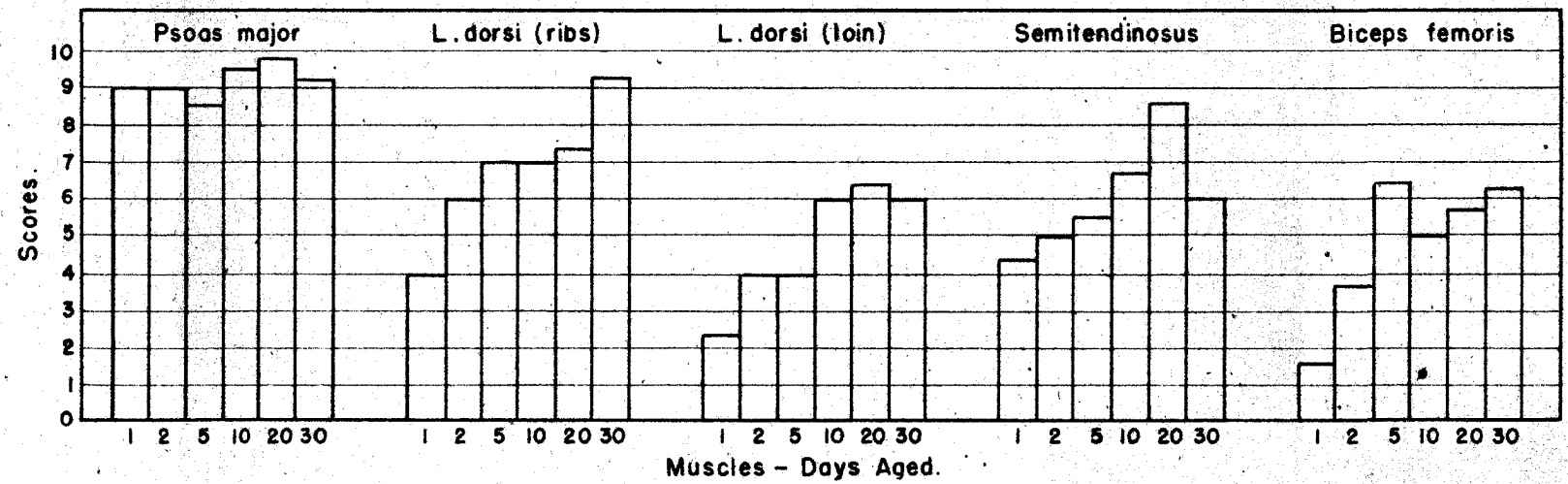


Fig. 14. Tenderness Scores of Roasts from Animal I.

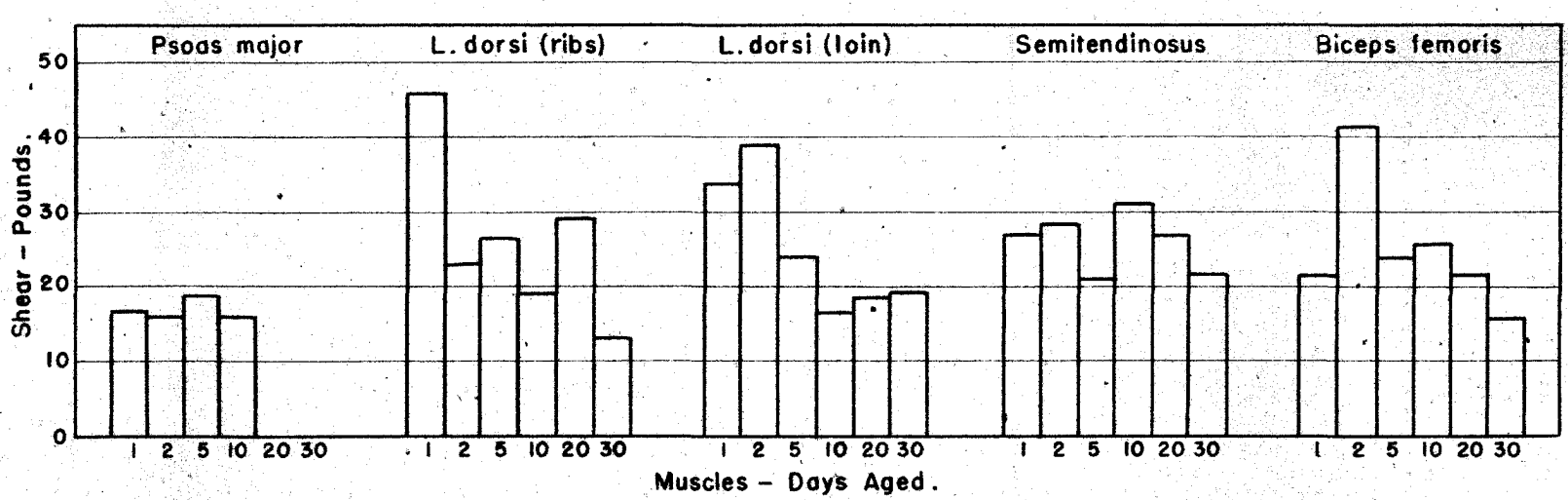


Fig.15. Shear Force of Roasts from Animal II.

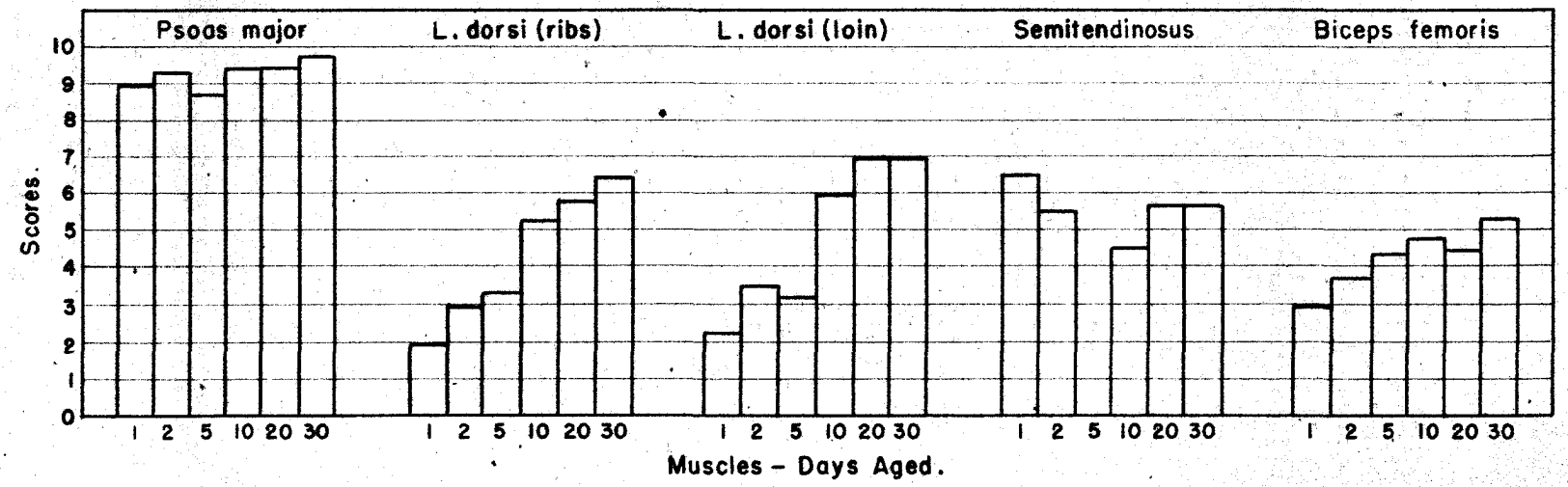


Fig.16. Tenderness Scores of Roasts from Animal II.

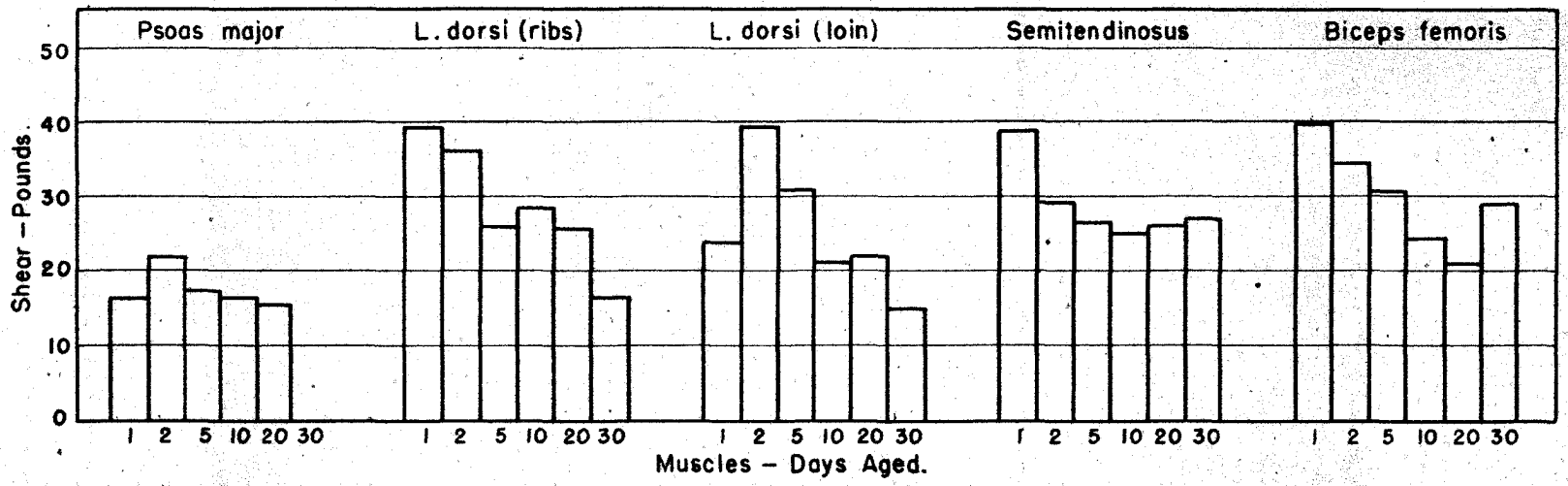


Fig. 17. Shear Force of Roasts from Animal III.

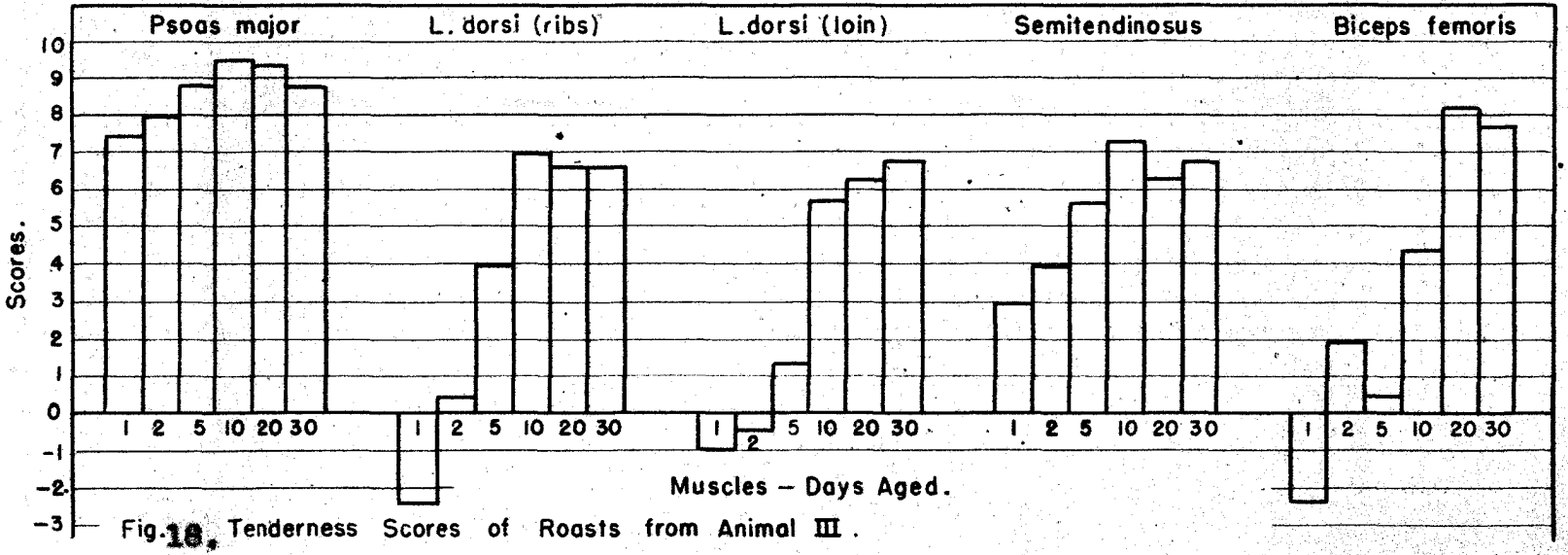


Fig. 18. Tenderness Scores of Roasts from Animal III.

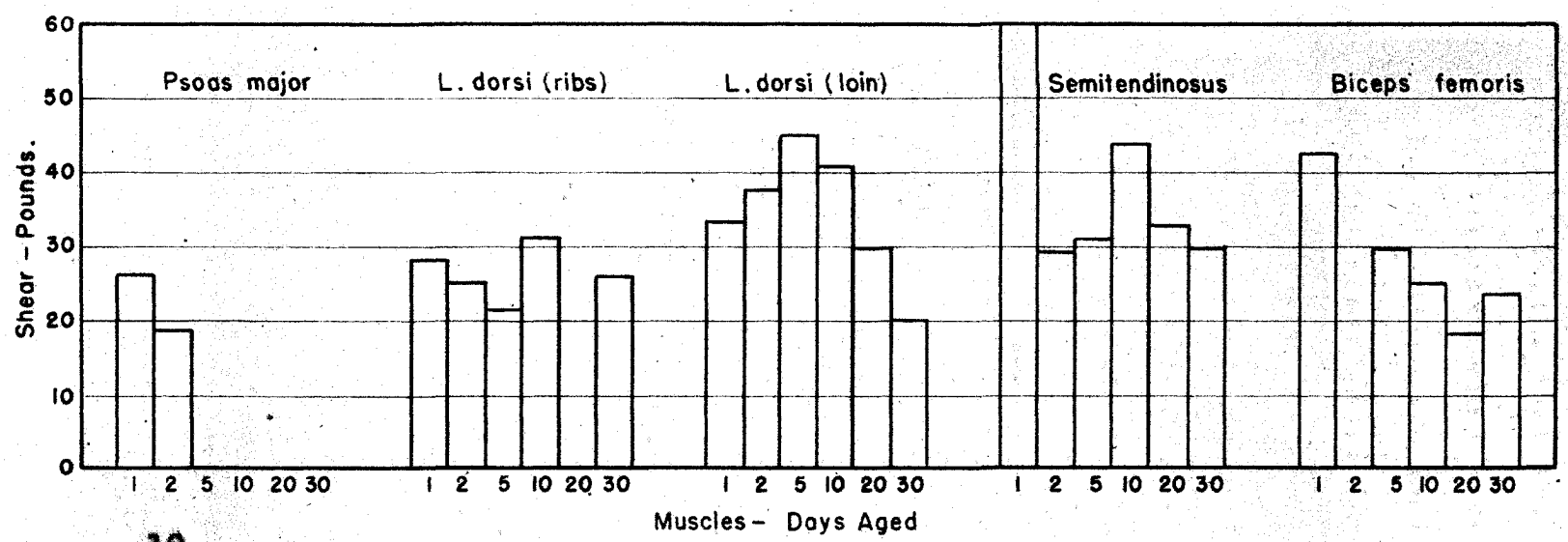


Fig. 19. Shear Force of Roasts from Animal IV.

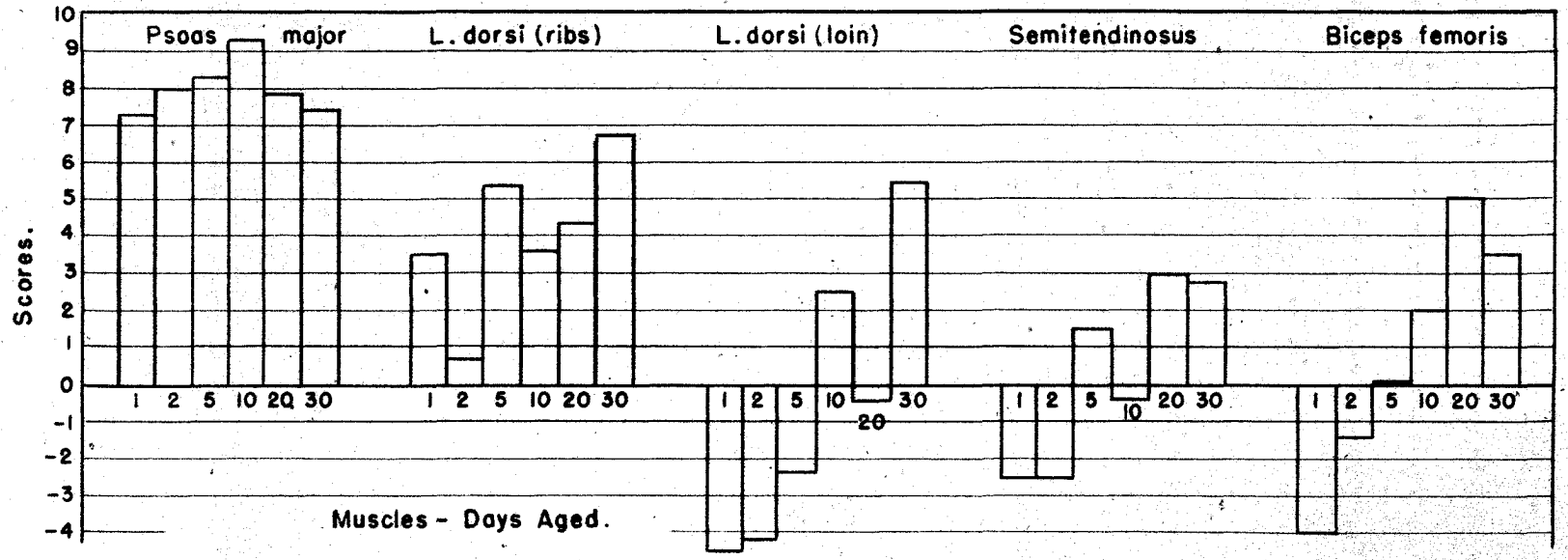


Fig. 20. Tenderness Scores of Roasts from Animal IV.

Average juiciness scores followed the same pattern. However, when the differences in juiciness scores among the muscles are considered, the results of juiciness scores and press fluid determinations do not agree. Paul (22) also found there was very little correlation between juiciness scores and press fluid.

The pH measurements of samples of muscle cut from the fore-part of the chuck of each animal soon after slaughter and at various intervals thereafter are given in Table 11.

Table 11.

pH Readings of the Animals After Slaughtering and at Various Intervals Thereafter

Animal	Time After Slaughtering Hours	Minutes	pH Measurement
I	1	15	6.35
II	0	40	6.69
	1	20	6.60
	2	15	6.60
	4	05	6.38
	6	30	6.26
III	0	50	7.30
	1	50	6.92
	3	05	6.80
	5	45	6.62
	7	05	6.79
IV	0	10	6.85
	0	50	6.61
	1	35	6.65
	2	35	6.56
	8	00	6.14

The data for animals II, III, and IV show an acidification of muscle post mortem. The rate of acidification varies among the animals. The pH measurements made at approximately the same time after slaughtering the animals also vary from animal to animal. These results are in line with those of Smith (29) who reported extraordinary variability in pH from animal to animal and from one area to another in a given muscle.

The average pH readings of the cooked and uncooked roasts are given in Table 12.

The results of the uncooked roasts indicate a change in pH with storage of the roasts. The general pattern of the change in pH was a slight drop in pH followed by a slow rise. Paul (22) reported similar results for pH changes in aged beef. In her study the change in the pH of the meat stored from 0 to 18 days was great enough to be highly significant. The difference in pH among muscles was very small. At any given period up to 20 days of storage the range in the pH of the muscle with the lowest pH to the muscle with the highest pH was less than 0.2 of a point. However, after 30 days of storage this range was 0.55 of a point.

During storage the change in the pH of the cooked roasts did not follow a regular pattern. However, at all aging periods the average pH of the cooked roasts from

Table 12.

Average pH Readings
of Cooked and Uncooked Roasts

Muscle	Days Aged 1	2	5	10	20	30
Psoas Major						
Uncooked	5.58	5.51	5.50	5.61	5.63	6.21
Cooked	5.82	5.74	5.79	5.78	5.74	5.79
Longissimus dorsi (ribs)						
Uncooked	5.48	5.42	5.48	5.44	5.50	5.66
Cooked	5.80	5.77	5.78	5.86	5.78	5.89
Longissimus dorsi (loin)						
Uncooked	5.48	5.44	5.44	5.47	5.45	5.98
Cooked	5.75	5.76	5.76	5.85	5.70	6.09
Semitendinosus						
Uncooked	5.41	5.46	5.51	5.50	5.52	5.74
Cooked	5.72	5.74	5.81	5.74	5.70	5.81
Biceps femoris						
Uncooked	5.39	5.43	5.43	5.45	5.48	5.79
Cooked	5.71	5.74	5.70	5.71	5.73	5.76
Average of all muscles						
Uncooked	5.47	5.45	5.47	5.49	5.51	5.88
Cooked	5.76	5.74	5.77	5.78	5.73	5.87

every muscle was slightly higher (0.4 of a point or less) than that of the uncooked roasts except in the cases of the biceps femoris and psoas major muscles after 30 days of storage. Bendall (4) found a considerable shift in pH to the alkaline side when beef was cooked at 100° C. for one hour. He stated that this shift in pH is a reflection of the molecular changes undergone by the proteins, of which the formation of free sulfhydryl groups, observed during coagulation, is one example. There are also other factors such as the loss of carbon dioxide during cooking which may contribute to this change in pH.

The Connective Tissues

Tendons.

Strips of tendons from around the anterior end of the longissimus dorsi muscle of each animal and strips of Achilles tendons from each animal were heated in distilled water at given temperatures for definite periods of time. The first type of tendons were all about the same width and thickness, but there was a little variation in the width and thickness of the strips of Achilles tendons because they had to be cut. The heated samples were examined for change in length, width, and thickness and for the degree of softening as compared to the

untreated samples.

The percentage decrease in length of the heated strips of tendons is given in Tables 13 and 14. The data in Table 14 show that the strips of tendons from around the anterior end of the longissimus dorsi muscle decreased in length as the temperature of the water in which they were heated increased. Also at each temperature these strips decreased in length as the time of treatment increased up to one minute. With two minutes of heating at each temperature the decrease in length was always less than it was after one minute of heating. At 60°, 65°, and 70° C. the samples gradually shortened, whereas at 95° C. the greater amount of the shortening occurred almost as soon as the sample was surrounded with water.

The strips of Achilles tendons were more dense than those of the tendons from around the anterior end of the longissimus dorsi muscle. Hence, they were heated in distilled water at the two higher temperatures and for longer periods than the strips of tendons from around the anterior end of the longissimus dorsi muscle. With this modified treatment the strips of Achilles tendons decreased in length similarly to the strips of tendons from around the anterior end of the longissimus dorsi muscle. For both types of tendons and with a given

Table 13.

Tendons from Around the Anterior End of the Longissimus dorsi Muscle: Percentage Decrease in Length of Strips Heated in Distilled Water.

Time Heated	Animal	Temperature of Water, °C. 60		65		70		95	
		A	B	A	B	A	B	A	B
15 seconds	I		2.8	11.1	15.1	31.0	60.0	66.7	69.1
	II	1.7	2.4	13.7	21.4	53.3	69.4	70.8	73.1
	III	1.7	4.0	4.2	5.0	42.1	61.6	57.9	61.1
	IV	1.2	1.2	1.7	8.7	45.8	57.4	61.9	64.4
30 seconds	I	-	-	-	-	-	-	-	-
	II	5.5	7.8	11.1	29.3	61.7	67.7	65.6	66.7
	III	1.0	3.7	4.4	5.7	32.4	46.3	58.3	68.1
	IV	0.7	3.5	20.	21.9	33.3	37.2	67.2	74.1
1 minute	I	-	-	-	-	-	-	-	-
	II	32.5	35.6	45.5	50.0	60.0	61.2	69.4	69.9
	III	5.9	10.5	28.5	33.1	62.1	66.2	56.4	56.5
	IV	5.6	5.9	4.3	13.3	39.0	40.2	71.9	75.8
2 minutes	I	-	-	-	-	-	-	-	-
	II	20.0	26.2	34.6	45.0	36.6	44.2	50.8	64.3
	III	2.9	16.6	42.4	43.5	53.1	54.3	73.0	73.8
	IV	2.8	3.7	65.8	65.9	43.0	60.9	74.6	78.5

A, B - Samples from the same animal

Table 14.

Achilles Tendons: Percentage Decrease in Length of Strips Heated in Distilled Water.

Time Heated (Minutes)		Temperature of Water, °C. 70				95			
		I	II	III	IV	I	II	III	IV
1	A	35.7	26.9	43.9	42.7	55.0	43.3	63.1	52.1
	B	45.0	33.6	54.5	-	55.0	48.7	63.4	-
2	A	65.0	34.2	49.4	45.9	71.4	48.0	56.9	62.7
	B	67.9	42.5	51.1	-	72.2	48.5	60.0	-
3	A	-	61.4	59.1	52.4	-	41.9	59.0	64.6
	B	-	63.0	63.8	55.7	-	46.5	61.6	64.9
5	A	-	58.6	49.6	51.7	51.0	55.0	37.6	60.5
	B	-	63.0	60.0	55.7	68.2	59.2	57.1	61.7
10	A	-	62.5	-	50.0	-	68.8	-	56.9
	B	-	63.7	-	51.1	-	69.3	-	62.9
15	A	-	52.1	-	-	53.1	64.4	-	-
	B	-	56.4	-	-	59.2	69.8	-	-
20	A	-	55.0	-	55.3	57.1	54.5	-	66.5
	B	-	63.9	-	56.9	58.3	55.0	-	-
30	A	-	50.5	-	68.4	39.0	53.8	-	67.6
	B	-	53.9	-	-	43.8	59.1	-	-

I, II, III, IV - Animal numbers.
A, B - Samples from the same animal.

treatment there was considerable variation in the decrease in length between two samples from the same animal and among samples from different animals. This variation occurred in spite of the fact that the two samples, A and B, from the same animal had been aged the same period of time and were heated simultaneously. Therefore, average values for the effect of hot water on the decrease in the length of tendons would have little meaning unless there were many more samples for each treatment.

The temperatures used in the heating of the tendons were selected for the following reasons:

1. Temperatures of 60° and 65° C. were used because the more tender muscles are often cooked to the rare stage and at this stage of cooking the interior temperature of the meat is 58° to 60° C. Also in preliminary studies on tendons from lamb that were heated in distilled water in which the temperature of the water was gradually raised from 25° to 95° C., the first noticeable shortening of the tendons came over a temperature range of 55° to 70° C.

2. A temperature of 70° C. was used because the roasts in this study were cooked to an internal temperature of 70° C.

Table 15.

Tendons from Around the Anterior End of the Longissimus dorsi: Shear Force* of Strips Heated in Distilled Water. (The shear force of unheated tendons was more than 60 pounds, the capacity of the shearing apparatus).

Time Heated	Animal	Temperature of Water, °C. 60		65		70		95	
		A	B	A	B	A	B	A	B
15 Seconds	I	29.8	x	x	x	13.3	18.5	6.1	7.5
	II	x	x	17.6	17.8	7.8	8.9	4.4	6.6
	III	x	x	x	x	10.5	15.1	7.0	12.3
	IV	x	x	x	x	x	x	46.4	48.0
30 Seconds	I	-	-	-	-	-	-	-	-
	II	x	x	12.8	13.0	5.0	5.1	2.9	3.8
	III	x	x	x	x	18.4	20.4	6.0	8.8
	IV	x	x	x	x	x	x	36.1	42.5
1 Minute	I	-	-	-	-	-	-	-	-
	II	x	x	10.0	10.8	5.7	5.7	5.3	5.7
	III	x	x	14.3	32.2	3.9	6.3	5.0	6.9
	IV	x	x	x	x	47.9	52.2	26.4	36.5
2 Minutes	I	-	-	-	-	-	-	-	-
	II	x	x	10.7	14.2	7.0	7.6	3.2	7.0
	III	x	x	10.4	12.2	6.0	6.7	4.3	6.8
	IV	x	x	x	50.4	39.2	53.3	14.6	15.9

* Average of 3 shears, in pounds.
x - Samples would not shear at 60 pounds.
A, B - Samples from the same animal.

Table 16.

Achilles Tendons: Shear Force* of Strips Heated in Distilled Water.
(The shear force of unheated tendons was more than 60 pounds, the capacity of the shearing apparatus).

Time Heated (Minutes)		Temperature of Water, °C. 70				95			
		I	II	III	IV	I	II	III	IV
1	A	x	x	x	x	19.5	x	x	x
	B	48.8	x	x	-	21.8	x	x	-
2	A	x	x	x	x	49.4	25.5	27.0	43.2
	B	x	x	x	-	58.4	29.8	27.8	-
3	A	-	x	x	x	-	18.0	11.4	48.0
	B	-	x	x	x	-	18.4	14.7	48.3
5	A	-	46.4	46.8	x	6.8	13.2	13.1	43.6
	B	-	46.9	51.1	x	x	13.8	15.7	44.2
10	A	-	51.7	-	52.2	-	32.6	-	40.7
	B	-	52.5	-	53.9	-	47.8	-	42.0
15	A	-	3.8	-	-	17.7	34.7	-	-
	B	-	5.0	-	-	30.5	35.5	-	-
20	A	-	5.0	-	53.6	8.8	1.6	-	34.4
	B	-	5.3	-	53.8	11.3	2.2	-	-
30	A	-	2.9	-	25.2	3.6	0.9	-	30.8
	B	-	3.2	-	-	3.3	0.9	-	-

* Average of 3 shears, in pounds.
x - Samples would not shear at 60 pounds.
A, B - Samples from the same animal.

tendons decreased. This indicates a softening of the tendons with an increase in the temperature of the water. In general, there was an increase in the softening of the samples as the time of heating at a given temperature was increased. Since most of the samples heated in water held at the two lower temperatures would not shear at 60 pounds (the capacity of the shearing apparatus) the greater softening with increased time of heating was more noticeable at the two higher temperatures. The data also show a wide variation in the shear force of samples with a given treatment but from the different animals, and in some cases there was variation between the two samples from the same animal which were treated identically. The shear force of the samples from animal IV, carcass grade cutter, was from 3 to 12 times higher than the shear force of the samples from animals I, II, and III. The differences in the shear force of the samples from the same animal and with the same treatment may be attributed to the variation in the compactness of the bundles of collagen fibers in the tendons. Also the method of handling the samples before heating may have had some effect on the shear force. The tendons and ligaments were removed from the carcass and the visible fat and muscle scraped from them. They were kept in the refrigerator in distilled water, which contained a crystal of thymol, to

prevent dehydration. Previous experience had shown that if they dried out, they were exceedingly tough and would not hydrate well when heated in water. There was no definite storage time before heating for the tendons and ligaments, but the two samples, A and B, from the same animal and with a given treatment were stored for the same length of time. The tendons from around the anterior end of the longissimus dorsi, animal I, were treated after a storage period of 5 weeks, and the Achilles tendons from this animal were heated 6 weeks after removal from the carcass. For the samples from animal II the storage time was 1 to 3 weeks for the tendons from around the anterior end of the longissimus dorsi and 3 weeks for the strips of Achilles tendons. All samples of tendons from animal III were treated 1 to 1.5 weeks after removal from the carcass and those from animal IV were heated after 3 weeks of storage. The ligaments from all animals were heated at the same time which was after 7, 4, 3, and 2 months storage for animals I, II, III, and IV, respectively.

The shear force of strips of the dense Achilles tendons treated at 70° and 95° C. was greater than that of the tendons from around the anterior end of the longissimus dorsi muscle which were treated at the same temperatures and for the same periods of time (1 and 2 minutes). However, after 20 to 30 minutes treatment the strips of

the dense tendons required little force for shearing except in the case of the samples from animal IV. Strips of tendons from animal IV had somewhat less shear force after 1 and 2 hours treatment at 95° C. (23 and 14 pounds, respectively) than the samples from this animal which were treated for 30 minutes.

Bendall (4) explained that the softening of collagen is the second of three steps which occur in the conversion of collagen to gelatin. First, at 56° to 60° C. there is a shift from collagen A to collagen B which brings about a shortening of the fiber; second, there is the uptake of water by collagen B and the consequent swelling and softening of the connective tissue; and third, the dissolution of collagen B to form a gelatin sol. The last step occurs under ordinary cooking conditions only after prolonged cooking. Cherbuliez et al. (6) described a softening of collagen as an irreversible process which was actually hydrolysis resulting in a decrease in mechanical strength, appearance of plasticity, and finally solution into gelatin.

Chemical analysis for the percentage of collagen and elastin in samples from the roasts used in this study are now in progress. The data collected on the samples from animal I indicate that the amount of collagen and elastin in the roasts did not decrease regularly during aging and that there was not much transformation of

collagen to gelatin during cooking. The latter finding agrees with the report of Bendall (4).

There has been controversy in the literature as to which is the more tender, raw or cooked meat. Moran and Smith (21) stated: "It is a matter of general experience amongst those accustomed to raw meat that cooked meat is tougher than raw meat". Ramsbottom et al. (24) found that 6 of the 25 muscles studied were more tender after cooking; the other 19 muscles were less tender after cooking. The muscles which were more tender after cooking were muscles that contained large amounts of connective tissue. These investigators also demonstrated that both collagenous and elastic connective tissue softens when cooked, the collagenous tissue softening more than the elastic tissue. The results of the present study confirm the work of Ramsbottom et al. (24). The collagenous tissues became softer as the time and temperature of heating in water increased. Thus, cuts of meat containing large amounts of connective tissue tenderize during cooking because the connective tissue softens when the meat is cooked for several hours by moist heat. Since connective tissue softens during cooking any decrease in the tenderness of meat that occurs during cooking is probably associated with such factors as denaturation of the muscle proteins and the shrinkage and hardening of the muscle fibers.

The data for the percentage increase in the width of the two types of tendons which were treated are given in Tables 17 and 18. The increase in the width of the treated samples followed no regular pattern except that at 95° C. all samples did increase in width and at 70° C. all but a few samples increased in width. However, the range of the increases in width which occurred at these temperatures was very great. At 60° C. only two samples of the tendons from around the anterior end of the longissimus dorsi muscle increased in width and at 65° C. about half of the treated samples increased in width.

The percentage increases in the thickness of the treated samples are given in Tables 19 and 20. None of the samples heated in water held at a temperature of 60° C. increased in thickness during the treatment, whereas, 4 of the 26 samples treated at 65° C. increased as much as 200 and 400 percent of their initial thickness. At 70° and 95° C. a larger number of the samples increased in thickness. The strips of tendons from around the anterior end of the longissimus dorsi muscle showed a greater increase in thickness after heating for 1 and 2 minutes than they did after heating for 15 and 30 seconds.

Table 17.

Tendons from Around the Anterior End of the Longissimus dorsi Muscle: Percentage Increase in Width of Strips Heated in Distilled Water.

Time Heated	Animal	Temperature of Water, °C.							
		60		65		70		95	
		A	B	A	B	A	B	A	B
15 Seconds	I	0	0	36.4	60.0	15.3	18.1	11.1	80.0
	II	0	0	0	0	33.3	66.7	42.9	66.7
	III	0	0	0	0	23.1	50.0	28.6	38.5
	IV								
30 Seconds	I	-	-	-	-	-	-	-	-
	II	10.0	25.0	7.1	11.1	25.0	50.0	38.9	53.3
	III	0	0	0	0	0	33.3	36.4	66.6
	IV	0	0	33.3	50.0	25.0	25.0	33.3	37.5
1 Minute	I	-	-	-	-	-	-	-	-
	II	0	0	0	0	36.5	61.5	14.3	21.4
	III	0	0	0	0	60.0	85.7	36.4	44.4
	IV	0	0	33.3	40.0	28.6	60.0	66.6	100.0
2 Minutes	I	-	-	-	-	-	-	-	-
	II	0	0	0	11.1	15.4	15.4	25.0	25.0
	III	0	0	0	0	18.2	20.0	36.4	80.0
	IV	0	0	33.3	100.0	40.0	80.0	37.5	75.0

A, B - Samples from the same animal.

Table 18.

Achilles Tendons: Percentage Increase in Width of Strips Heated in Distilled Water.

Time Heated (Minutes)		Temperature of Water, °C. 70				95			
		I	II	III	IV	I	II	III	IV
1	A	10.0	0	0	22.2	10.0	33.3	60.0	25.0
	B	25.0	0	0	-	12.5	33.3	87.5	-
2	A	60.0	0	25.0	22.2	25.0	33.3	50.0	40.0
	B	75.0	0	33.3	-	33.3	33.3	50.0	-
3	A	-	66.7	33.3	28.6	-	33.3	40.0	50.0
	B	-	100.0	57.0	28.6	-	33.3	66.7	50.0
5	A	-	60.0	50.0	10.0	36.4	33.3	33.3	9.1
	B	-	133.0	50.0	20.0	75.0	33.3	75.0	20.0
10	A	-	33.3	-	22.2	-	66.7	-	25.0
	B	-	33.3	-	25.0	-	66.7	-	36.4
15	A	-	28.6	-	-	11.1	80.0	-	-
	B	-	60.0	-	-	33.3	80.0	-	-
20	A	-	60.0	-	20.0	37.5	80.0	-	62.5
	B	-	60.0	-	20.0	44.4	100.0	-	-
30	A	-	33.3	-	50.0	18.2	50.0	-	100
	B	-	60.0	-	-	20.0	60.0	-	-

I, II, III, IV - Animal number.
A, B - Samples from the same animal.

Table 19.

Tendons from Around the Anterior End of the Longissimus dorsi Muscle: Percentage Increase in Thickness of Strips Heated in Distilled Water.

Time Heated	Animal	Temperature of Water, ° C. 60		65		70		95	
		A	B	A	B	A	B	A	B
15 Seconds	I	0	0	0	0	0	0	0	0
	II	0	0	0	0	100	100	100	100
	III	0	0	0	0	0	0	100	100
	IV	0	0	0	0	0	0	100	200
30 Seconds	I	-	-	-	-	-	-	-	-
	II	0	0	0	0	100	100	100	100
	III	0	0	0	0	0	0	100	100
	IV	0	0	0	0	0	0	100	100
1 Minute	I	-	-	-	-	-	-	-	-
	II	0	0	0	0	0	0	0	50.5
	III	0	0	0	0	100	100	100	100
	IV	0	0	0	0	100	100	400	400
2 Minutes	I	-	-	-	-	-	-	-	-
	II	0	0	100	100	100	100	100	200
	III	0	0	0	0	100	100	400	400
	IV	0	0	200	400	100	100	200	200

A, B - Samples from the same animal.

Table 20.

Achilles Tendons: Percentage Increase in Thickness of Strips Heated in Distilled Water.

Time Heated (Minutes)		Temperature of Water, 70° C.				Temperature of Water, 95° C.			
		I	II	III	IV	I	II	III	IV
1	A	100	0	0	0	50.0	0	50.0	0
	B	150	0	0	-	150	50.0	80.0	-
2	A	100	0	0	450	300	50.0	150	150
	B	400	0	0	-	300	50.0	300	-
3	A	-	200	100	100	-	0	133	100
	B	-	300	200	100	-	0	133	150
5	A	-	100	100	100	20.0	150	33.3	200
	B	-	200	100	100	100	150	75.0	200
10	A	-	100	-	150	-	100	-	150
	B	-	100	-	200	-	100	-	150
15	A	-	100	-	-	20.0	200	-	-
	B	-	100	-	-	150	200	-	-
20	A	-	0	-	150	50	100	-	200
	B	-	100	-	150	100	100	-	-
30	A	-	100	-	200	100	100	-	300
	B	-	100	-	-	150	100	-	-

I, II, III, IV - Animal numbers.
A, B - Samples from the same animal.

Ligaments

Strips of ligamentum nuchae, which is mostly elastic connective tissue, were heated in distilled water at 70° and 95° C. for 30 minutes and for 1 and 2 hours. The same data were recorded on these samples as were recorded on the collagenous tissues. The effect of the treatment on the change in the length of the samples is illustrated by the data in Table 21.

Table 21.

Ligamentum Nuchae: Percentage Change in Length of Strips Heated in Distilled Water. (All figures represent a decrease in length except those indicated +.)

Time Heated (Hours)		Temperature of Water, ° C. 70				95			
		I	II	III	IV	I	II	III	IV
1/2	A	6.1	6.7	4.8	3.8	6.1	6.9	12.5	11.5
	B	7.1	9.2	5.5	8.2	13.2	7.9	17.0	13.5
1	A	8.0	5.6	6.7	6.9	+8.2	5.9	10.1	11.1
	B	20.0	8.4	16.2	12.0	+8.6	6.6	12.1	27.3
2	A	6.4	7.7	11.8	12.4	7.0	10.3	5.9	12.5
	B	8.8	10.9	14.7	18.5	10.0	19.7	7.0	16.7

I, II, III, IV - Animal numbers
A, B - Samples from the same animal

The strips of elastic tissue decreased in length with the treatments, but the decrease was small when compared to that occurring in the collagenous tissues heated at the same temperatures for much shorter periods. In general, at 70° C. the effect of the treatment on the length of the elastic tissues was greater as the time of the treatment increased, but this did not hold true at 95° C.

Shear force values for untreated and treated strips of ligamentum nuchae are given in Table 22.

Table 22.

Ligamentum Nuchae: Shear Force of Untreated Strips and Strips Heated in Distilled Water. (Average of 3 Shears, in Pounds)

		I	II	III	IV
Untreated	A	25.8	32.7	45.6	30.0
	B	29.9	41.5	44.3	35.0

Time Heated (Hours)		Temperature of Water, 70° C. I	II	III	IV	95° C. I	II	III	IV
1/2	A	12.8	11.0	10.4	11.8	12.7	9.0	15.2	14.9
	B	15.6	16.7	12.7	12.0	14.4	12.1	15.8	16.0
1	A	15.1	13.9	10.9	11.0	10.2	9.8	12.1	10.8
	B	16.4	22.8	12.1	11.7	10.3	11.6	14.8	20.5
2	A	15.7	11.9	10.8	12.2	7.9	7.8	10.4	11.0
	B	19.1	13.9	15.7	12.8	8.9	9.8	13.7	11.6

I, II, III, IV - Animal numbers
A, B - Samples from the same animal

The most outstanding feature of these data is the difference in the shear force values of the treated and untreated samples. After heating in water the samples were from 2 to 4 times more tender than they were before they were treated. There was little difference in the shear force of the samples heated at 70° and those treated at 95° C. except that at 95° C. the samples heated for the longer periods (1 and 2 hours) had lower shear force values than those treated for one-half hour. The time of heating had no effect on the shear force of samples treated at 70° C. These results are contrary to the idea that cooking has no effect on elastic connective tissue. However, the results of this study agree with data reported by Ramsbottom et al. (24) which showed that after cooking ligamentum nuchae was twice as soft as it was before cooking.

Histological Studies

Explanation of descriptive terms

Part of the terms that will be used to describe the microscopic observations made in this study have been used by investigators in the food research laboratory at Iowa State College. Explanations of these terms will be given in the following paragraphs.

The term rigor node is used to describe a contraction of the muscle fiber. The cross striae are much closer together than they are in a normal fiber, and on each side of the contracted area is a rarefied area in which the cross striae are much wider than usual or sometimes are thrown out of alignment. In the contracted part of the node the fiber bulges so that it is wider than the normal fiber.

A rigor ridge describes areas where only a few cross striae are involved in contraction rather than the larger number of cross striae which are involved in a rigor node.

The term waves is self-explanatory. However, waves may be macroscopic in size with V or U bends. They may be deep or shallow, or may be an indentation along the edge like a scallop, or there may be many folds or "S" twists, each fiber showing variations. The waves may be rhythmic in that a pattern is repeated over and over along a fiber, or in that all fibers in certain areas of the sections are involved in the same pattern.

A suddenly rounded curve is referred to as a kink and multiple kinks as twists. Zig-zag (z-z) contractions describe sharp, angular bends in the fibers which give an accordian pleated effect.

Disintegration is a term applied to loss of the

histological characteristics of the protoplasm of the fiber, that is, the cross or longitudinal striae. If the sarcolemma remains intact, the disintegrated materia within the fiber appears granular. If the sarcolemma is entirely broken, the disintegrated material may have disappeared leaving a blank space. With a slight break in the sarcolemma granular material may exude and be noticeable around the break.

Observations

Longitudinal microscopic sections were prepared from raw and cooked samples of each of the roasts. In this way the histological changes which took place in each muscle during aging and cooking could be observed. In addition, the proportion of collagen and elastin in each muscle was determined as nearly as possible from examination of the sections.

General histological pattern of each muscle

Usually all sections from a given muscle had certain characteristics peculiar to that muscle. There was some variation in the sections for a given muscle from the different animals. Since these characteristics changed as aging progressed the following descriptions are those of the muscles after one day of storage.

Psoas major: The fibers of the psoas major muscle from the first three animals were thrown into deep macro-waves. In animal IV the fibers of this muscle were straight to slightly wavy. Often there were kinks or twists at the bends of the waves, and in the fibers of the psoas major from animal I there were occasional nodes in the straight portion of the fibers. The fibers were usually slender with distinct and widely spaced cross striae. This muscle had small amounts of fat and connective tissue except for animal IV which had a moderate amount of collagen and a large amount of fat deposited between the fibers. See Figure 21, upper picture, for the general picture of the pattern of the psoas major.

The psoas major of animal IV was particularly different from that of animals I, II, and III. The fibers and striae appeared more gnarled, just as older trees may have bark of the trunk and limbs more gnarled than that of younger trees of the same species.

Perhaps one of the most interesting points about the psoas major was the striations. Even in the cuts aged only one day, the longitudinal striations were never or seldom apparent. The psoas major is a very tender muscle; perhaps the histological structure has considerable influence upon its tenderness. In other

Fig. 21, Upper Picture. Cooked Psoas Major, One Day Storage. Animal II (Magnification, 150x)

Note the deep macro-waves with kinks and twists at the bends of the waves, the slender fibers with widely spaced cross striae, and the small amount of connective tissue and fat.

Fig. 21, Lower Picture. Uncooked Longissimus Dorsi (Ribs), One Day Storage. Animal II (Magnification, 150x)

Fibers with z-z contractions may be seen at the bottom of the picture. Just above the fibers with z-z contractions is a fiber containing small node or ridge. Still further toward the top of the picture are other straight fibers; one fiber has loose z-z contractions at the left end of the fiber. Connective tissue is evident between the fibers, particularly in the middle of the picture.

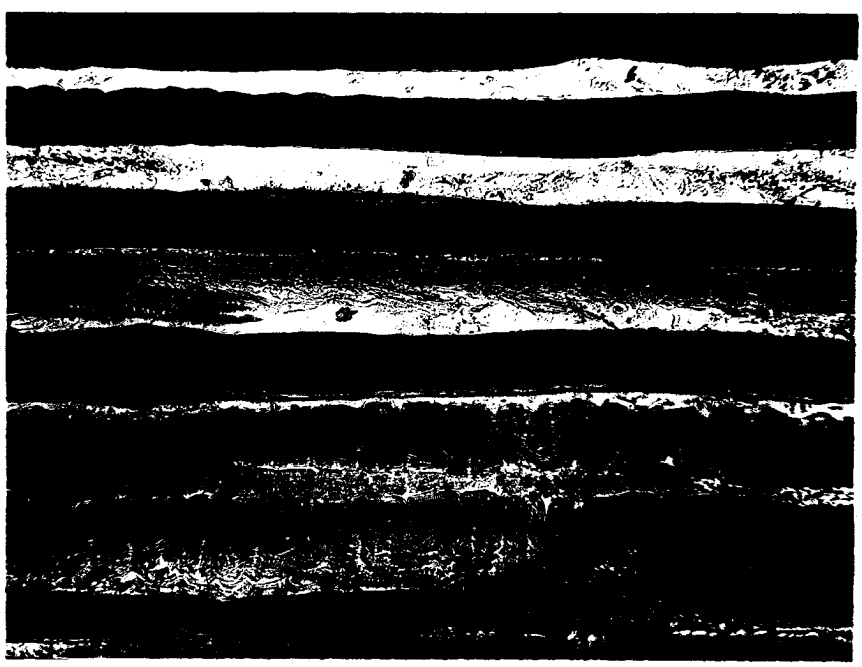


Fig. 21.

beef muscles and in muscles of poultry which are tough when aged short periods, the longitudinal striations are more distinct during the period while the muscle is tougher than after it has been tenderized by aging.

The cause of the macro-waves is not known. Paul (22) found the same type of waves in the semitendinosus muscle. She considered that since the semitendinosus muscle contains a large amount of elastin, it was probable that the elastin contracted and threw the muscle fibers into waves. However, the psoas major muscles contain less connective tissue than the other muscles used in the present study. The psoas major fibers exhibited deep macro-waves, whereas the fibers of the semitendinosus muscle were much straighter. Hence, along with contraction of the connective tissues, other factors, such as shortening of the molecules of the muscle fibers and the formation of rigor nodes, are perhaps responsible for inducing waves in the muscle fibers. Szent-Györgyi (34) explained muscle contraction on the basis of the structure and characteristics of the two chief proteins of muscle fibers, actin and myosin. Contraction is an extreme colloidal shrinkage which takes place in two stages; the loss of intermicellar water and the loss of hydrate water. Shrinkage attributed to the loss of intermicellar water is very large and that

attributed to hydrate water very small. Szent-Györgyi presented a model made up of a wooden stick, to represent the actin part of actomyosin, and a rubber tube, to represent the myosin part. The wooden stick was cut into cubes to represent the small globular particules of the actin and the rubber tube was stretched to some extent and its ends fixed to the actin rod. The completed model represented an actomyosin thread. If the system was released the rubber tube shortened somewhat, imitating the dehydration of myosin. Actin is inert and not precipitated or dehydrated by neutral salt, but because of its globular particles it bends when the rubber shortens, thus the model curls up.

Longissimus dorsi: The most outstanding characteristic of the longissimus dorsi muscle was the prominence of longitudinal striae in the fibers. Cross striae of the fibers were evident only under high power. Histological points of interest are shown in Figure 21, lower picture, and Figure 22, upper picture. Fibers with z-z contractions may be seen at the bottom of Figure 21. Just above the z-z contractions in the fibers is a straight fiber containing a small node or a ridge. Still further toward the top of the picture are other straight fibers; one fiber has loose z-z contractions at the left end of the fiber. Connective tissue is evident between the

Fig. 22, Upper Picture. Uncooked Longissimus Dorsi (Loin), One Day Storage. Animal I (Magnification, 150x)

This picture shows the rather sharp kinks or turns which were often seen in the fibers of the longissimus dorsi. In the lower right hand corner of the picture there are fat cells which lie on top of and between the fibers, whereas in the lower left hand corner a mass of elastic connective tissue with some collagenous tissue may be seen.

Fig. 22, Lower Picture. Uncooked Semitendinosus, One Day Storage. Animal I (Magnification, 150x)

The heavy dark strip and the less compact strip of short branched fibers are elastic connective tissue. The fairly straight muscle fibers show both longitudinal and cross striae.

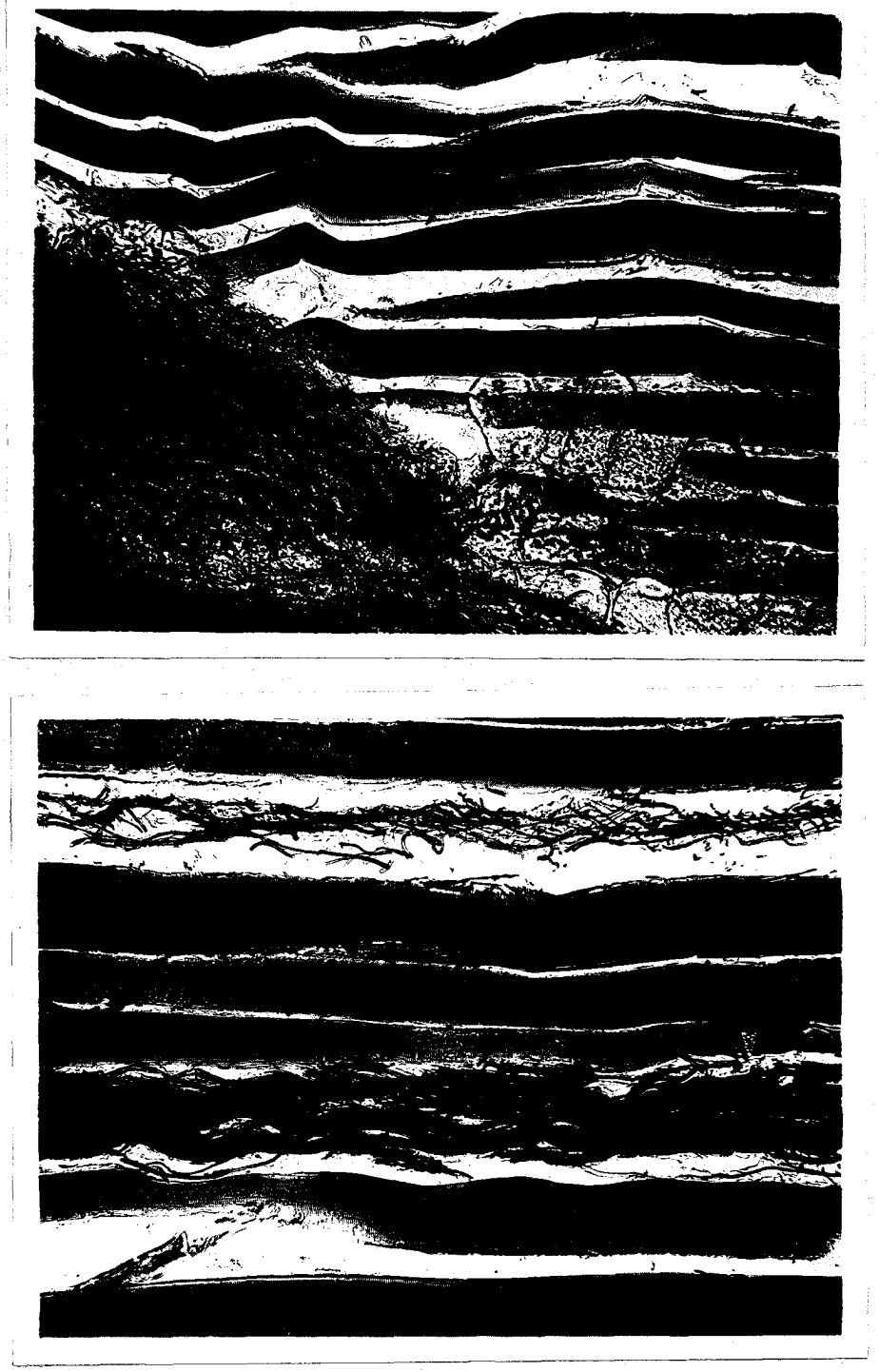


Fig. 22.

fibers, particularly in the middle of the picture. In Figure 22 the rather sharp kinks or turns which were often seen in the fibers of that muscle are shown. In the lower right hand corner of the picture there are fat cells which lie on top of and between the fibers, whereas in the lower left hand corner a mass of elastic connective tissue with some collagenous tissue may be seen. Areas like those seen in Figure 21, lower picture, and Figure 22, upper picture, were found interchangeably in the longissimus dorsi from the rib and loin sections. Paul (22) differentiated between active and passive contraction. Rigor nodes are a state of active contraction, whereas z-z contractions, kinks, twists, and waves are passive contraction. The explanation deemed probable for the formation of waves, are discussed under the pattern of the psoas major, may also be applied to the other types of passive contraction.

Semitendinosus: The semitendinosus muscle was the only muscle of those studied which had large amounts of elastic tissue. Almost every section made from this muscle had one or more dense strips of elastin such as the heavy dark strip and the less compact strip of short branched fibers seen in Figure 22, lower picture. The fibers of the semitendinosus muscle were fairly straight with some kinks and twists in them. The fibers of this muscle from animal IV were thrown into shallow waves.

Both longitudinal and cross striae were observed in semitendinosus fibers, and the cross striae were very fine and close together.

Biceps femoris: A typical picture of the sections made from the biceps femoris muscles from animals I and II is shown in Figure 23. Sections of this muscle from animals III and IV show less straight fibers and more z-z and waved contractions. The distinct cross striae of the straight fibers are illustrated in Figure 23. A node may be seen near the bottom and at the center of the picture, and a wide strip of dense collagenous tissue, which was prominent in this muscle, runs across the middle of the picture.

The effect of aging

All muscles followed much the same pattern throughout the storage periods. Sections made from muscles stored for two days were practically the same as those made from the same muscles after one day of storage. Even after five days of aging the picture had changed little except in a few cases in which disintegration had started. In general, as aging progressed beyond two days there was a tendency for the fibers to become straighter, with fewer waves, z-z contractions, twists, and kinks.

There were two types of changes in the muscle fibers

which indicated disintegration; one was an increasing fragility in the muscle fiber, like worn textile fibers, the other was a disintegration of the protoplasm over an area in the fiber. The disintegration might extend over only a few or many cross striae. Sometimes the sarcolemma remained intact, sometimes it broke. Sometimes only a short area or part of the fiber (one or two cross striae) was involved and sometimes a very long area or strip was affected. The areas with protoplasmic disintegration had lost all evidence of either longitudinal or cross striae, and the material within the sarcolemma had a granular appearance. The short "strip" of disintegration appeared in the muscle fibers in the earlier storage periods and the "strips" became longer and more numerous with aging. This type of disintegration was common in all muscles, except the psoas major, after 10 days of aging. In some sections there were as many disintegrated areas in the fibers after 10 days of aging as there were for the longer storage periods. In other sections the disintegrated areas increased in number and length after 20 and 30 days of aging. An example of a cooked section in which the extent of disintegration is not large after 10 days of storage is shown in Figure 24, upper picture. Under low power the disintegrated areas appeared as cracks in the fibers. A section where the disintegrated areas came frequent enough to break the fibers into extremely short

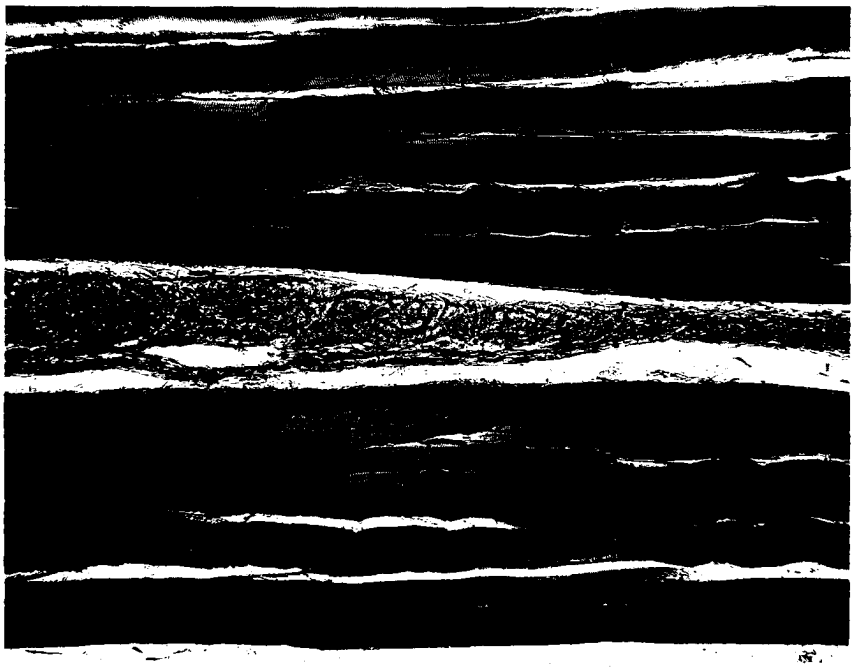


Fig. 23. Uncooked Biceps Femoris, One Day Storage. Animal I (Magnification 150x)

Note the distinct cross striae of the straight fibers. A node may be seen near the bottom and at the center of the picture, and a wide strip of dense collagenous tissue runs across the middle of the picture.

segments is shown in the lower picture of Figure 24. In Figure 25 the disintegration is shown at a higher magnification than that of Figure 24. The higher magnification brings out the rough edges of the striations in which disintegration has occurred and the granular exudate which was often observed with fragments of broken fibers. By the time disintegration was evident the fibers had lost most of their waves, z-z contractions, kinks and twists which were characteristic of the short aging periods. Thus as the meat became more tender, the fibers became straighter and more fragile.

Characteristics illustrated by Figures 26 and 27.

In Figure 26, upper picture, two straight fibers with nodes and a partially disintegrated area in one fiber are shown. Kinked and twisted fibers lie on each side of the straight fibers. A high magnification of a node is shown in Figure 26, lower picture. In the contracted portion of the fiber the cross striae are very fine and close together. On each side of the contracted portion or node the striae are out of alignment and the areas have a turbulent appearance. The lighter area in which the longitudinal striae run obliquely across the picture in Figure 27, upper picture, is dense collagenous tissue.

Fig. 24, Upper Picture. Cooked Biceps Femoris, Ten Days Storage. Animal II (Magnification, 150x)

This is an example of a cooked section in which the extent of disintegration is not large after 10 days of storage. Under low power the disintegrated areas appear as cracks in the fibers.

Fig. 24, Lower Picture. Uncooked Biceps Femoris, Thirty Days Storage. Animal II (Magnification, 150x)

A section where the disintegrated areas come frequent enough to break the fibers into extremely short segments is shown in this picture.

Fig. 24.

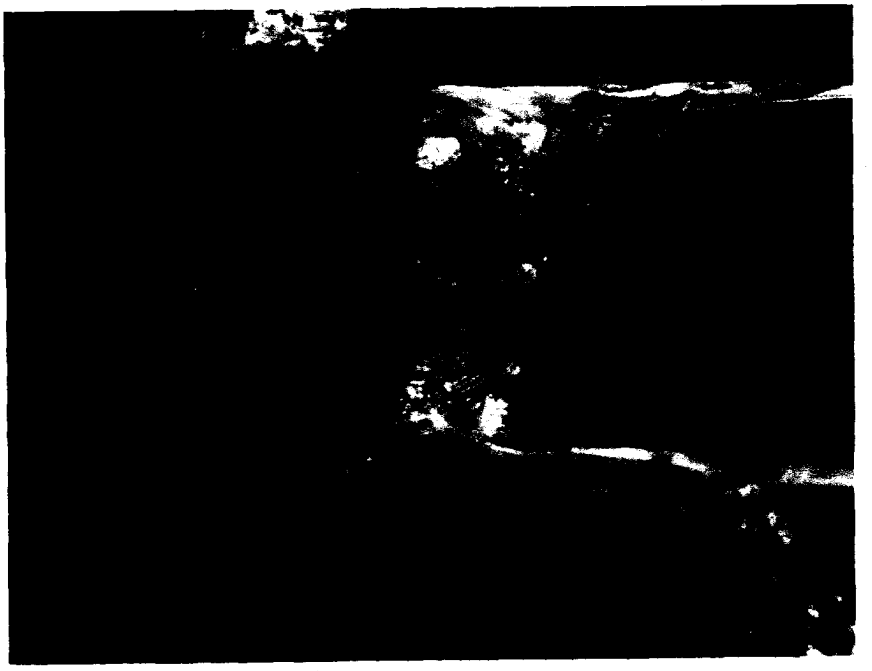


Fig. 25. Uncooked Biceps Femoris, Twenty Days Storage. Animal II (Magnification, 710x)

Disintegration is shown at a higher magnification than that of Figure 24. The rough edges of the striations in which disintegration has occurred and the granular exudate often observed between fragments of fibers are brought out.

Areas similar to this were frequently found in all the muscles of animals III and IV except the psoas major. The strips of dense collagenous tissue and the fat globules which are typical of the muscles of animal IV are shown in Figure 27, lower picture.

Effect of cooking

The sections prepared from the cooked muscles were more opaque and appeared thicker before staining than the sections from uncooked muscles. The collagenous tissue did not stain as bright a pink as it did in the uncooked sections except in areas of dense collagen. The connective tissue between the fibers appeared granular and in muscles in which there were large amounts of collagen a film of granular tissue often covered the entire section. Usually cooked fibers were straighter with less kinks, twists, and waves than the fibers in the raw sections. Contrary to the findings of Paul (22) cooking did not intensify the microscopic characteristics of the fibers.

Relative proportion of connective tissue in the muscles studied

The histological rating of the proportion of connective tissue in the muscles studied is given in Table 23.

Fig. 26, Upper Picture. Uncooked
Longissimus Dorsi (Ribs),
Five Days Storage.
Animal III
(Magnification, 300x)

Note the two straight fibers with nodes and a partially disintegrated area in one fiber. Kinked and twisted fibers lie on each side of the straight fibers.

Fig. 26, Lower Picture. Uncooked
Longissimus Dorsi (Ribs),
Five Days Storage.
Animal IV
(Magnification, 710x)

A high magnification of a node. In the contracted portion of the fiber the cross striae are very fine and close together. On each side of the contracted portion or node the striae are out of alignment and the areas have a turbulent appearance.

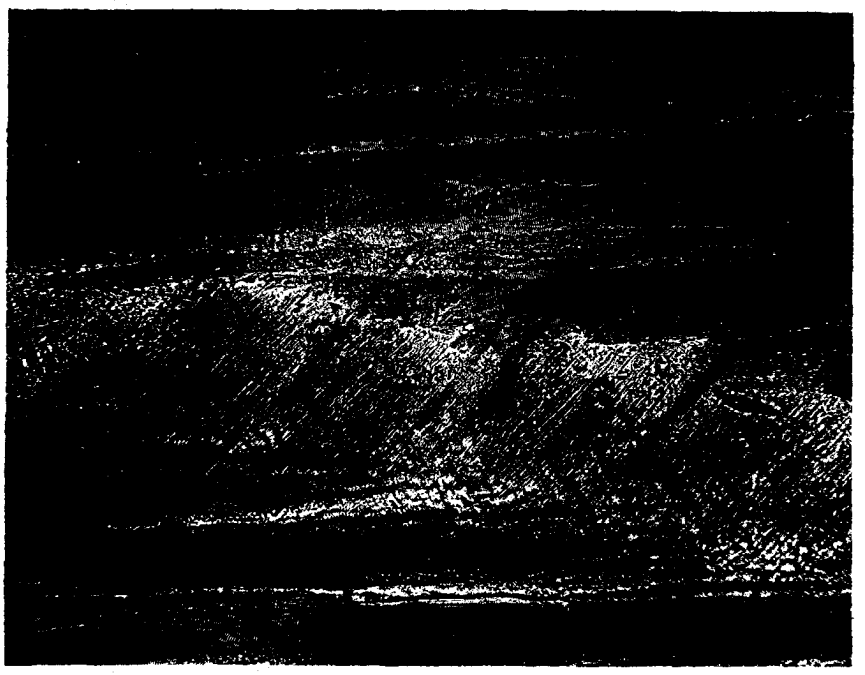
Fig. 26.

Fig. 27, Upper Picture. Cooked
Longissimus Dorsi (Ribs),
Ten Days Storage.
Animal III
(Magnification, 150x)

The lighter area in which the longitudinal striae run obliquely across the picture is dense collagenous connective tissue. Areas similar to this were found in all the muscles of animals III and IV except the psoas major. Muscle fibers lie on either side of the collagenous tissue.

Fig. 27, Lower Picture. Uncooked
Longissimus Dorsi (Ribs),
Thirty Days Storage.
Animal IV
(Magnification, 150x)

Strips of dense collagenous tissue, in the center of the picture, and the fat globules, near the bottom of the picture, are typical of sections from the muscles of animal IV.



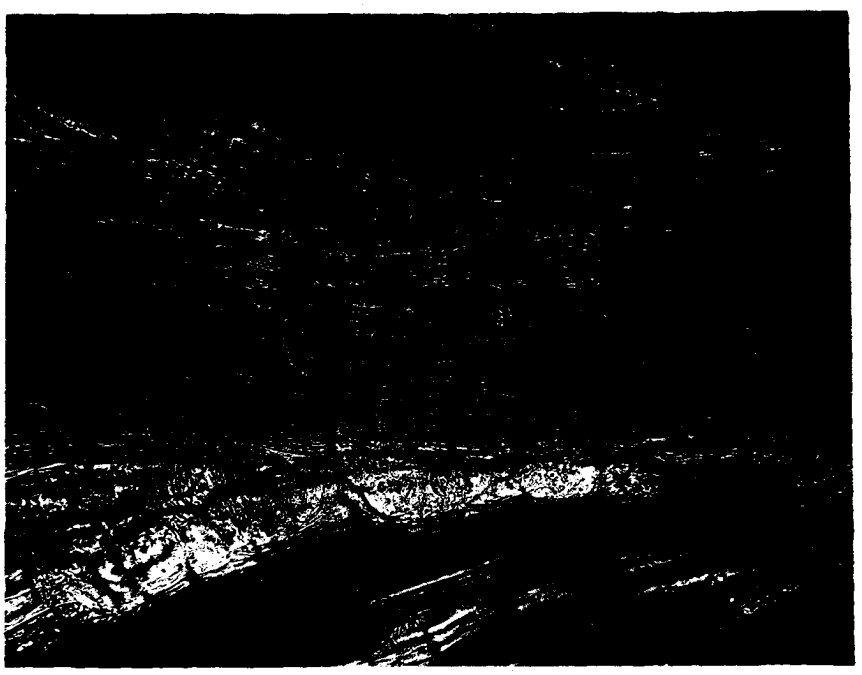


Fig. 27.

The ratings show a larger proportion of collagenous tissue than elastic tissue in all muscles except the semitendinosus. Because of the large amounts of elastin the semitendinosus had the highest average rating. The psoas major rated lower than the other muscles, whereas the longissimus dorsi and biceps femoris muscles rated between the two other muscles. The histological rating is in accord with the shear values obtained for these muscles, that is, the muscles with high shear values had high histological ratings. Thus the proportion of connective tissue, particularly elastin, has an effect on the amount of force required to shear a piece of meat of a given size, or in other words on the tenderness of meat.

Table 23.

Histological Rating of the Relative Amount of Connective Tissue in Certain Muscles from Four Animals

Muscle	*	Collagenous Conn. Tissue		Elastic Conn. Tissue		Total	Ave.
		Raw	Cooked	Raw	Cooked		
Psoas Major	I	3	3	3	3	12	3
	II	3	3	3	3	12	3
	III	5	5	3	3	16	4
	IV	5	5	3	3	16	4
Longissimus dorsi (ribs)	I	5	5	3	3	16	4
	II	5	5	3	3	16	4
	III	7	7	5	5	24	6
	IV	7	7	5	5	24	6
Longissimus dorsi (loin)	I	5	5	3	3	16	4
	II	5	5	3	3	16	4
	III	7	7	5	5	24	6
	IV	7	7	5	5	24	6
Semitend-inosus	I	5	5	7	7	24	6
	II	5	5	7	7	24	6
	III	7	7	7	7	28	7
	IV	7	7	7	7	28	7
Biceps femoris	I	5	5	3	3	16	4
	II	5	5	3	3	16	4
	III	7	7	5	5	24	6
	IV	7	7	5	5	24	6

* Animal number
1 = none, 3 = small, 5 = medium, 7 = large amounts collagen and elastin.

SUMMARY

The histological, physical, and organoleptic changes during varying storage periods at 34° to 36° F. of four beef muscles from the carcasses of four animals were studied. In addition the effect of moist heat on collagenous and elastic connective tissues was observed. Animals I and II were yearling steers, carcasses grade, good; animal III was a steer, carcass grade, commercial; and animal IV was an eight year old dairy cow, carcass grade, cutter. The paired psoas major, longissimus dorsi, semitendinosus, and biceps femoris muscles were utilized. Twenty four hours after slaughtering each animal, the muscles were dissected from the carcass, most of the visible fat removed, and divided into roasts. In the usual commercial practice of dividing the carcass into cuts, these muscles are protected to a greater or lesser extent by the fell, fat, and bones. Each longissimus dorsi was divided between the 12th and 13th rib into the rib portion and the loin portion, and each portion was cut into 3 roasts. The roasts were placed unwrapped on enamel trays and stored in the Animal Husbandry meat cooler. The aging periods used were 1, 2, 5, 10, 20, and 30 days. The statistical pattern for the aging periods consisted of a 5 x 6 table for each animal and the aging periods determined from a table of

random numbers. One roast from each muscle was included in every aging period.

For cooking, the roasts were placed on a rack in a kettle deep enough to cover them with bland lard which was held at a temperature of 96° to 98° C. They were cooked to an internal temperature of 70° C. Data were recorded before and after cooking the roasts to determine: (1) the percentage loss in weight during aging and cooking, (2) the percentage decrease in length and width and the percentage increase in thickness of the roasts during cooking, (3) shear force of the cooked roasts, (4) percentage of press fluid of the cooked roasts, (5) pH measurements of the cooked and uncooked roasts, and (6) palatability scores for aroma, flavor, tenderness, and juiciness of the cooked roasts.

Histological sections were made from samples of the cooked and uncooked roasts to determine the microscopic changes during the storage of beef and the proportion of connective tissue in the muscles studied. Longitudinal sections were cut 15 to 25 microns thick on a freezing microtome and stained to differentiate collagen, elastin, and muscle fibers. Arbitrary numerical evaluations were used to compare the relative proportion of collagen and elastin in the muscles.

In addition to the pH determinations made on the

roasts, the pH of a sample of muscle from the fore-part of the chuck was determined soon after the slaughter of each animal and at various intervals thereafter for 6 to 8 hours.

In order to study the effect of moist heat on connective tissues, strips of tendons from around the anterior end of the longissimus dorsi muscle, strips of Achilles tendons, and strips of ligamentum nuchae were heated in distilled water. Samples of the first type of tendons were heated for 15 and 30 seconds and for 1 and 2 minutes at temperatures of 60°, 65°, 70° and 95° C. Samples of Achilles tendons were heated at the same temperatures for 1, 2, 3, 5, 10, 15, 20, and 30 minutes, and the strips of ligamentum nuchae at 70° and 95° C. for 1 and 2 hours. The two types of tendons were from 0.1 to 0.3 centimeters thick, 0.5 to 1.5 centimeters wide, and 10 to 20 centimeters long. The strips of ligamentum nuchae varied from 0.3 to 0.8 centimeters in thickness and were about the same width and length as those of the collagenous tissues.

Since the roasts were stored unwrapped on enamel trays, evaporation of moisture caused loss of weight. The roasts from each muscle gradually decreased in weight as storage time increased. Roasts from the psoas major lost the most weight, whereas those from the biceps femoris lost the least. Gradually the exposed surfaces of the roasts

became dark and dry. After 30 days of storage these surfaces were covered with a crust about 1/4 inch thick, and occasionally had small areas of mold on them. The surfaces of the meat next to the trays were moist and sticky from the 5th day through the 30th day of storage.

In general, the weight lost during cooking decreased slightly as the aging period increased. At each storage period roasts from the psoas major muscle lost less weight during cooking than roasts from other muscles.

The decrease in length of the roasts during cooking was not always linearly related to the time of aging the roasts before cooking. The decrease in length of the roasts, after 2 days of aging, was less than after 1 day of storage, and the length decreased gradually with 5, 10, and 20 days of storage, but increased slightly after 30 days of storage.

All but one of the 120 roasts decreased in width during cooking, and all but one roast increased in thickness during cooking. Because of the wide variation of these data within the roasts of a given muscle the percentage changes in width and thickness during cooking were not averaged.

The average of four judges' scores for aroma and flavor of the roasts varied only slightly among the muscles but varied considerably among the animals. Likewise the

aroma and flavor scores for a given animal varied little during the 1st to 20th days of aging, but dropped slightly after 30 days of aging. The less desirable aroma and flavor in the roasts stored 30 days were attributed to a musty odor and an acid or "high" flavor.

The juiciness scores of the cooked roasts remained about the same (approximately 7.0) for the first 20 days of aging, then dropped slightly (to 6.2) after 30 days of aging. The average press fluid values followed the same pattern as the juiciness scores.

Tenderness scores obtained by averaging the scores for the roasts from all muscles indicated a gradual increase in tenderness as aging time progressed, with the greatest increase in tenderness taking place during the first 10 days of aging. However, when each muscle was considered separately the increase in tenderness with aging was not always linear, that is individual muscles toughened at certain periods during the aging process. At each aging period the psoas major muscle was scored from 45 to 62 percent more tender than the other muscles. The tenderness rating of the other muscles decreased in the order given: longissimus dorsi (ribs), semitendinosus, biceps femoris, and longissimus dorsi (loin). However, after 30 days of storage the longissimus dorsi (loin) rated higher than the semitendinosus and the biceps

femoris muscles. Analysis of variance of scores showed that the change in tenderness with aging, the variation among muscles, and the variation among animals were highly significant.

The average shear force, like the tenderness scores, of all muscles showed a gradual increase in tenderness with aging, but shear force of individual muscles did not always change linearly with aging. As determined by shear force the muscles became increasingly tougher in the order given: psoas major, longissimus dorsi (ribs), biceps femoris, longissimus dorsi (loin), and semitendinosus.

Acidification of muscle occurred post mortem. The rate of this acidification varied among the animals, but was rapid during the first 1 to 2 hours. During storage the general pattern of the change in the pH of uncooked muscle was a slight drop in pH followed by a slow rise. The difference in pH among muscles was exceedingly small. The cooked roasts were slightly more alkaline than the uncooked roasts.

Strips of tendons heated in distilled water progressively decreased in length as the temperature of heating was increased. They also decreased in length as the time of heating was increased to one minute for tendons from around the anterior end of the longissimus dorsi muscle,

and to five minutes for Achilles tendons. Further heating caused no additional decrease in length of the tendons. With a given treatment there was considerable variation in the decrease in length between two samples from the same animal and among samples from different animals.

Shear force of heated tendons indicated a softening of tendons with an increase in the temperature of heating. Also, there was an increase in the softening of the tendons as the heating time at a given temperature was increased. The shear force of tendons from animal IV was from three to twelve times higher than the shear force of tendons from the other animals. In some cases there was also variation between identically treated samples from the same animal. The differences in shear force were probably influenced by the variation in the compactness of the bundles of collagen fibers in the tendons and by the method of handling the samples before heating.

The increase in width and thickness of the tendons varied tremendously and followed no regular pattern except that the higher the temperature of heating, the greater the number of samples which increased in width.

Strips of elastic tissue decreased in length when heated but the decrease was small when compared to that which occurred in the collagenous tissues. At 70° C. the

effect of heating on the length of the elastic tissues was greater as the time of the treatment increased.

Shear force values of ligamentum nuchae showed that under the conditions of this study, samples heated for one to two hours were from two to four times more tender than they were before heating. At 95° C. the shear force decreased as the time of heating increased, but at 70° C. the time of the treatment had no appreciable effect on the shear force. These results are contrary to the idea that cooking does not effect elastic connective tissue.

Microscopic examination of sections of the cooked and uncooked roasts revealed that histological characteristics of muscle followed a general pattern during the first 5 days of storage. The most tender muscle, the psoas major, differed from the other muscles in that in general, it did not exhibit longitudinal striae and it contained small amounts of connective tissue. The fibers of this muscle were slender and the cross striae widely spaced and distinct. The longissimus dorsi muscle fibers varied from straight fibers with nodes to fibers containing z-z contractions, kinks, and twists. The fibers of the semitendinosus were fairly straight with a few kinks. A large number of strips of dense elastin occurred between the muscle fibers. The biceps femoris exhibited straight,

wavy, kinked, and twisted fibers. The last three muscles contained moderate to large amounts of collagen. Since the psoas major differed in histological pattern from the other muscles it was considered probable that the histological structure of muscle fibers is related to the tenderness of beef.

The muscle fibers of animal IV, particularly those of the psoas major, appeared more gnarled and worn with age than the fibers from the muscles of the other animals. Sections made from the muscles of animals III and IV contained large proportions of collagen and in addition those from animal IV contained large amounts of fat between the muscle fibers.

Disintegration of the muscle fibers started at about 10 days of storage and became more evident as time of storage progressed. The disintegration consisted of a destruction of the striae in strips of the muscle fibers resulting in fragility of the fibers.

CONCLUSIONS

The conclusions drawn from the results of this study must be considered in terms of the number of carcasses of each grade that were used, and the way the roasts were handled during storage. Biological variation is too great to permit unlimited statements about any one grade of carcass. With these restrictions the conclusions from this study were:

1. The greatest improvement in the palatability of beef comes during the first 10 days of aging at 34° to 36° F. After aging for 20 and 30 days the beef is a little more tender, but it also develops a musty odor and an acid or "high" flavor. The "off" flavor was probably greater in this study than it would be if the entire carcass had been stored. The increase of tenderness during aging is not linear.

2. Collagenous connective tissue contracts, swells, and softens when heated in water, and elastic connective tissue contracts and softens in the presence of moist heat. In general, the degree of such changes in the two connective tissues increased as the temperature and time of heating is increased. Thus, cuts of meat containing a large proportion of connective tissue tenderize as the

connective tissues soften during long slow cooking.

3. Aged beef loses less weight during cooking than fresh beef loses during cooking.

4. There is an acidification of beef muscle post mortem and the rate of acidification varies from animal to animal. During storage at 34° to 36° F. the pH of uncooked muscle decreases slightly, then slowly rises. Beef muscle becomes slightly more alkaline during cooking than it was before cooking.

5. It is probable that the histological structure of muscle fibers is related to the tenderness of beef. There is histological disintegration of the muscle fibers during aging at 34° to 36° F.

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APPENDIX

Table 24.

Percentage Weight Loss of Roasts
During Aging

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	0%	- %	- %	- %	12.8%	20.4%
	II	0	2.8	2.8	4.1	9.8	17.0
	III	0	1.4	1.6	4.0	9.9	13.5
	IV	0	0.6	1.6	3.0	14.1	19.2
	Ave.	0	1.6	3.0	3.7	11.7	17.5
Longissimus dorsi (ribs)	I	0	-	-	-	10.2	16.3
	II	0	1.9	2.9	4.8	8.2	10.5
	III	0	1.3	1.5	4.3	5.1	8.5
	IV	0	0.01	2.1	4.7	8.7	13.5
	Ave.	0	1.1	2.2	4.6	8.1	12.2
Longissimus dorsi (loin)	I	0	-	-	-	15.3	16.4
	II	0	1.7	1.5	1.0	5.9	7.5
	III	0	0.9	3.1	4.1	6.4	8.1
	IV	0	0.0	2.0	4.2	10.7	14.0
	Ave.	0	0.9	2.2	3.1	9.6	11.5
Semitendinosus	I	0	-	-	-	16.1	14.5
	II	0	1.4	0.6	1.0	8.1	9.3
	III	0	0.9	2.4	3.6	4.5	8.1
	IV	0	0.06	0.5	3.0	10.9	14.4
	Ave.	0	0.8	1.2	2.5	9.9	11.6
Biceps femoris	I	0	-	-	-	20.0	16.3
	II	0	0.54	1.5	3.7	7.6	10.8
	III	0	1.3	1.6	2.0	4.8	7.3
	IV	0	0.15	1.5	2.7	8.5	11.4
	Ave.	0	0.7	1.5	2.8	10.2	11.5
Total			14.96	27.2	50.2	197.6	257.0
Ave.			1.0	1.8	3.3	9.9	12.9

* Animal number

Table 25.

Percentage Weight Loss of Roasts
During Cooking

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	17.2%	18.2%	17.6%	12.6%	15.5%	16.3%
	II	21.8	23.2	20.4	19.5	18.1	16.2
	III	24.9	20.3	25.9	13.3	13.0	-
	IV	17.0	25.3	17.7	20.0	10.5	15.7
	Ave.	20.2	21.8	20.4	16.4	14.3	16.1
Longissimus dorsi (ribs)	I	19.8	18.6	19.1	14.9	15.7	17.1
	II	30.8	21.5	26.5	20.7	23.3	19.2
	III	25.5	23.9	25.7	24.7	22.1	25.7
	IV	27.1	28.7	30.9	26.9	22.5	18.6
	Ave.	25.8	23.2	25.6	21.8	20.9	20.2
Longissimus dorsi (loin)	I	26.9	33.9	18.1	12.6	15.7	11.8
	II	30.3	21.4	27.0	23.4	15.2	18.9
	III	19.4	21.6	22.0	27.9	25.9	28.3
	IV	23.8	23.4	28.5	19.9	23.5	23.4
	Ave.	25.1	25.1	23.9	21.0	20.1	20.6
Semitend-inosus	I	21.6	16.3	17.0	18.2	15.1	21.6
	II	38.7	17.2	22.6	23.6	16.8	21.4
	III	22.9	26.6	26.1	29.3	22.3	26.2
	IV	27.3	23.4	27.0	26.0	24.6	24.9
	Ave.	27.6	20.9	23.2	24.3	19.7	23.5
Biceps femoris	I	24.9	25.0	18.5	22.2	17.1	12.7
	II	35.8	30.7	24.1	11.6	25.9	24.5
	III	26.5	20.9	30.3	22.9	28.6	20.6
	IV	24.5	26.2	21.7	25.0	22.8	25.1
	Ave.	27.9	25.7	23.7	20.4	23.6	20.7
Total		506.7	466.3	466.7	415.2	394.2	388.2
Ave.		25.3	23.3	23.3	20.7	19.7	30.4

* Animal number

Table 26.

Percentage Decrease in Length of Roasts During Cooking

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	17.6%	34.9%	36.4%	12.6%	15.5%	16.3%
	II	40.7	47.4	44.0	17.8	37.6	16.2
	III	51.3	41.1	32.1	34.1	32.4	35.3
	IV	50.9	50.0	35.7	51.3	25.0	38.1
	Ave.	40.1	43.3	37.1	29.0	27.6	26.5
Longissimus dorsi (ribs)	I	18.4	13.3	26.3	14.9	15.7	17.1
	II	33.3	25.0	21.9	17.9	23.3	19.2
	III	32.2	25.9	25.8	21.7	19.1	22.7
	IV	48.0	47.8	44.3	33.0	6.5	31.5
	Ave.	33.0	28.0	29.6	21.9	16.2	25.1
Longissimus dorsi (loin)	I	8.7	23.8	8.3	12.6	15.7	11.8
	II	29.2	28.0	42.6	33.3	22.7	18.9
	III	34.6	25.2	20.2	32.3	20.8	30.2
	IV	40.1	42.9	30.4	46.2	16.7	29.7
	Ave.	28.2	30.0	25.4	31.1	19.0	22.7
Semitend-inosus	I	20.5	23.5	14.3	18.2	15.1	21.6
	II	16.7	36.0	16.8	18.8	30.0	21.4
	III	18.7	40.9	8.9	22.2	14.1	20.4
	IV	18.8	25.0	17.8	29.5	15.4	27.3
	Ave.	18.7	31.4	14.5	22.2	18.7	22.7
Biceps femoris	I	10.4	21.7	5.5	22.2	17.1	12.7
	II	28.0	46.4	15.0	23.1	17.9	24.5
	III	22.2	19.2	25.8	29.2	32.8	11.3
	IV	26.5	18.2	36.0	5.3	12.5	28.6
	Ave.	21.8	26.4	20.6	20.0	20.1	19.3
Total		566.8	636.1	508.1	496.2	405.9	454.8
Ave.		28.3	31.8	25.4	24.8	20.3	22.7

* Animal number

Table 27.

Percentage Change[1] in Width of Roasts During Cooking

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	14.3%	21.1%	11.8%	6.3%	22.2%	10.0%
	II	37.5	13.3	0.0	16.7	9.6	7.9
	III	0.0	11.8	4.5	0.0	20.2	15.7
	IV	11.1	-41.8	0.0	5.9	7.7	22.7
Longissimus dorsi (ribs)	I	11.1	17.9	28.0	20.8	10.7	0.0
	II	6.7	10.0	13.3	9.7	9.4	21.1
	III	12.4	15.6	13.3	22.6	15.6	17.2
	IV	5.8	9.5	16.7	14.8	13.9	0.0
Longissimus dorsi (loin)	I	6.7	15.6	13.5	22.6	18.5	16.7
	II	7.7	12.0	42.9	22.2	19.2	21.1
	III	16.7	12.1	8.0	8.3	10.3	25.5
	IV	23.1	12.5	12.4	11.1	22.6	16.7
Semitend-inosus	I	13.6	19.0	30.0	23.8	0.0	12.5
	II	10.5	20.0	25.0	8.9	18.3	5.8
	III	18.3	8.7	15.0	9.1	11.0	13.0
	IV	17.6	15.0	22.3	17.9	19.4	16.3
Biceps femoris	I	10.3	13.3	25.0	20.7	2.5	19.2
	II	61.9	21.7	36.6	16.0	16.7	18.5
	III	3.7	6.7	0.0	31.0	16.7	0.0
	IV	14.6	14.3	22.6	10.0	29.0	29.6

[1] All numbers represent a decrease in width except the one designated -.

* Animal number

Table 28.

Percentage Change[1] in Thickness of Roasts During Cooking

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	- %	- %	44.0%	33.3%	37.5%	22.2%
	II	55.5	60.0	57.1	32.5	55.6	30.4
	III	28.0	21.8	52.0	46.7	13.6	60.5
	IV	35.0	50.0	37.5	60.0	70.6	71.1
Longissimus dorsi (ribs)	I	-	-	33.0	33.3	57.1	50.0
	II	10.0	25.0	44.7	75.6	44.4	62.5
	III	8.8	17.3	15.4	18.2	25.9	49.1
	IV	66.7	88.0	25.9	55.6	20.0	95.0
Longissimus dorsi (loin)	I	-	-	11.1	11.1	37.5	25.0
	II	20.0	33.3	35.4	77.8	44.4	15.4
	III	16.7	3.4	7.7	25.0	17.2	31.7
	IV	56.3	84.2	26.3	55.6	17.6	33.3
Semitend-inosus	I	-	-	7.1	6.0	50.0	18.2
	II	29.0	40.0	18.1	6.3	40.0	31.0
	III	18.3	3.5	23.3	32.9	15.8	28.6
	IV	14.3	35.2	13.3	27.4	3.3	16.7
Biceps femoris	I	-	-	29.4	20.0	29.4	46.1
	II	0.0	44.4	31.1	-9.5	38.9	17.6
	III	17.4	7.7	40.9	45.0	25.0	16.7
	IV	40.0	0.0	10.0	8.3	27.8	50.7

[1]All numbers represent an increase in thickness except the one designated -.
*Animal number

Table 29.

Average of Four Judges' Scores for Aroma of Roasts (Maximum score possible, 10)

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	8.8	8.3	8.3	8.8	7.8	8.3
	II	8.8	8.8	8.7	8.3	8.5	6.8
	III	8.5	9.3	9.0	8.5	8.5	6.0
	IV	8.0	7.8	6.3	6.0	6.8	5.0
	Ave.	8.5	8.6	8.1	7.9	7.9	6.5
Longissimus dorsi (ribs)	I	8.3	8.3	8.5	8.3	7.8	7.5
	II	8.0	8.8	8.3	8.8	8.5	7.0
	III	8.5	8.8	8.8	9.0	8.0	6.0
	IV	7.8	5.3	6.0	6.8	6.8	6.0
	Ave.	8.2	7.8	7.9	8.2	7.8	6.6
Longissimus dorsi (loin)	I	6.3	7.8	8.5	8.5	7.8	7.8
	II	8.0	8.5	8.3	8.3	8.0	7.8
	III	8.3	8.5	9.0	8.8	8.3	5.5
	IV	7.8	5.0	6.0	6.0	6.5	6.5
	Ave.	7.6	7.5	8.0	7.9	7.7	6.9
Semitend-inosus	I	8.0	7.0	8.3	8.5	8.3	8.5
	II	8.8	8.8	7.5	8.5	8.3	6.5
	III	9.3	8.8	8.8	9.0	8.5	5.8
	IV	7.8	6.3	6.8	6.5	5.3	6.3
	Ave.	8.5	7.7	7.9	8.1	7.6	6.8
Biceps femoris	I	8.8	8.5	9.0	9.3	9.0	8.5
	II	8.3	8.0	9.0	9.0	8.5	6.8
	III	9.3	9.3	9.0	9.3	8.3	6.5
	IV	8.0	5.5	6.8	7.5	6.0	6.0
	Ave.	8.6	7.8	8.5	8.8	8.0	7.0
Total		165.4	157.4	160.9	163.7	155.5	135.1
Ave.		8.3	7.9	8.0	8.2	7.8	6.8

* Animal number

Table 30.

Average of Four Judges' Scores for Flavor of Roasts
(Maximum score possible, 10)

Muscle	*	Days Aged					
		1	2	5	10	20	30
Psoas Major	I	9.0	8.0	7.5	8.8	8.5	8.8
	II	8.8	8.8	8.7	9.0	8.3	9.0
	III	8.5	8.0	8.5	8.5	8.3	6.3
	IV	7.3	6.8	7.0	6.8	7.3	5.3
	Ave.	8.4	7.9	7.9	8.3	8.1	7.4
Longissimus dorsi (ribs)	I	7.8	7.5	8.5	8.8	8.0	8.8
	II	7.5	8.0	7.3	8.5	6.3	6.8
	III	8.5	9.0	8.5	8.5	8.3	5.8
	IV	5.8	5.3	5.5	6.5	5.8	6.3
	Ave.	7.4	7.5	7.5	8.1	7.1	6.9
Longissimus dorsi (loin)	I	7.3	7.3	7.3	8.8	8.5	8.0
	II	7.3	8.0	8.0	8.5	7.3	6.8
	III	8.0	8.8	8.3	8.5	8.0	5.8
	IV	4.5	4.0	6.0	6.0	5.8	5.8
	Ave.	6.8	7.0	7.4	8.0	7.4	6.6
Semitend-inosus	I	7.3	6.5	6.8	7.8	8.0	8.5
	II	8.5	8.3	7.0	8.8	8.0	5.8
	III	8.5	8.8	8.8	8.0	7.3	6.0
	IV	5.3	5.8	5.3	5.0	4.8	6.3
	Ave.	7.4	7.9	7.0	7.4	6.8	6.7
Biceps femoris	I	7.5	7.8	8.3	8.3	8.8	8.8
	II	8.8	7.3	8.3	8.5	7.5	6.8
	III	8.3	9.0	9.0	8.5	8.0	6.5
	IV	5.8	5.0	6.8	6.0	5.8	6.0
	Ave.	7.6	7.3	8.1	7.8	7.3	7.0
Total		150.3	150.0	151.4	158.1	146.6	138.2
Ave.		7.5	7.5	7.6	7.9	7.3	6.9

* Animal number

Table 31.

Average of Four Judges' Scores for Juiciness of Roasts (Maximum score possible, 10).

Muscle	*	Days Aged					
		1	2	5	10	20	30
Psoas Major	I	8.5	7.0	6.8	8.3	8.3	7.0
	II	7.5	8.3	8.0	8.0	6.8	6.0
	III	5.8	8.0	7.5	9.5	8.3	5.8
	IV	9.0	5.5	8.3	9.0	7.5	7.5
	Ave.	7.7	7.2	7.7	8.7	7.7	6.6
Longissimus dorsi (ribs)	I	6.3	7.5	7.8	8.8	7.8	7.8
	II	7.0	8.3	8.0	6.8	6.0	5.8
	III	8.0	8.5	6.8	6.8	7.8	5.0
	IV	7.0	6.5	7.0	6.3	4.8	6.0
	Ave.	7.1	7.7	7.4	7.2	6.6	6.2
Longissimus dorsi (loin)	I	4.8	6.5	6.8	8.5	7.5	7.8
	II	6.8	7.5	6.0	7.8	6.5	8.5
	III	7.5	8.3	8.3	7.0	7.3	5.8
	IV	7.5	7.3	5.5	6.8	5.5	6.0
	Ave.	6.7	7.4	6.7	7.5	6.7	7.0
Semitend-inosus	I	6.0	6.5	4.8	6.5	7.5	6.3
	II	7.0	8.0	6.3	6.3	7.3	6.0
	III	7.8	8.0	8.0	5.0	7.8	5.5
	IV	5.5	7.0	5.5	4.3	3.8	4.0
	Ave.	6.6	7.4	6.2	5.5	6.6	5.5
Biceps femoris	I	5.0	5.5	7.3	7.5	7.5	7.0
	II	8.0	7.5	7.0	5.8	5.3	4.5
	III	8.0	7.5	7.5	8.3	7.3	5.8
	IV	7.3	8.3	6.0	9.0	6.3	6.0
	Ave.	7.1	7.2	7.0	7.7	6.6	5.8
Total		140.3	147.5	139.2	146.3	136.9	124.1
Ave.		7.0	7.4	7.0	7.3	6.8	6.2

* Animal number

Table 32.

Average of Four Judges' Scores for Tenderness of Roasts (Maximum score possible, 10).

Muscle	*	Days Aged					
		1	2	5	10	20	30
Psoas Major	I	9.0	9.0	8.5	9.5	9.8	9.3
	II	9.0	9.3	8.7	9.5	9.5	9.8
	III	7.3	8.0	8.8	9.5	9.3	8.8
	IV	7.3	8.0	8.3	9.3	7.8	7.5
	Ave.	8.2	8.6	8.6	9.5	9.1	8.9
Longissimus dorsi (ribs)	I	4.0	6.0	7.0	7.0	7.3	9.3
	II	2.0	3.0	3.3	5.3	5.8	6.5
	III	-2.5	0.3	4.0	7.0	6.8	6.8
	IV	3.5	0.8	5.3	3.5	4.3	6.8
	Ave.	1.8	2.5	4.9	5.7	6.1	7.6
Longissimus dorsi (loin)	I	2.3	4.0	4.0	6.0	6.3	6.0
	II	2.3	3.5	3.3	6.0	7.0	7.0
	III	-1.0	-0.3	1.3	5.8	6.3	6.8
	IV	-4.5	-4.3	-2.5	2.5	-0.5	5.5
	Ave.	-0.2	0.7	1.5	5.1	4.8	6.3
Semitend-inosus	I	4.3	5.0	5.5	6.8	8.8	6.0
	II	6.5	5.5	4.0	4.5	5.8	5.8
	III	3.5	4.0	5.8	7.3	6.3	6.8
	IV	-2.5	-2.5	1.5	-0.3	3.0	2.8
	Ave.	3.0	3.0	4.2	4.6	6.0	5.4
Biceps femoris	I	1.5	3.8	6.5	5.0	5.8	6.3
	II	3.0	3.8	4.3	4.8	4.3	5.3
	III	-2.3	2.0	0.5	4.5	8.3	7.8
	IV	-4.0	-1.5	0.0	2.0	5.0	3.5
	Ave.	-0.5	2.0	2.8	4.1	5.9	5.8
Total		48.7	67.4	88.1	115.5	127.0	134.4
Ave.		2.4	3.7	4.4	5.8	6.4	6.7

*Animal number

Table 33.

Shear Force (Pounds) of Roasts
at Six Aging Periods
(Average of 3 shears).

Muscle	*	Days Aged					
		1	2	5	10	20	30
Psoas Major	I	15.9	20.4	-	-	-	-
	II	16.9	16.0	18.7	16.6	-	-
	III	15.9	22.8	17.3	16.8	15.5	-
	IV	25.9	19.5	-	-	-	-
	Ave.	18.7	19.7	18.0	16.7	15.5	-
Longissimus dorsi (ribs)	I	24.3	-	-	19.0	-	-
	II	46.0	23.2	27.2	19.3	28.7	13.9
	III	39.0	36.0	26.0	27.9	25.3	16.8
	IV	28.1	25.6	22.1	30.8	-	26.3
	Ave.	34.4	28.3	25.1	24.3	27.0	19.0
Longissimus dorsi (loin)	I	-	25.7	18.9	24.4	-	-
	II	33.2	38.6	23.8	17.4	19.0	19.2
	III	24.3	39.7	31.2	21.8	22.0	15.0
	IV	33.7	37.9	45.0	40.2	30.1	20.2
	Ave.	30.4	35.5	29.7	26.0	23.7	18.1
Semitend-inosus	I	29.5	-	-	25.0	-	-
	II	27.8	28.1	25.8	31.2	27.4	22.3
	III	39.0	29.6	27.6	25.4	25.9	22.6
	IV	60	29.4	30.9	44.4	32.9	30.9
	Ave.	38.8	29.0	28.1	31.5	28.7	25.3
Biceps femoris	I	14.3	29.2	27.6	20.3	23.0	23.3
	II	22.3	42.5	23.9	25.6	22.1	16.1
	III	39.9	34.9	31.5	24.1	21.8	28.8
	IV	42.8	20.0	30.2	25.2	18.8	24.0
	Ave.	29.8	31.7	28.3	23.8	21.4	23.1
Total		577.8	519.1	427.7	455.4	312.5	279.4
Ave.		30.4	28.8	26.7	25.3	24.0	21.5

*Animal number

Table 34.

Percentage of Press Fluid in Cooked Roasts (Averages of 3 determinations)

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	42.8%	35.4%	41.8%	38.0%	34.4%	35.5%
	II	34.0	40.3	41.0	36.5	36.2	40.7
	III	35.5	44.4	41.6	37.9	34.2	34.2
	IV	42.9	39.9	32.9	32.8	42.9	31.8
	Ave.	38.8	40.0	39.3	36.3	36.9	35.6
Longissimus dorsi (ribs)	I	37.6	32.2	29.8	37.1	36.6	28.2
	II	36.1	33.7	40.8	46.5	45.2	36.7
	III	40.6	39.8	39.9	37.6	40.9	37.7
	IV	33.3	36.4	34.9	41.0	41.8	31.8
	Ave.	36.9	35.5	36.4	40.6	46.1	33.6
Longissimus dorsi (loin)	I	33.0	42.2	37.8	36.1	44.4	45.3
	II	39.7	42.3	49.0	46.9	38.2	37.3
	III	40.8	37.2	43.0	32.4	34.4	33.8
	IV	40.6	42.1	32.7	39.4	41.9	44.5
	Ave.	38.5	41.0	40.6	38.7	39.8	40.2
Semitend-inosus	I	35.7	36.9	40.9	33.2	41.4	26.8
	II	42.1	46.7	39.5	37.0	39.7	38.1
	III	32.6	32.4	33.7	33.0	35.6	37.9
	IV	35.7	42.1	39.5	33.0	42.4	41.7
	Ave.	36.5	39.5	38.4	34.1	39.8	36.1
Biceps femoris	I	40.6	39.2	30.7	40.8	40.3	48.2
	II	50.6	49.3	51.1	48.6	26.3	42.0
	III	35.2	33.9	41.9	37.9	37.9	33.9
	IV	51.7	42.9	35.8	42.8	38.9	32.9
	Ave.	44.5	41.3	39.9	42.5	35.9	39.2
Total		781.1	789.3	778.3	768.5	773.6	739.0
Ave.		39.1	39.5	38.9	38.4	38.7	37.0

*Animal number

Table 35.

pH Readings of Uncooked Roasts

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	5.50	5.40	5.40	5.50	5.65	5.62
	II	5.62	5.50	5.42	5.48	5.64	7.14**
	III	5.68	5.49	5.77	5.76	5.62	6.40
	IV	5.48	5.63	5.42	5.69	5.62	5.68
	Ave.	5.58	5.51	5.50	5.61	5.63	6.21
Longissimus dorsi (ribs)	I	5.45	5.38	5.42	5.40	5.58	5.48
	II	5.42	5.32	5.39	5.40	5.39	5.93**
	III	5.46	5.48	5.52	5.51	5.58	5.61
	IV	5.59	5.49	5.57	5.44	5.43	5.62
	Ave.	5.48	5.42	5.48	5.44	5.50	5.66
Longissimus dorsi (loin)	I	5.42	5.40	5.34	5.38	5.50	5.40
	II	5.50	5.39	5.50	5.49	5.50	6.48**
	III	5.52	5.52	5.54	5.62	5.46	6.08
	IV	5.48	5.43	5.39	5.38	5.34	5.96
	Ave.	5.48	5.44	5.44	5.47	5.45	5.98
Semitend-inosus	I	5.35	5.40	5.40	5.44	5.50	5.40
	II	5.36	5.48	5.62	5.56	5.61	6.21**
	III	5.47	5.46	5.50	5.49	5.60	5.76
	IV	5.46	5.49	5.50	5.50	5.36	5.58
	Ave.	5.41	5.46	5.51	5.50	5.52	5.74
Biceps femoris	I	5.40	5.40	5.40	5.40	5.52	5.44
	II	5.32	5.42	5.42	5.40	5.39	6.16**
	III	5.38	5.43	5.50	5.57	5.58	5.73
	IV	5.47	5.48	5.40	5.42	5.42	5.82
	Ave.	5.39	5.43	5.43	5.45	5.48	5.79
Total		109.33	108.99	109.42	109.83	110.29	117.50
Ave.		5.47	5.45	5.47	5.49	55.1	5.88

*Animal number
** See Cooked Roasts

Table 36.

pH Readings of Cooked Roasts

Muscle	*	Days Aged 1	2	5	10	20	30
Psoas Major	I	5.72	5.62	5.68	5.76	5.88	5.74
	II	5.91	5.72	5.79	5.70	5.82	5.85**
	III	5.89	5.69	5.99	5.73	5.78	5.82
	IV	5.74	5.92	5.69	5.92	5.48	5.75
	Ave.	5.82	5.74	5.79	5.78	5.74	5.79
Longissimus dorsi (ribs)	I	5.76	5.68	5.72	5.73	5.80	5.90
	II	5.79	5.70	5.72	5.72	5.72	5.80**
	III	5.72	5.73	5.85	5.84	5.93	5.82
	IV	5.92	5.98	5.82	6.13	5.66	6.02
	Ave.	5.80	5.77	5.78	5.86	5.78	5.89
Longissimus dorsi (loin)	I	5.70	5.70	5.68	5.79	5.78	5.70
	II	5.70	5.79	5.80	-	5.71	6.68**
	III	5.82	5.83	5.88	5.91	5.82	6.03
	IV	5.79	5.72	5.68	-	5.50	5.93
	Ave.	5.75	5.76	5.76	5.85	5.70	6.09
Semitend-inosus	I	5.68	5.70	5.68	5.70	5.64	5.60
	II	5.72	5.70	5.82	5.73	5.80	5.84**
	III	5.74	5.73	5.92	5.78	5.82	5.94
	IV	5.73	5.83	5.83	-	5.55	5.84
	Ave.	5.72	5.74	5.81	5.74	5.70	5.81
Biceps femoris	I	5.62	5.68	5.68	5.64	5.70	5.60
	II	5.72	5.68	5.72	5.69	5.72	5.72**
	III	5.69	5.75	-	5.81	5.82	-
	IV	5.80	5.83	5.70	5.68	5.69	5.95
	Ave.	5.71	5.74	5.70	5.71	5.73	5.76
Total		115.16	114.98	109.65	98.26	114.62	111.53
Ave.		5.76	5.74	5.77	5.78	5.73	5.87

*Animal number

**Run 3 days late on different pH meter (same buffer). Kept in refrigerator.

K-709

Sample No. _____ Date _____

SCORE CARD FOR MEAT

Factor	10	9	8	7	6	5	4	3	2	1	Remarks
	Extremely good	Very good	Good	Medium			Fair	Poor	Very poor	Extremely poor	
				plus		minus					
Aroma											
Flavor Fat											
Lean											
	Extremely tender	Very tender	Tender	Medium			Fair	Tough	Very tough	Extremely tough	
				plus		minus					
Tenderness											
	Extremely juicy	Very juicy	Juicy	Medium			Fair	Dry	Very dry	Extremely dry	
				plus		minus					
Juiciness											

Descriptive Terms

Aroma

1. Mild ----
2. Sharp ----
3. Strong ----
4. Faint ----
5. Foreign ---
6. _____ ----
7. _____ ----
8. _____ ----

Flavor

1. Flat ----
2. Mild ----
3. Mellowed ----
4. Rich ----
5. Strong ----
6. Old ----
7. Bitter ----
8. Acid ----
9. Salty ----
10. Sweet ----

Color of Lean

1. Light brown ----
2. Dark brown ----
3. Red and brown ----
4. Gray ----
5. Irridescent ----

Texture

1. Stringy ----
2. Dense, compact ----
3. _____ ----
4. _____ ----
5. _____ ----

Preference _____
(among samples judged at one time)

Scorer _____