THE INFLUENCE OF PRE- AND POST-RIGOR EXCISION ON SOME BOVINE MUSCLES

By

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EXCISION ON SOME BOVINE MUSCLES

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CHAPTER I

INTRODUCTION

Many factors affecting the tenderness attribute of beef have been elucidated and extensively reported. Connective tissue content, fiber size, aging, ionic balance, water retention, temperature, and time during storage are listed among the most important factors in tenderness of beef. In recent years, post mortem muscle contraction has also been linked with the tenderness. Relaxed muscles were reported to be more tender than partially contracted muscles. This was thought to be evident in the muscles low in total connective tissue. Muscles excised prior to the onset of rigor mortis are subjected to greater contraction than the muscles chilled intact on the skeleton during the onset of rigor mortis. The evidence for a direct relationship between the tension on muscle and the microstructural changes in its muscle fibers have not been reported.

Separating the muscles or meat from the freshly slaughtered carcass and then chilling the parts would appear to be more economical than the present conventional chilling of the muscles on the skeleton. If muscle excision from the hot carcass followed by chilling has no effect on tenderness, then it seems likely that the industry will adopt this more economical practice.

This study was designed to learn the effect of excision on muscles removed immediately after slaughter (pre-rigor excision) on fiber size, fiber contraction, and tenderness. Release of tension on muscles by removing them from bones was considered to affect the physical nature of its fiber. Hence, the emphasis in this investigation was to learn the extent of structural change when influenced by the amount of connective tissue and fiber orientation. In this experiment, longissimus dorsi was considered as a muscle low in connective tissue with its fibers mostly oriented in one direction, gluteus medius a muscle containing fairly high amounts of connective tissue with the majority of its fibers oriented in different directions, and semitendinosus as a muscle containing high amount of connective tissue with the majority of its fibers running parallel.

CHAPTER II

REVIEW OF LITERATURE

Bovine skeletal muscle fiber is elongated, cylindrical, and multinucleated, the nuclei being elliptical in shape. Fiber length has not been reported; however, the fiber diameter ranges from 10 to 150 μ depending upon the muscle and age of the animal at slaughter. Muscle fibers are encased in a layer of connective tissue referred to as the sarcolemma and contain fibrils bathed in a fluid called sarcoplasm. The fibril shows dark and light bands which constitute a sarcomere, the contractile unit.

Four major topics are considered in this review. They are; A) muscle fiber, B) degree of rigor in fibers, C) length of sarcomere, and D) shear force. Information given has been confined to the conditions which relate directly to the problem.

Muscle Fiber Size

Species Influence

The effect of specie on body weight and muscle fiber diameter at birth and maturity for rabbit, pig, sheep, and cattle was reported by Joubert (1956a). When absolute measurements were used, no consistent relationship appeared to exist between body weight and mean fiber diameter among the species at birth. Despite appreciable differences in weight, the rabbit had but slightly smaller fiber on an average than sheep. Though intermediate in weight between sheep and cattle, pig on the contrary, had appreciably thinner fibers, while cattle possessed larger muscle fibers than those of the sheep, yet not proportional to differences in body weight. At maturity, the rank of fiber diameter had altered noticeably. The thickest muscle fibers were those of pig, followed in decreasing order of magnitude, by rabbit and cattle with rather similar sized fibers, and sheep with the smallest fibers.

The relative increase in fiber diameter varied greatly with specie at maturity. In these four species, increase in average fiber diameter from birth to maturity were shown as follows:

Specie	Birth	Maturity
rabbit	10	77
pig	5	90
sheep	11	50
cattle	14	73

He concluded that fiber diameter had no clear relationship to size of species. However, increase in fiber diameter was closely associated with relative increase in body weight.

Though the investigation on the effect of specie on muscle fiber diameter was based on too limited number to allow for intra-species variation, inter-species differences appeared to be fairly distinct. In absolute measure, the results on fiber diameter at both birth and maturity for rabbit were comparable with those reported by Meara (1947). Differences in fiber size among pig, sheep, and cattle again were comparable with the data of Warringshollz (1903). His investigation showed no relationship between size of the animal and size of muscle fiber when different species of farm animals were compared. The pig, cattle, horse, and sheep forming a series, possessed decreasing diameter of muscle fiber when measured at a mature age. Similarly Paff (1930) found the fibers of the guineapig considerably larger, in general, than those of rat and cat. Fibers of the latter two species were approximately equal in cross section area.

Franck (1914) first suggested in this connection that the difference between species may be partly determined by degree of post-natal development, for while adult the pig reaches about 100 times its birth weight, sheep reaches only about thirteen times, and cow about fifteen times.

The general principle involved agreed with the results of Janeba (1933) who compared muscle fiber development between cattle and pigs. Though fibers increased with the age in both species, the increase was much more marked in swine.

Breed Difference

Using cattle, Joubert (1956a) studied the effect of breed on fiber diameter. Cattle included were Dairy Shorthorn, and British Friesian, plus Angus and Hereford crosses on these two breeds, making six groups. Only steers were used to eliminate the effect of sex. All cattle were fed to a constant grade; therefore, differences in age, 28 to 32 months, and differences in size were not eliminated. Friesian groups, including pure breds as well as Angus and Hereford crosses, had significantly greater fiber diameter than Hereford corssbreeds. This breed difference was not shown to be independent of body weight. Friesian cattle had significantly heavier body weight than the Shorthorn cattle.

Adametz (1888) reported breed differences in respect to muscle fiber diameter, but data strictly related to this work are not available. Hammond and Applleton (1932) found that muscle fibers of four year old Suffolk rams were larger (49.20μ) than those of the semi-wild Shetland (45.50μ) at the age of five years. Comparing muscle fiber size between two Rumanian breeds of sheep, Strateciuc (1933) found greater individual variation within than between breeds. Glebina (1952) found that large White X Berkshire crossbreed pigs had larger muscle fiber on an average at all ages than either of the parent breeds.

Interbreed differences in muscle fiber size in fowl were studied by Mehner (1938). His investigation included twelve races and crosses of 90 chickens which revealed distinct breed differences, almost parallel to differences in body size.

Sex Relationship

A review of early studies caused Joubert (1956a) to conclude that males generally have thicker fibers than females. These references, he observed, did not consider the differences in size due to sex. From his studies in both newborn lambs and their post-natal development, he concluded that differences in fiber thickness could be accounted for largely by body weight. He found that with body weight held constant, there was a slight tendency for females to have thicker fibers than males. Thus, he postulated that males might possess a greater number of fibers.

With reference to farm animals, Adametz (1888) found that muscle fibers of bulls are appreciably larger than those of cows, but that only slight differences existed between bulls and steers. His results have since been confirmed by Hammond and Appleton (1932) in the sheep, by Mehner (1938) in the fowl, and Ishihara et al. (1953) in their studies on the carcasses of Japanese Black cattle.

Contradictory evidence has been presented by Brady (1937), and Sartorius and Child (1938) who found that cows had significantly thicker muscle fibers than steers.

Work on a more comparable basis by Eliot et al. (1943) revealed no marked differences in size of muscle fiber in soleus muscle of male and female rats.

Age Effect

Age changes in fiber diameter in pigs from birth to 28 weeks were reported by McMeekan (1940-41). Significant increases were found for each of the four week intervals at which animals were slaughtered. According to his data, fiber diameter in the pig increased from 2.48 ± 0.17 μ at birth to 21.35 ± 0.77 μ at 28 weeks.

Post-natal muscular growth in the rabbit was studied by Meara (1947). He found considerable fiber thickening from birth to maturity. In general, after a period of marked increase from birth to 600 g. body weight, the curves flattened out progressively in the subsequent groups so that only a slight increase between 3000 g. and maturity was observed. The slope at which the flattening became apparent differed between muscles, depending upon their degree of post-natal development.

Hiner et al. (1953), in a study of veal and beef carcasses, found that as the age of the animal increased, the diameter of the muscle fiber increased, in most cases the difference between consecutive age groups being significant at the five per cent level.

Joubert (1956a) studied the effect of age on fiber diameter in sheep. He used observations from gastrocnemius, rectus femoris, and longissimus dorsi to show effects on individual muscle. At birth the gastrocnemius possessed the largest fibers and the longissimus dorsi developed most, but fibers of the rectus femoris were still slightly larger on the average. Fibers of the gastrocnemius increased least and were smallest at maturity.

Thompson (1942) pointed out that the individual muscle fibers appeared to possess a maximum capacity for development which could not be exceeded. But despite the relative reduction in variations with age, even in the mature animal, the dispersion remained considerable in absolute terms. The factors controlling ultimate size of single fiber in relation to the population as a whole would be difficult to assess. He also concluded that as the animal increased in weight from birth to maturity, the muscle fibers increased in size until their maximum capacity was reached.

Hiner et al. (1953) studied the average diameter of the fiber for nine muscles from 52 animals consisting of eight cows that averaged approximately five and one-half years of age; eight three-year old barren heifers; twenty-five 14-month old 900-pound steers; eight seven-month old 500-pound steer calves; and three veal calves of two months of age. An increase in the fiber diameter with the increase in age was noticed in all the muscles studied.

He also found that the difference in muscle fiber diameter from veal calves and 500-pound steer calves was not significant at the five per cent level. However, the difference between steer calves and 900-pound steers was highly significant. Other highly significant differences were found between cows and 900-pound steers; cows and 500-pound steer calves; and heifers and 500-pound steer calves. These analyses for fiber diameters indicated that the greatest change occurred between eight and 14 months of age.

Studies were made by Tuma et al. (1962) to examine the muscle fiber diameter-tenderness and muscle fiber diameter-meatiness relationship. Herefords of five age groups, between six and 90 months old, were used. A gradual increase in fiber diameter with increasing animal age was noted for the longissimus dorsi muscle. The fiber diameter in semitendinosus muscle increased at six, 18, and 24 months, then leveled off.

Carpenter et al. (1962) found an increase in the muscle fiber diameter with increasing age. A positive association was noticed between fiber diameter and thickness of the connective tissue and bundle size.

Henrickson et al. (1963) studied mean fiber diameter as influenced by age and aging in bovine longissimus dorsi and semitendinosus muscles. They concluded that there was an increase in fiber diameter with advancing animal age in both muscles. The bulk of muscle fiber diameter development was noticed at six months of age. Growth continued during the ensuing months and tended to plateau prior to age 42 months. The actual age at which muscle fiber growth plateaus was not evident from their studies; however, it appeared to be between 18 and 42 months.

Studies were made by Henrickson et al. (1965) on thirty-six Hereford heifers to investigate the effect of advancing age on the changes in carcass tissues. The heifers at six months of age were randomly assigned to six age groups. Average fiber size of the muscles of one side of the carcass was taken as muscle fiber size of that animal. It was shown that the major changes in muscle fiber size occurred with advance in age. At nine months of age, the cross sectional fiber area was 1533.1 square microns, whereas at 24 months the area increased to 3512.3 square microns.

Weight Difference

Joubert (1956a) observed a change in fiber diameter with corresponding changes in the carcass weight, indicating muscular growth as primarily a function of physiological age and not strictly one of chronological age. In lambs, correlations were found between average fiber diameters from the longissimus dorsi and body weight ($r = + 0.826$), as well as fiber diameter and carcass weight ($r = + 0.760$). In each case, 41 lambs were included in the analysis. Fiber diameter was found to be most closely related to the weight of the individual muscle ($r = + 0.856$). When the cross sectional area of the fiber was estimated by the square of the diameter (d^2), the correlation with muscle weight was $+ 0.936$.

Henrickson *et al.* (1965) revealed that the muscle weight and fiber area were closely related to one another and that increases in cross sectional fiber area might account for the change in total muscle weight.

Tuma *et al*. (1962) estimated total muscle in the carcass using the ninth, tenth and eleventh rib separation data. The total pounds of carcass lean when correlated with the average fiber diameter of the longissimus dorsi muscle gave a correlation coefficient of 0.83. The average fiber diameter of the semitendinosus muscle when correlated with the total carcass lean gave a correlation of 0.73. When the animal age effect was removed, the correlations were 0.00 and 0.35 for the longissimus dorsi and semitendinosus, respectively. With these data, they suggested that fiber diameter was not a good indicator of total carcass lean or muscle size.

Nutrient Intake

The effect of level of nutrient intake on fiber size was studied by Joubert (1956a) in both lambs and mature ewes, and was shown to influence muscle fiber diameter appreciably in both age groups. Muscle fiber diameter of mature ewes on a super-maintenance diet increased in proportion to increases in total muscle while on a submaintenance diet, the opposite was found. He observed that the fiber diameter of the high plane group at 60 days was comparable to those of the low plane group at 290 days. He also observed that continuation of the super-maintenance treatment would have resulted in but little additional changes in the diameter of fibers, while prolongation of the sub-maintenance treatment probably could have caused considerable shrinkage of individual fibers.

Yeates (1964) studied starvation changes and subsequent recovery of adult beef muscle. Two pairs of identical twin steers and six other adult cattle were killed and their carcasses and tissues examined as necessary to study:
(a) the muscle changes resulting from severe weight loss from starvation; (b) the reversibility of such changes, as shown at various stages in recovery of the animal's weight.

The experiment revealed that with starvation of the adult animal the shrinkage in cross sectional areas of the muscles, after allowing for the loss of some intramuscular fat, was associated with the reduction in diameter of the individual fibers. There was no suggestion of the complete loss of any fibers; thus, with repair of live weight, recovery both of whole muscle dimensions and muscle fiber diameter appeared to be complete.

Muscle Variation

Studies were made by Hiner *et al.* (1953) to determine the relationship between tenderness and fiber diameter in beef muscles that varied widely in tenderness. Nine muscle samples from each of 52 beef animals were used. The animals ranged in age from ten-week-old veal calves to nine-year-old cows. The carcasses were aged approximately 14 days at 0.6 to 1.7°C, sectioned into primal cuts and from these nine samples were prepared.

Diameters of the fibers from the nine samples classified themselves into four general groups in increasing magnitude as follows: (a) tenderloin (psoas major); (b) the two chuck samples (longissimus dorsi and triceps brachii), eighth rib (longissimus dorsi), shortloin and loin end (longissimus dorsi and gluteus medius); (c) round (semimembranosus, semitendinosus, and biceps femoris); (d) neck and foreshank (serratus ventralis and deep digital flexor).

Tuma *et al*. (1962) studied the fiber diameter in relation to tenderness and meatiness in two bovine muscles using different age groups. The longissimus dorsi and semitendinosus muscles from both sides of each carcass were studied. The average fiber diameter for longissimus dorsi muscle was reported to be higher than semitendinosus muscle (64.4 and 62.4 microns respectively).

Within Muscle Variation

Swanson *et al*. (1965) investigated the variation in muscle fiber size of ten bovine longissimus dorsi muscles taken from the right and left sides of five animals, using two different methods. The longissimus dorsi muscle was sampled at five positions along its length and at five cross sectional locations within each position. A great deal of variation was found in muscle fiber size both among different positions along the longissimus dorsi muscle and among different locations within each position. The smallest fibers were found over the 12th rib and at the lateral edge of the muscle.

Tuma et al. (1963) studied the variation in fiber size in longissimus dorsi muscle. A significant dorsal, middle, and lateral "position" effect for fiber diameter was observed in the longissimus dorsi muscle. Fiber diameter decreased from the dorsal to lateral position.

Carcass-Muscle Position

Herring et al. (1965b) in a study of the effect of carcass position on the sarcomere length and fiber diameter of various bovine muscles found a great variation in the fiber diameter among muscles in vertically suspended sides, with mean diameters varying by 30 microns, ranging from 34.5 to 64.5 μ. These values were in general agreement with those of Hiner et al. (1953). However, when sides were placed horizontally this variation among means was reduced to 7.1 μ. Psoas major, rectus femoris, and latissimus dorsi had smaller fiber diameters when the sides were suspended vertically than when they were placed horizontally. Conversely, fiber diameter increased ($P < 0.05$) in semitendinosus, biceps femoris, semimembranosus, and triceps brachii. Non-significant differences ($P < 0.05$) between sides for fiber diameter were noted in the serratus ventralis, longissimus dorsi, adductor, gluteus medius, and infraspinatus. They also concluded that differences in fiber diameter between sides were due to muscle shortening or lengthening.

Degree of Rigor in Fibers

Harrison et al. (1949) in their study of histological changes in beef during aging reported that, 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. These changes were not always linearly related to the time of aging.

Sarcomere Length

Tension on Muscle

Herring et al. (1965a) studied the sarcomere length of free and restrained bovine muscles. The psoas major and semitendinosus muscles were excised pre-rigor (45 minute post-mortem) from one side of each of six randomly selected bovine carcasses of U. S. choice grade. Each muscle was freed of external fat and connective tissue and was divided longitudinally into two identical 18 cm.-long portions of approximately parallel fibers. One portion of each muscle was stretched with a force of 15 kg/kg. of muscle weight, and held in stretched state for 48 hours. The other portion of each muscle was allowed to contract. 'Post-rigor excised muscles' were excised 48 hour post-mortem from the opposite sides of the vertically suspended carcasses and were used as controls in these studies.

Unfixed samples (48 hour post-mortem) were blended for one minute in 0.08 M-Potassium chloride in a chilled blender.

The suspension of myofibrils was examined directly under a phase contrast microscope with the sarcomere length determined as an average from 25 myofibrils of each of the stretched-restrained, free (contracted) and post-rigor excised (control) muscles. The control psoas major had a sarcomere length of 3.8 compared with 2.4 microns for the control semitendinosus. In semitendinosus muscle sarcomere lengths were shortened as a result of pre-rigor excision and subsequent shortening especially when compared to the stretched-restrained samples. Pre-rigor excised, stretched-restrained semitendinosus muscle exhibited longer sarcomeres than the control samples, in all but one instance. Excised 'free' psoas major muscles had sarcomere lengths of approximately 50 per cent of the control post-rigor excised muscles (1.8 versus 3.5 μ). Pre-rigor excised samples which were stretched-restrained had sarcomere lengths of 2.2 to 2.4 μ.

Carcass Position

Herring et al. (1965b) studied the interrelationships of fiber diameter, sarcomere length, and tenderness in 12 bovine muscles of horizontally placed and vertically suspended carcass sides. Two pairs of similarly treated fraternal twins were used for the experiment. All right sides were suspended vertically according to normal procedure. The left sides were placed horizontally, bone down, on a flat surface; the flexible flank was supported with metal supports to facilitate cooling; and the limbs were oriented and fixed perpendicular to the long axis of the sides. Carcasses were chilled 48 hours at 4°C and samples were taken from all 12 muscles for sarcomere length and fiber diameter determination.

In comparison with the horizontally placed sides, the vertically suspended sides had longer sarcomeres in the psoas major, latissimus dorsi, and rectus femoris muscles. Conversely, vertical suspension permitted the sarcomere length to shorten in the longissimus dorsi, gluteus medius, adductor, biceps femoris, and semitendinosus muscles. In general, the differences in sarcomere length of muscles (between sides) were associated ($r = -0.82$, $P < 0.01$) with the differences in fiber diameter. When muscles shortened, there was a corresponding decrease in sarcomere length, increase in fiber diameter, and decrease in tenderness.

Mechanical Shear Force

Fiber Size

Studies were made by Hiner et al. (1953) to determine the relationship between fiber diameter and tenderness. To study this relationship, correlation coefficients between diameter of fiber and values for resistance to shearing were calculated.

Nine samples of muscles from each of 52 beef animals were used. The animals ranged in age from ten weeks to nine years. The carcasses were aged approximately 14 days at 33 to 35°F, divided into their primal cuts and from these the nine samples were prepared. All coefficients of correlation except one were very highly significant. The relationship between tenderness and fiber diameter for all of the samples was shown to be curvilinear. The curvilinear correlation was 0.83. All coefficients of correlation involving samples from any one age group were very highly significant. On this basis it was concluded that meat having small fibers is more tender than meat having larger fibers.

Studies were made by Tuma _et al_. (1962) to examine various muscle fiber diameter-tenderness and muscle fiber diameter-meatiness relationships. Herefords of five age groups, between six and 90 months old, were used. Longissimus dorsi and semitendinosus muscle samples were taken from the left and right sides. All correlations uncorrected for animal age were positive and significant ($P < 0.05$). On these results it was concluded that, the larger the fiber diameter the greater the shear force. However, when the effect of age was removed the correlations ranged from - .22 to .47 which would leave doubt as to the effect of fiber diameter on shear force within any one age group. Hence, within age groups, they observed little relationship between fiber diameter and tenderness.

Carpenter _et al_. (1962) reported correlation coefficient between fiber diameter and the raw shear and denture tenderometer values as - .20 and - .38 respectively. He explained that cores taken from the muscles having small muscle fibers, contained more fibers in the core. Therefore, more of the sarcolemma and endomysial connective tissue were present, resulting in a less tender product. The opposite results with the cooked samples were explained as being due either to the selective alteration and subsequent tendering of the connective tissue in the cooked samples or by a major decrease in tenderness as the result of denaturation of the fibrillar proteins.

Tension on Muscle

Locker (1960) studied the degree of muscular contraction and tenderness in beef. He concluded that the various muscles of the ox undergo rigor in widely differing states of contraction, and the final state of the muscle appears to depend on the strain imposed on it in the hanging position might be modified by cutting or excising the muscle. No correlation was found between the tenderness grading of the muscle and their contraction state. He attributed this fact to the dominant effect of connective tissue. Taste tests on psoas muscles, excised one hour of the time of death and allowed to shorten, showed that these muscles were tougher than the muscles excised the following day. It was also concluded that relaxed muscles were more tender than partly contracted muscles and that this effect might be significant in the grading of muscles of low connective tissue content.

Herring *et al.* (1965a) explained that a positive association may exist between organoleptic tenderness and sarcomere length. Muscles possessing fibers with long sarcomeres were more tender than those with short sarcomeres. The state of contraction was therefore considered as a factor contributing to tenderness where the effect of connective tissue was small.

They also concluded that tenderness was not affected by a single factor such as amount or kind of connective tissue, amount of fat or marbling, or sarcomere length. He explained that the sarcomere length, as a measure of contraction state, was probably only a gross indication of the molecular changes occurring in the actin and myosin of muscle. A large share of tenderness variation was attributed to molecular alterations associated with strong contraction.

They further postulated that post-mortem tenderness was due to the dissociation of actomyosin into actin and myosin. Further evidence that contraction affects tenderness was shown with samples which had been allowed to undergo thaw rigor in a stretched-restrained condition. The samples which had undergone thaw rigor and associated contraction were markedly less tender than their respective controls or samples which had been allowed to undergo thaw rigor in a stretched-restrained condition. In their experiment, an attempt was made to learn the immediate effect of the state of muscle contraction on tenderness. Contractions observed were due to the excision and removal of the muscle from hot carcass, and was associated with the onset of rigor mortis. It also appeared that the contraction markedly affected the tenderness, and muscles under less tension would shorten generally along their length while those held under more tension could not shorten as much or could perhaps shorten only in localized areas. With the above postulations they concluded that the effect of contraction was one of the considerable factors affecting tenderness.

CHAPTER III

MATERIALS AND METHODS

Source of Materials

Five Hereford steers of similar breeding, age, feeding, and management were obtained from the Oklahoma Agricultural Experiment Station herd. The animals were received at the meat laboratory approximately 15 hours prior to slaughter. Feed and water were withheld for 12 hours prior to slaughter. The animals were slaughtered and dressed according to the standard procedures followed in the laboratory (Deans, 1951 and Wellington, 1953). Each carcass was halved and the left half was vertically suspended from a rail in a 34°F cooler for 48 hours. The longissimus dorsi, semitendinosus, and gluteus medius muscles were excised post-rigor (48 hour post-mortem) from the chilled side and used as the controls. Similar muscles were excised pre-rigor (one hour post-mortem) from the warm right half of each carcass, freed of external fat and chilled for 48 hours, suspended in vegetable oil prechilled and maintained at 34°F. In all cases the longissimus dorsi muscle was excised from the hind quarter, starting from the 12th thoracic vertebra. The anterior portion of the longissimus dorsi was not used in this experiment.

Sampling Method

Samples were taken from both pre- and post-rigor excised muscles. The sampling locations for various analyses in different muscles are shown in Figure 1. Each steak was identified by animal and work code number. All shear samples were individually wrapped in aluminum foil, quick-frozen in an air blast freezer, and then held at -20°F until the time of evaluation. Three three-fourth inch cores were removed from each of the steak for histological studies. Positions of these cores taken in different muscles are shown in Figure 2. Care was taken to avoid pressing the tissue or causing distorted fiber orientation by using a newly honed bore.

Jars containing chilled buffered physiological saline with ten per cent formalin (36°F) were labelled for each muscle and sample location. As the sample core was removed from the muscle it was placed directly into the jar. After 24 hours the fixative was replaced by fresh fixative to restore the formalin concentration to near ten per cent. The samples were fixed for the minimum period of one week before being removed for histological studies.

Determination of Shear Values

Steaks used for shear force determination were permitted to thaw for 24 hours at 40°F. These steaks were cooked to an internal temperature of 150°F by the deep-fat-frying method (oil pre-heated to 275°F). Care was taken to

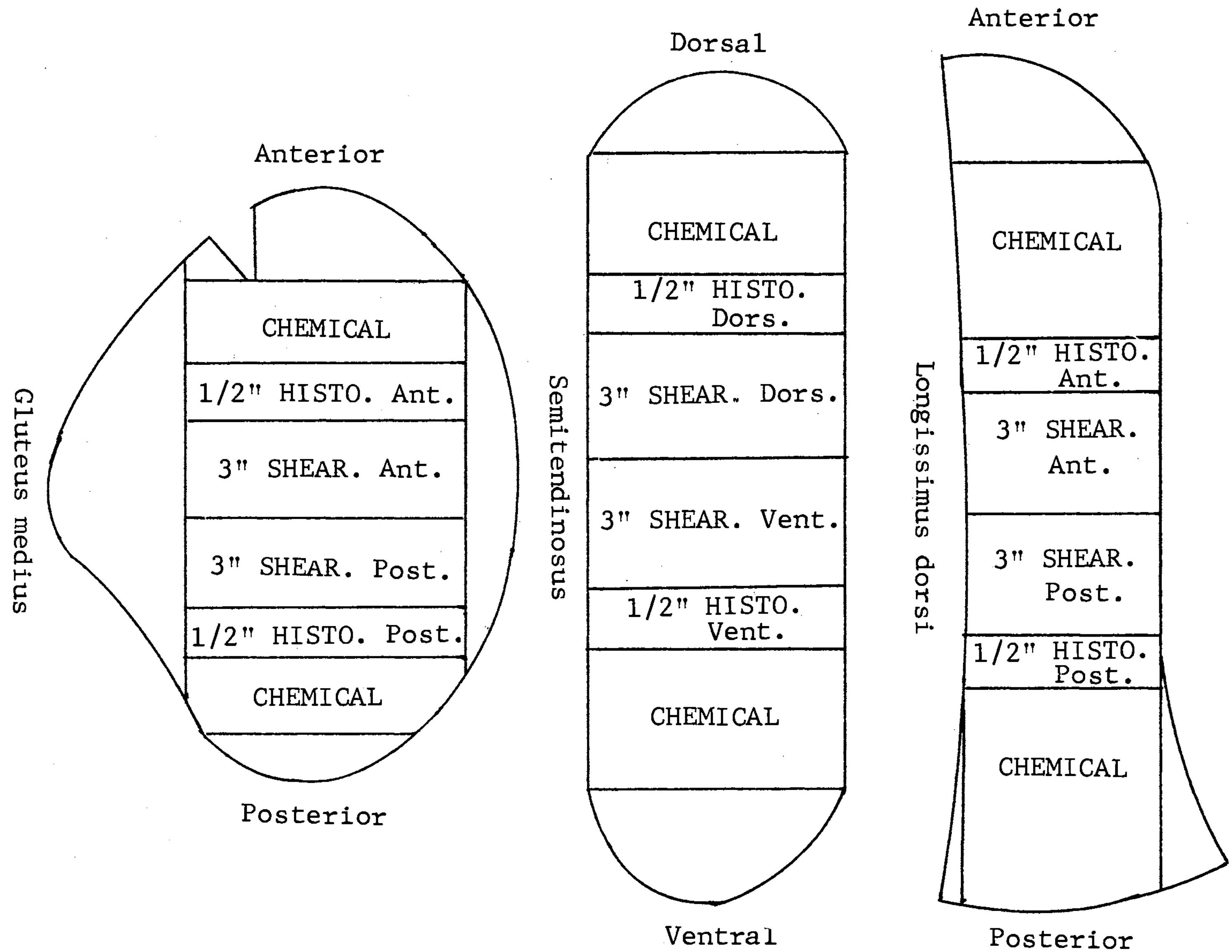


Figure 1. Sampling Location for Three Bovine Muscles

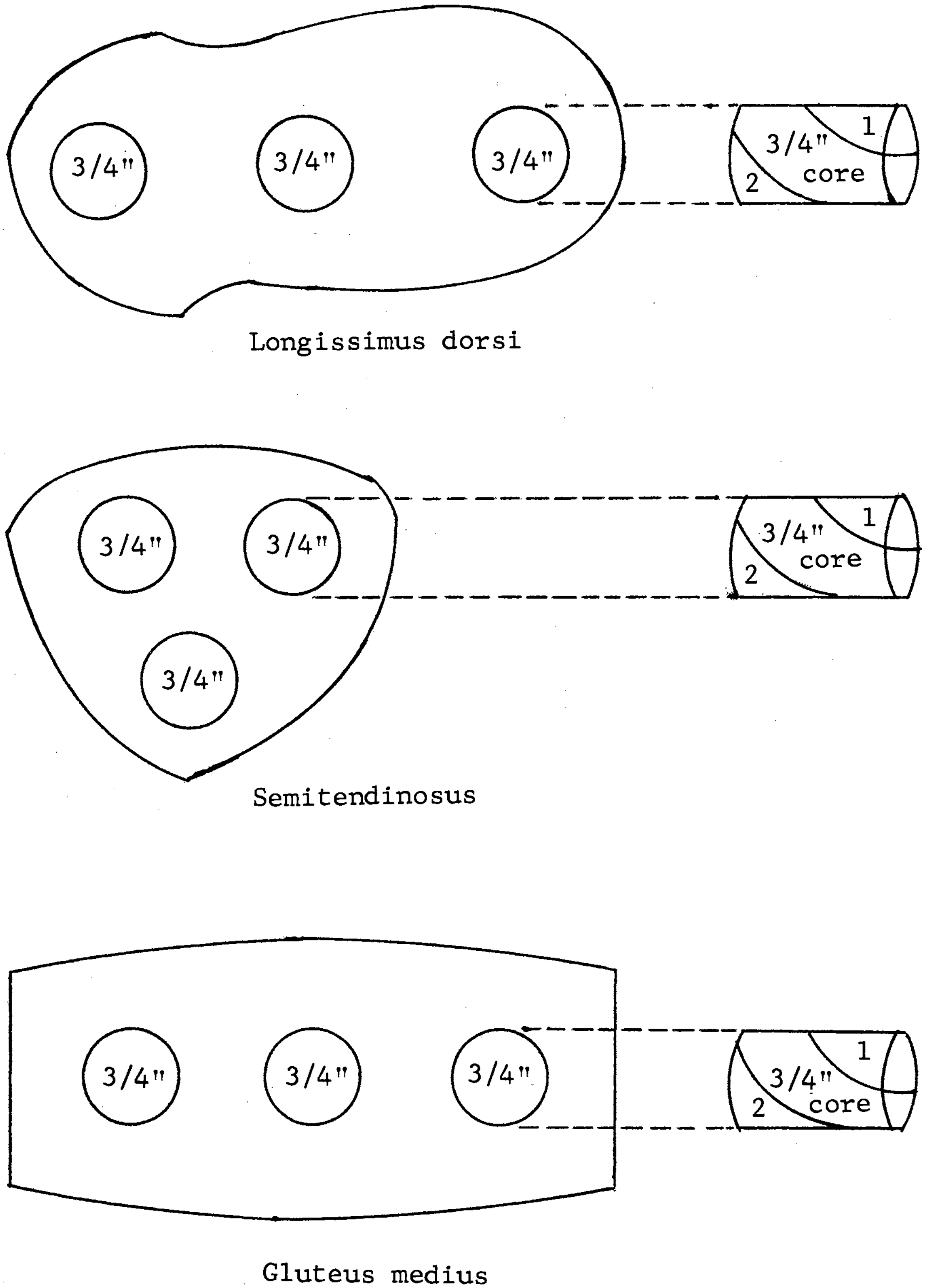


Figure 2. Core Sampling Position From Three Bovine Muscles for Histological Observations

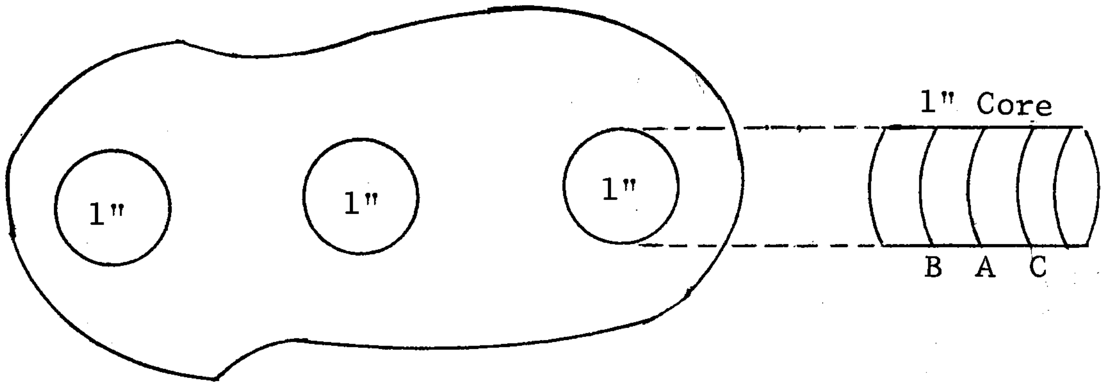
place the steaks fully immersed in the oil to ensure uniform cooking of the muscle. Internal temperature of each steak was determined by the use of a meat thermometer, carefully placing the tip of the stem in the center of the steak. Each steak was moved occasionally to assure uniform degree of doneness.

When cooking was complete each steak was removed to a tray, covered with aluminum foil, and placed in a cold room at 40°F until the next day. Cooling of the steaks was done to enable the handling of many samples without permitting physical and chemical variation due to temperature.

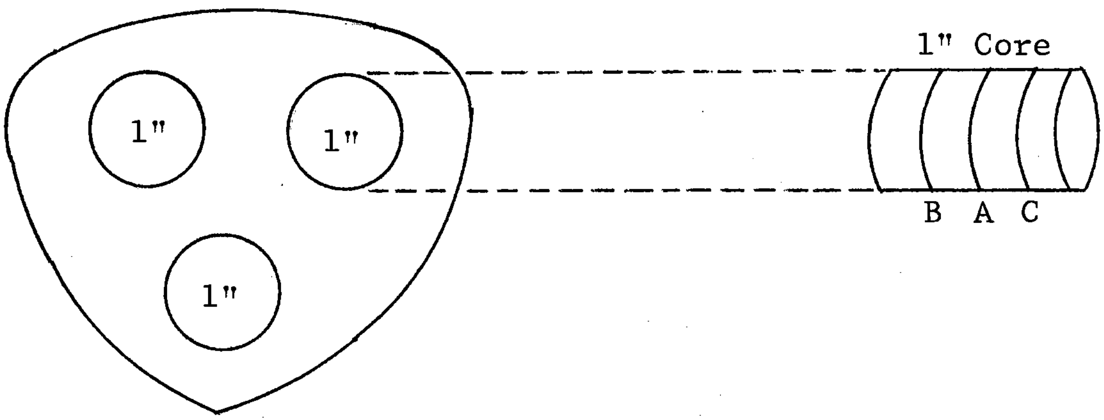
Three one-inch diameter cores were removed from each of the steaks as shown in Figure 3. Care was taken in cutting each core to assure uniformity in thickness. Using a Warner-Bratzler shearing device, each core was first sheared in half and each half sheared again; thus, each core was divided into four equal parts. A total of nine shear values were obtained from each steak. The average of these nine values was used in the statistical analysis.

Measure of Muscle Fiber Diameter and Rigor Mortis

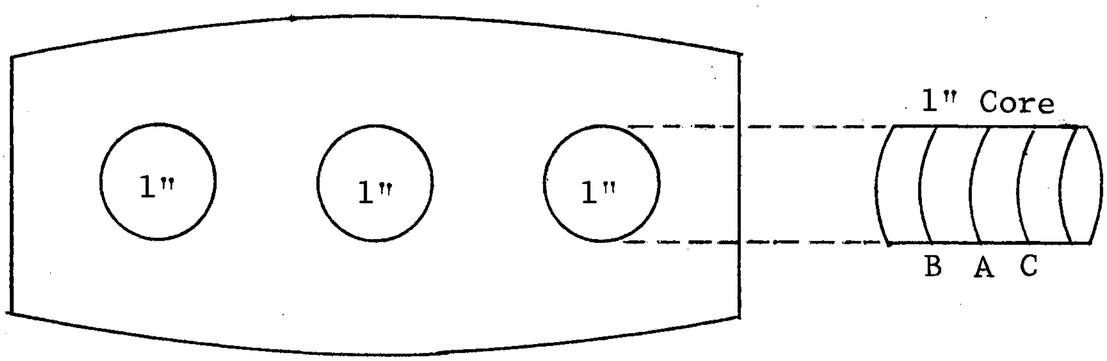
The fixative solution containing one part formalin to nine parts distilled water, 20 g./liter sodium acetate, and 9 g./liter sodium chloride was useful in maintaining the shape and size of the muscle fibers. Formalin and sodium acetate acted as a fixative and a buffering agent respectively.



Longissimus dorsi muscle steak



Semitendinosus muscle steak



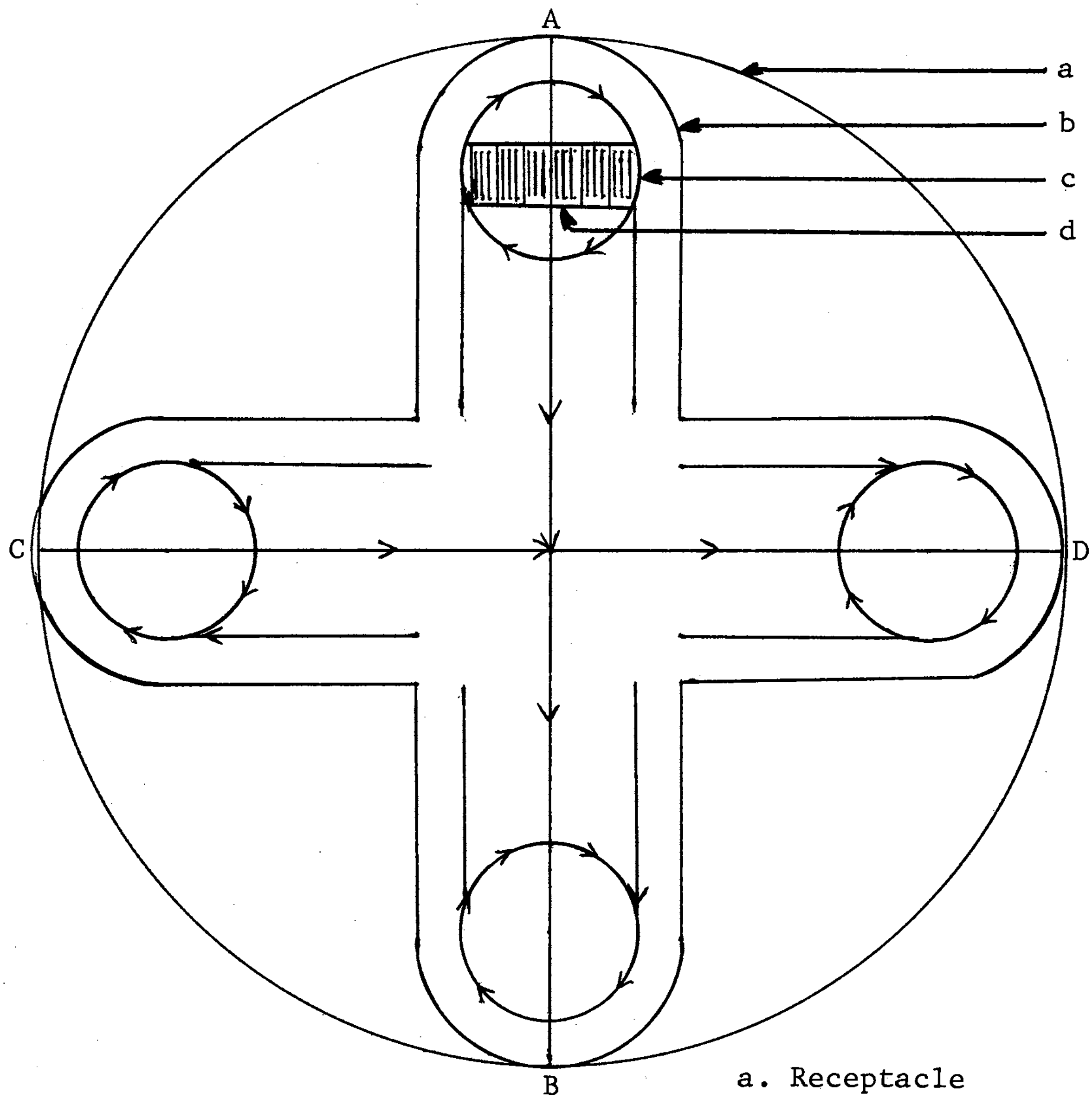
Gluteus medius muscle steak

Figure 3. Sample Locations for Shear Cores

A) Three shearing
B) locations in the
C) cores

Two sections were obtained from both ends of each core (Figure 2) to provide a representative sample for histological observations. The two sample sections were placed together in a microblender with enough buffered ten per cent formalin solution to cover the blender blades. The cutting edges of the blades were reversed to avoid chopping the fibers. The blending process found most satisfactory was 30 seconds at a low speed. Fibers were separated from one another without causing physical damage. A small portion of the teased fibers and the fixative solution poured into a two inch diameter petri dish was taped to the microscope stage. After one minute most of the fibers sank to the lower levels of the solution and measurement was commenced. Measurement in whole microns were made by means of an ocular micrometer inserted into a 10X eyepiece of a compound microscope. A stage micrometer was used to determine the calibration of the ocular micrometer. Each ocular micrometer unit represented ten microns when the 10X objective was used with a 10X eyepiece. The same microscope was used throughout the study. Artificial lighting served as illumination while making the fiber measurements.

The procedure followed in studying the fibers can best be illustrated by means of a diagram (Figure 4). When measuring the fibers, a field was fixed at position A, then the receptacle was moved such that the field movement was from position A to B. If the required number of fibers was not observed with this field, a new field was fixed at



a. Receptacle
b. Field covered by objective lense
c. Field covered by the radius of the ocular micrometer
d. Ocular micrometer

Figure 4. Diagram Illustrating the Technique of Choosing a Field for Muscle Fibers Measurement

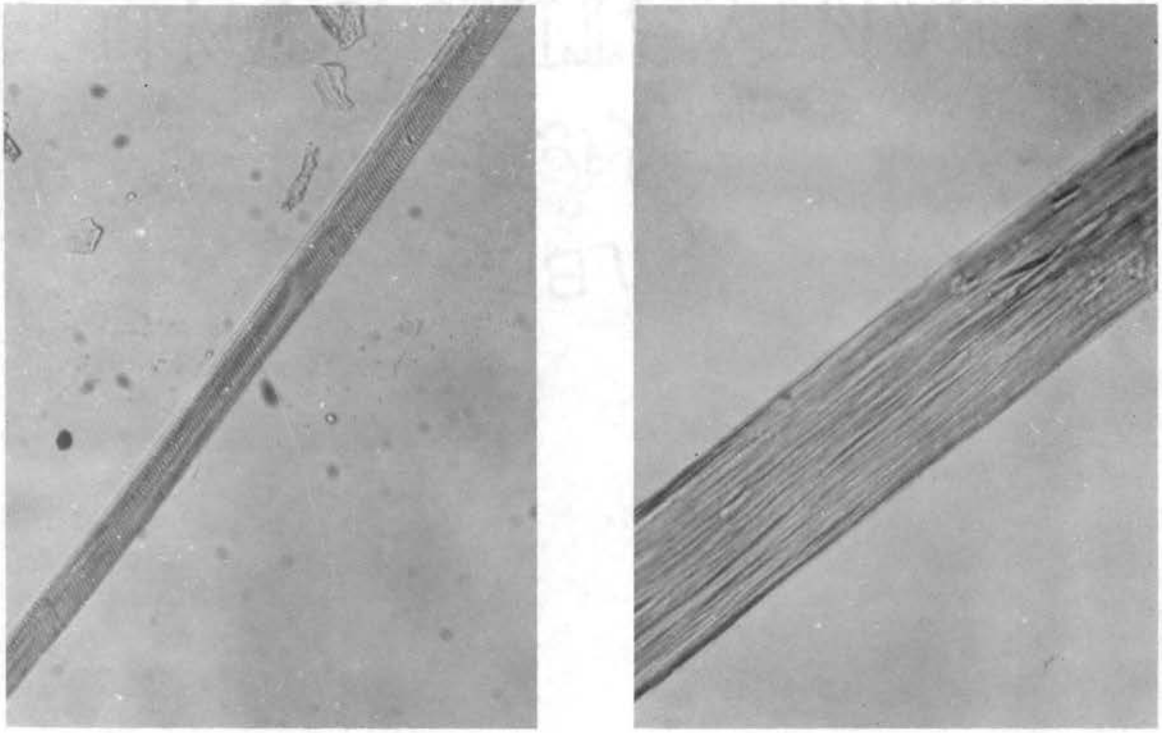
position C and was moved towards position D. As the field was moved in the described manner all fibers within the radius of the ocular micrometer were measured. Care was taken to accurately measure the diameter of kinky fibers. This was accomplished by measuring the fiber from one border of its kink to the other border in the same plane.

Twenty-five intact muscle fibers were measured from each core for the diameter and condition. Thus a total of 75 fibers per steak or 150 fibers per muscle sample were measured. Each muscle fiber was classified according to the degree of observed rigor as follows:

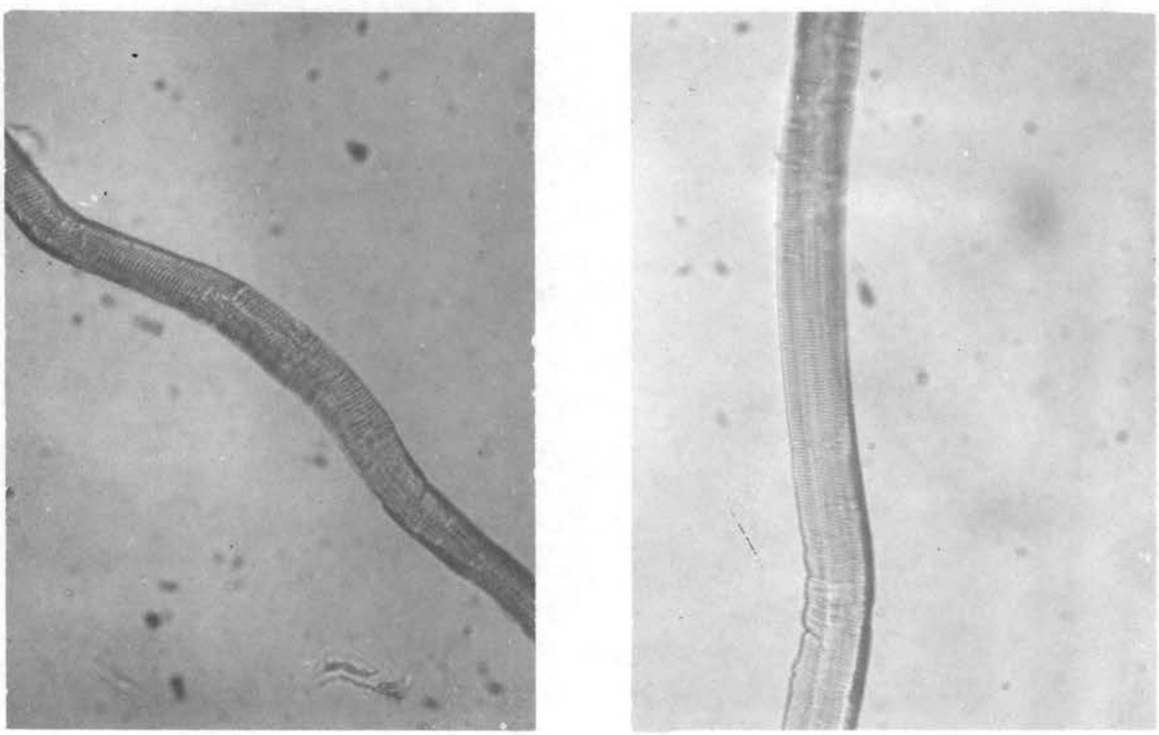
Shape of the fiber	Rigor mortis value
1. Straight	0
2. Wavy	1
3. Twisted	2
4. Kinky	3

The appearance of the above classified fibers is shown in Figure 5.

The number of fibers of each shape was multiplied by the allotted rigor value and the degree of rigor expressed on a percentage basis. Using the allotted values, it was assumed that the maximum cumulative rigor value of all the fibers in a core would be 300 (if all the fibers were kinky) and minimum rigor value zero (if all the fibers were straight).



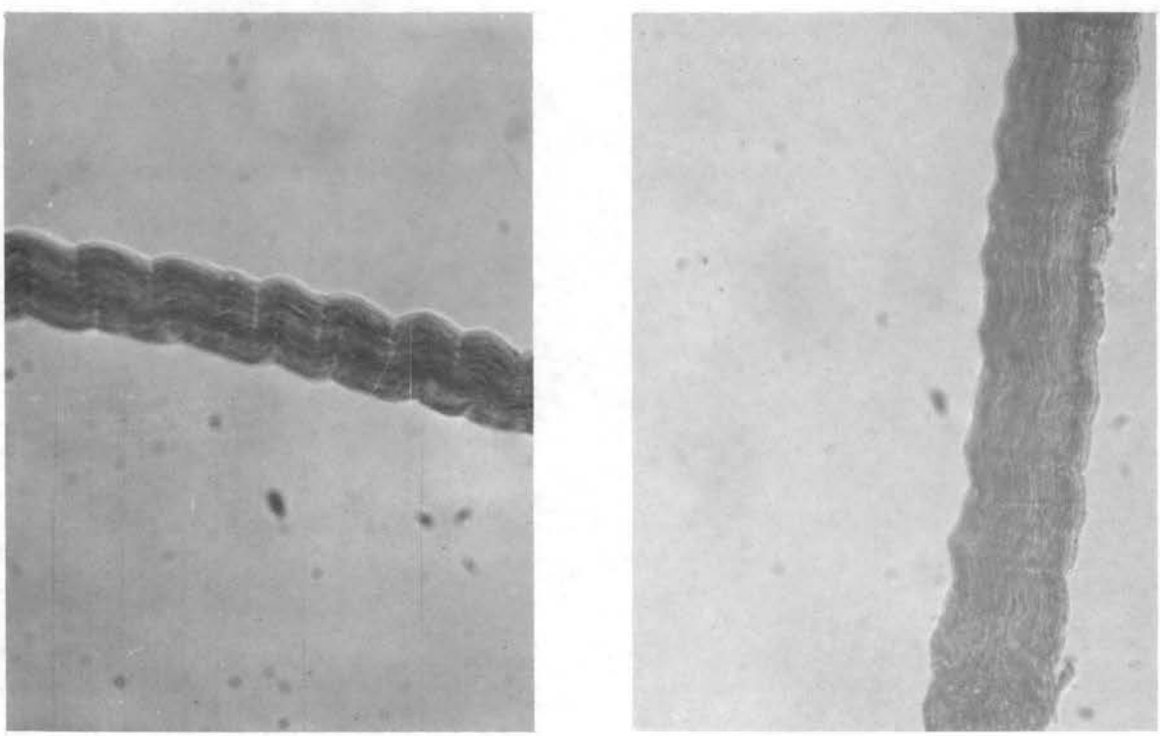
1. Straight fibers



2. Wavy fibers

Figure 5. Classification of Muscle Fibers According to the Degree of Rigor Mortis

3. Twisted fibers



4. Kinky fibers

Figure 5. (Concluded)

CHAPTER IV

RESULTS AND DISCUSSION

The longissimus dorsi, semitendinosus, and gluteus medius muscles varied in fiber diameter, degree of rigor, and shear force either among animals or by pre- and post-rigor excision of the muscles.

The data demonstrating these variations were resolved by the analysis of variance method. Mean values and standard deviation of the means were calculated for pre- and post-rigor excised muscle samples. The discussion and tables are separated into the effect of pre- and post-rigor muscle excision on: 1) the longissimus dorsi; 2) the semitendinosus; and 3) the gluteus medius.

Longissimus Dorsi

Muscle Fiber

The longissimus dorsi muscle fiber diameter means, standard deviations, and analysis of variance for pre- and post-rigor excised muscles are shown in Table I. A larger fiber diameter was noted in pre-rigor excised samples than those excised post-rigor from the longissimus dorsi. The standard deviations illustrate a wider variation in the fiber diameter of post-rigor excised muscles than in those

TABLE I

FIBER DIAMETER OF THE LONGISSIMUS DORSI AS INFLUENCED BY PRE-RIGOR EXCISION

Animal No.	PRE-RIGOR EXCISED Fiber Diameter μ	POST-RIGOR EXCISED Fiber Diameter μ
1.	69.13	68.13
2.	68.07	64.67
3.	67.47	64.33
4.	60.93	59.20
5.	67.87	73.67
Mean	66.69	65.99
St. Dev.	3.28	5.35

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	158.306		
Treatment	1	1.201	1.201	0.17
Animals	4	128.797	32.199	4.56*
Error	4	28.308	7.077	

* $P < 0.1$

excised pre-rigor. No uniformity was noticed in standard deviations between the two treatments. The results are in general agreement with the work of Herring *et al.* (1965b) who indicated that muscle fibers respond differently to the tension imposed on the muscle and undergo different degrees of rigor mortis. No significant effect on the fiber size was observed by pre-rigor excision of the muscle. However, the difference ($P < 0.1$) in fiber diameter was attributed to animal difference. These observations support the statements by Herring *et al.* (1965b) and Swanson *et al.* (1965).

Rigor Mortis

Pre-rigor excised longissimus dorsi muscle showed more rigor in fibers. The standard deviation in both treatments was high, thus considerable variation existed in both pre- and post-rigor excised samples (Table II). This also suggested that longissimus dorsi muscle fibers from different animals will undergo different degrees of rigor mortis. The reason for this difference is obscure at present and further work is suggested. A significant increase ($P < 0.1$) in per cent rigor was attributed to pre-rigor excision of the muscle. However, no significant effect ($P < 0.1$) resulting from animal variation was observed in this muscle.

Shear Force

Very little difference in shear force existed ($P < 0.05$) between pre- and post-rigor excised muscle. A slightly

TABLE II

PER CENT RIGOR IN THE LONGISSIMUS DORSI
AS INFLUENCED BY PRE-RIGOR EXCISION

	PRE-RIGOR EXCISED	POST-RIGOR EXCISED
Animal No.	Rigor %	Rigor %
1.	71.33	76.44
2.	87.33	66.22
3.	84.22	65.11
4.	85.11	67.78
5.	80.89	75.56
Mean	81.78	70.22
St. Dev.	6.28	5.49

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	606.920		
Treatment	1	333.841	333.841	5.360*
Animal	4	23.954	5.989	0.082
Error	4	249.125	62.281	

* $P < 0.1$

greater shear force in post-rigor muscle was attributed to animal variation (Table III). The standard deviation in both treatments was large, but more variation was apparent in post-rigor excised muscle. The analysis of variance indicated no association between the time of muscle excision and the shear force.

Conclusions

The results of this work indicated that the longissimus dorsi has a great tendency to vary in its fiber size and shear force, but has little variation in the degree of rigor due to animal difference. The variation in per cent rigor can be attributed to the imposed muscle treatments. The slight increase in per cent rigor in pre-rigor excised muscle is in general agreement with the work by Locker (1960) and Herring et al. (1965a). A significant difference ($P < 0.1$) in per cent rigor with no significant difference in fiber diameter and shear force due to pre-rigor excision of the muscle indicated that, below certain levels, rigor mortis in a muscle will cause little change in its tenderness or fiber size. Variation in fiber diameter and shear force due to animal differences suggest that fibers mature both physically and chemically at a different rate and depend to some extent on the composition of the muscle.

TABLE III

SHEAR FORCE OF THE LONGISSIMUS DORSI AS INFLUENCED BY PRE-RIGOR EXCISION

	PRE-RIGOR EXCISED	POST-RIGOR EXCISED
Animal No.	Shear Force *	Shear Force *
1.	22.42	29.03
2.	27.70	24.40
3.	25.49	22.25
4.	26.59	29.92
5.	36.01	37.08
Mean	28.04	28.53
St. Dev.	4.62	5.74

* Pounds of shear force for 1 inch core.

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	218.718		
Treatment	1	1.503	1.503	0.231
Animal	4	191.181	47.795	7.345 **
Error	4	26.034	6.509	

** $P < 0.05$

Semitendinosus

Muscle Fiber

Mean fiber diameter was found to be significantly affected (Table IV) by pre-rigor excision of the muscle. An increase in fiber diameter in pre-rigor excised muscle was associated with the pre-rigor excision of the muscle ($P < 0.05$). Variation due to animals was not significant ($P < 0.1$) in this muscle as was indicated in the longissimus dorsi and gluteus medius. Standard deviations for both treatments were fairly uniform but smaller in the pre-rigor excised muscle. This supports earlier work by Henrickson et al. (1963), Herring et al. (1965a), and Locker (1960), and agrees with the explanation previously given for the longissimus dorsi.

Rigor Mortis

Rigor mortis in the semitendinosus was greatly influenced ($P < 0.05$) by pre-rigor excision of the muscle (Table V) and was nearly doubled in the post-rigor excised muscle. However, animal variation was not a contributing factor ($P < 0.1$). Standard deviation was high in both cases with wide variation between pre- and post-rigor excised muscles. A comparatively smaller standard deviation in post-rigor excised muscles would indicate uniform stress on most of the muscle fibers when the carcass was vertically suspended. This was observed in this muscle due to the fact

TABLE IV

FIBER DIAMETER OF THE SEMITENDINOSUS AS INFLUENCED BY PRE-RIGOR EXCISION

	PRE-RIGOR EXCISED	POST-RIGOR EXCISED
Animal No.	Fiber Diameter μ	Fiber Diameter μ
1.	66.67	65.07
2.	67.87	56.93
3.	65.99	56.80
4.	65.93	61.13
5.	61.53	61.93
Mean	65.59	60.37
St. Dev.	2.65	3.53

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	140.969		
Treatment	1	88.257	88.257	13.25**
Animal	4	26.069	6.517	0.98
Error	4	26.643	6.661	

** $P < 0.05$

TABLE V

PER CENT RIGOR IN THE SEMITENDINOSUS AS INFLUENCED BY PRE-RIGOR EXCISION

	PRE-RIGOR EXCISED	POST-RIGOR EXCISED
Animal No.	Rigor %	Rigor %
1.	33.33	25.55
2.	61.33	33.99
3.	50.44	19.11
4.	40.88	25.99
5.	41.33	31.99
Mean	45.46	27.33
St. Dev.	10.75	5.89

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	1422.577		
Treatment	1	821.978	821.978	14.48**
Animal	4	373.544	93.386	1.65
Error	4	227.055	56.763	

** $P < 0.05$

that a majority of its fibers are oriented in the same direction. A uniform stress on the muscle fibers was not anticipated in the longissimus dorsi and gluteus medius as many of their fibers are oriented in different directions.

Shear Force

A significant increase in shear force ($P < 0.05$) was noticed in the pre-rigor excised muscle (Table VI) as compared with post-rigor excised muscle. These results are in general agreement with the work by Ramsbottom and Strandine (1949), Lowe and Stewart (1946), Locker (1960), Marsh (1963), de Fremery and Pool (1960), Goll *et al.* (1964), and Herring *et al.* (1965a). Animal variation was not a significant factor in accounting for the difference in shear value. Standard deviations were small in both treatments. The smaller standard deviation in the post-rigor excised samples indicates some uniformity in the physical and chemical maturity of the muscle. A uniform stress on the muscle fibers while the carcass was vertically suspended may also account for the smaller standard deviations.

Conclusions

In a muscle like semitendinosus, which is uniformly matured (physically and chemically), where most of the fibers are oriented in a parallel direction, pre-rigor excision of the muscle effects fiber size, degree of rigor, and shear force of the fibers. Semitendinosus muscle fibers would be

TABLE VI

SHEAR FORCE OF THE SEMITENDINOSUS AS INFLUENCED BY PRE-RIGOR EXCISION

	PRE-RIGOR EXCISED	POST-RIGOR EXCISED
Animal No.	Shear Force *	Shear Force *
1.	28.48	27.89
2.	37.21	28.94
3.	32.93	27.90
4.	30.36	26.83
5.	31.96	31.93
Mean	32.18	28.69
St. Dev.	3.28	1.95

* Pounds of shear force for 1 inch core.

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	88.726		
Treatment	1	32.380	32.380	8.72 **
Animal	4	41.486	10.375	2.79
Error	4	14.860	3.715	

** $P < 0.05$

under uniform tension when the carcass was vertically suspended due to the uniformity in its fiber orientation. If this muscle is excised before the onset of the rigor mortis its fibers undergo a greater degree of contraction with the increase in its fiber size and a decrease in its tenderness.

A significantly lower degree of rigor in fibers was observed in the semitendinosus when compared to longissimus dorsi and gluteus medius muscles (Table III and VII). This also provides evidence that different muscles in the same animal have different potentials to undergo different degrees of rigor mortis.

Gluteus Medius

Muscle Fiber

The small difference in the mean fiber diameter of the gluteus medius (Table VII) was due to animal variation ($P < 0.1$). However, pre-rigor excision did not cause a significant change ($P < 0.1$) in fiber size. These results are compatible with those of Herring et al. (1965a) who noted a non-significant difference ($P < 0.05$) for fiber diameter in this muscle between vertically suspended and horizontally placed sides. Standard deviations were fairly uniform with smaller variation in post-rigor excised muscle samples.

TABLE VII

FIBER DIAMETER OF THE GLUTEUS MEDIUS AS
INFLUENCED BY PRE-RIGOR EXCISION

	PRE-RIGOR EXCISED	POST-RIGOR EXCISED
Animal No.	Fiber Diameter μ	Fiber Diameter μ
1.	67.07	64.67
2.	65.27	64.07
3.	60.80	61.93
4.	63.40	64.00
5.	69.40	69.13
Mean	65.19	64.76
St. Dev.	3.31	2.65

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	72.304		
Treatment	1	0.656	0.656	0.73
Animal	4	68.107	17.027	18.86 **
Error	4	3.601	0.903	

** $P < 0.05$

Rigor Mortis

No significant difference ($P < 0.1$) between pre- and post-rigor excised muscles was noticed, indicating little effect due to either treatment or animal variations for the degree of rigor in this muscle. However, a slight increase in per cent rigor in post-rigor excised samples was observed (Table VIII). The increase in per cent rigor in the gluteus medius when post-rigor excised is contrary to the results observed in both the longissimus dorsi and semitendinosus muscles. One explanation for the unrelated condition of the gluteus medius muscles to longissimus dorsi and semitendinosus may be due to the effect of carcass suspension. Vertical carcass suspension tends to release the tension on certain muscles, permitting them to shorten and produce a more favorable condition for rigor mortis. A similar condition was noted by Marsh (1954) and Sink et al. (1965). Herring et al. (1965) also recorded the shortening of gluteus medius when the carcass was vertically suspended.

In both excised treatments, high standard deviations with wide variations between them were noticed.

Shear Force

Analysis of variance for shear force (Table IX) indicated that animal difference was a significant source of variation ($P < 0.1$). However, no treatment effect for tenderness was noticed ($P < 0.1$). Standard deviations for treatments were more uniform and low.

TABLE VIII

PER CENT RIGOR IN THE GLUTEUS MEDIUS AS INFLUENCED BY PRE-RIGOR EXCISION

Animal No.	PRE-RIGOR EXCISED Rigor %	POST-RIGOR EXCISED Rigor %
1.	46.67	73.11
2.	74.67	75.11
3.	81.78	77.11
4.	76.22	84.22
5.	79.33	68.84
Mean	71.42	75.91
St. Dev.	14.28	5.79

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	987.347		
Treatment	1	50.378	50.378	0.45
Animal	4	491.176	122.794	1.10
Error	4	445.793	111.448	

TABLE IX

SHEAR FORCE OF THE GLUTEUS MEDIUS AS INFLUENCED BY PRE-RIGOR EXCISION

	PRE-RIGOR EXCISION	POST-RIGOR EXCISION
Animal No.	Shear Force *	Shear Force *
1.	20.93	22.36
2.	23.27	26.33
3.	23.49	20.25
4.	23.88	24.56
5.	27.78	27.64
Mean	23.87	24.23
St. Dev.	2.47	2.98

* Pounds of shear force for 1 inch core.

Analysis of Variance

Source	df	SS	MS	F-Test
Total	9	60.272		
Treatment	1	0.331	0.331	0.12
Animal	4	49.058	12.265	4.51*
Error	4	10.883	2.721	

* $P < 0.1$

Conclusions

With the above results it can be stated that pre-rigor excision of the gluteus medius has no significant effect on its fiber diameter, per cent rigor, or shear force. Variation due to animal differences supports the view that muscles differ in their rate of reaching chemical and physical maturity. High standard deviations in pre- and post-rigor excised samples indicate that different fibers in the same muscle respond differently to the same kind of treatment. This leads one to postulate that there are differences in the chemical composition and physical makeup of different fibers in the same muscle causing high variations in rigor mortis.

CHAPTER V

SUMMARY

Three bovine muscles, longissimus dorsi, semitendinosus, and gluteus medius, from five Hereford steers of similar breeding, age, feeding and management were studied to determine the effects of pre-rigor excision of the muscles on their fiber diameters, degrees of rigor, and shear forces.

In the longissimus dorsi, variation in fiber diameter ($P < 0.1$) and shear force ($P < 0.05$) was accounted for by carcass differences. Degree of rigor was the only variable significantly affected ($P < 0.1$) by pre-rigor excision of the muscle. The amount of variation observed in rigor mortis due to pre-rigor excision of the muscle had no significant effect on the shear force and fiber diameter. Pre-rigor excision exerted a significant influence ($P < 0.05$) in the semitendinosus muscle, resulting in an increase in the fiber diameter, rigor mortis, and shear force. Non-significant variation among animals suggests uniformity in muscle maturity. Uniformity in fiber orientation in the semitendinosus muscle exerted a great and uniform stress on the fibers in a vertically suspended carcass causing a decrease in fiber diameter, degree of rigor, and shear force. Pre-rigor excision showed no effect on fiber diameter, degree of

rigor, and shear force in gluteus medius muscle. The significant variation in fiber size ($P < 0.05$) and shear force ($P < 0.1$) in pre- and post-rigor excised muscles was due to animal difference. A non-significant increase in the degree of rigor in post-rigor excised muscle can be attributed to the vertical carcass suspension, releasing the tension on the muscle. The slight increase in the degree of rigor in post-rigor excised gluteus medius muscle indicated no significant influence on the fiber diameter and shear force.

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APPENDIX

TABLE X

INFLUENCE OF PRE- AND POST-RIGOR EXCISION ON THREE BOVINE MUSCLES*

Muscle	Fiber Diameter μ	Rigor %	Shear Force**
Longissimus dorsi Pre-rigor excised	66.69	81.78	28.0
Longissimus dorsi Post-rigor excised	65.99	70.22	28.5
Semitendinosus Pre-rigor excised	65.59	45.46	32.2
Semitendinosus Post-rigor excised	60.37	27.33	28.7
Gluteus medius Pre-rigor excised	65.19	71.42	23.9
Gluteus medius Post-rigor excised	64.76	75.91	24.2

* Mean values observed for five animals.

** Pounds of shear force for 1 inch core.

TABLE XI

INFLUENCE OF PRE- AND POST-RIGOR EXCISION ON THE MUSCLES FROM FIVE ANIMALS*

Animal No.	State of Excision	Fiber Diameter μ	Rigor %	Shear Force**
1.	Pre-rigor	67.62	50.44	24.6
	Post rigor	65.96	58.89	26.4
2.	Pre-rigor	67.07	73.93	29.4
	Post-rigor	61.89	58.44	26.6
3.	Pre-rigor	64.75	72.15	27.3
	Post-rigor	61.02	53.78	23.5
4.	Pre-rigor	63.42	67.40	26.9
	Post-rigor	61.44	59.33	27.1
5.	Pre-rigor	66.27	67.18	31.9
	Post-rigor	68.24	58.67	32.2

* Mean values observed for longissimus dorsi, simi-tendinosus, and gluteus medius muscles.

** Pounds of shear force for 1 inch core.

TABLE XII

EFFECT OF PRE- AND POST-RIGOR EXCISION ON THE LONGISSIMUS DORSI

PRE-RIGOR EXCISED					POST-RIGOR EXCISED				
Position of the steak	Animal No.	Fiber Diameter μ	Rigor %	Shear force *	Position of the steak	Animal No.	Fiber Diameter μ	Rigor %	Shear force *
Anterior	1	64.13	77.33	24.71	Anterior	1	68.93	82.22	28.02
"	2	70.00	90.67	29.11	"	2	63.87	61.78	25.46
"	3	67.20	85.78	26.12	"	3	66.27	77.78	25.23
"	4	64.13	88.89	25.91	"	4	58.40	59.11	33.51
"	5	65.33	79.99	38.10	"	5	75.87	75.56	40.06
Mean		66.16	84.53	28.79	Mean		66.67	71.29	30.46
St. Dev.		2.49	5.72	-13.5	St. Dev.		6.45	10.23	6.32
Posterior	1	74.13	65.33	24.12	Posterior	1	67.33	70.67	30.48
"	2	66.13	83.99	26.29	"	2	65.47	70.67	23.34
"	3	67.73	82.67	24.84	"	3	62.40	52.44	19.27
"	4	57.73	81.33	27.21	"	4	60.00	76.44	26.33
"	5	70.40	81.78	33.91	"	5	71.47	75.56	34.09
Mean		67.23	79.22	27.28	Mean		65.33	69.15	26.70
St. Dev.		6.11	7.72	3.89	St. Dev.		4.44	5.19	5.82

* Pounds of shear force for 1 inch core.

TABLE XIII

EFFECT OF PRE- AND POST-RIGOR EXCISION ON THE SEMITENDINOSUS

PRE-RIGOR EXCISED					POST-RIGOR EXCISED				
Position of the steak	Animal No.	Fiber Diameter μ	Rigor %	Shear * Force	Position of the steak	Animal No.	Fiber Diameter μ	Rigor %	Shear * Force
Anterior	1	66.27	35.99	27.63	Anterior	1	68.67	21.78	29.68
"	2	70.80	64.00	40.57	"	2	58.80	31.11	30.64
"	3	67.06	35.11	32.90	"	3	56.93	19.99	27.84
"	4	64.80	32.44	30.42	"	4	63.33	23.56	28.59
"	5	62.53	46.67	33.36	"	5	62.40	29.33	34.54
Mean		66.29	41.78	32.98	Mean		62.02	25.16	30.26
St. Dev.		3.05	13.90	4.82	St. Dev.		4.53	4.83	2.62
Posterior	1	67.07	35.99	29.28	Posterior	1	61.47	29.33	26.09
"	2	64.93	58.67	33.85	"	2	55.07	36.89	27.24
"	3	64.80	65.11	32.96	"	3	56.67	18.22	27.96
"	4	67.07	49.33	30.29	"	4	58.93	28.44	25.07
"	5	60.53	35.99	30.56	"	5	61.47	34.67	29.33
Mean		64.88	49.02	31.39	Mean		58.72	29.51	27.14
St. Dev.		2.66	13.15	1.93	St. Dev.		2.86	7.24	1.65

* Pounds of shear force for 1 inch core.

TABLE XIV

EFFECT OF PRE- AND POST-RIGOR EXCISION ON THE GLUTEUS MEDIUS

PRE-RIGOR EXCISED					POST-RIGOR EXCISED				
Position of the steak	Animal No.	Fiber Diameter μ	Rigor %	Shear Force *	Position of the steak	Animal No.	Fiber Diameter μ	Rigor %	Shear Force *
Anterior	1	67.87	49.33	20.81	Anterior	1	65.07	83.55	23.24
"	2	61.87	62.22	24.03	"	2	66.80	83.99	25.97
"	3	59.87	80.89	26.86	"	3	62.53	80.89	22.30
"	4	61.60	63.99	24.42	"	4	62.40	86.67	27.36
"	5	70.67	81.33	30.85	"	5	66.40	65.33	30.57
Mean		64.37	67.55	25.39	Mean		64.64	80.09	25.89
St. Dev.		4.64	13.61	7.47	St. Dev.		4.17	8.50	3.31
Posterior	1	66.27	43.99	21.05	Posterior	1	64.27	65.78	21.47
"	2	68.67	84.44	22.51	"	2	61.33	66.22	26.69
"	3	61.73	82.66	20.12	"	3	61.33	73.33	18.19
"	4	65.20	88.44	23.34	"	4	65.60	81.78	21.82
"	5	68.13	77.33	24.70	"	5	71.87	71.55	24.70
Mean		65.99	75.38	22.34	Mean		64.88	71.73	22.57
St. Dev.		2.77	-37.16	3.63	St. Dev.		4.33	6.54	3.26

* Pounds of shear force for 1 inch core.

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