THE SHEAR FORCE OF THE INDIVIDUAL MUSCLE FIBER AND ITS USEFULNESS IN PREDICTING MEAT TENDERNESS

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CHAPTER I

INTRODUCTION

Tenderness is certainly a factor of prime importance in determining the eating quality of meat. However, it has proved to be difficult to obtain an objective measure of tenderness which corresponds with the subjective evaluation by a panel of judges. Mastication involves a number of physical processes, including shearing, tearing, pulling, cutting, grinding, and pressing. Since it would be virtually impossible to design an instrument which could evaluate all of the processes involved in chewing with any precision, the trend has been to design instruments which measure one physical process. For example, the Warner-Bratzler Shear Instrument (Black *et al.*, 1931, and Bratzler, 1932) was designed to measure shear force, while the Motorized Food Grinder (Miyada and Tappel, 1956) was designed to evaluate the relationship between the grinding process and meat tenderness.

Recently, there has been some work on the physical properties of muscle fasciculi and their relationship to the tenderness of the cooked product (Stanley *et al.*, 1971, 1972). This work has, however, dealt primarily with the tensile properties of muscle fiber bundles, leaving a need for the examination of other physical properties. Henrickson *et al.* (1974) reported an evaluation of a microsensitive shear instrument designed to measure shear properties of individual muscle fibers. This study was limited to formalin fixed fibers and made no attempt to relate the shear properties of the muscle fiber to meat tenderness, but did establish the feasability of measuring shear force for individual muscle fibers.

The purpose of this study was to evaluate the ability of the microsensitive shear instrument described by Henrickson _et al_. (1967) to distinguish between delayed chilled and conventionally processed bovine tensor fascia latae muscles in terms of fiber shear force and shear stress, and to relate these shear properties to meat tenderness.

CHAPTER II

REVIEW OF LITERATURE

Certain Physical and Chemical Properties of Muscle and Their Relation to Meat Tenderness

The purpose of this review is to report on the area of muscle tensile and shear properties. However, since most of the work in this area has involved various post-mortem treatment of muscles designed to alter the effects of rigor mortis, it was deemed necessary to briefly review rigor mortis and the physical phenomenon associated with it, and the effect of certain post-mortem treatments, particularly hot and cold muscle excision, on the physical manifestations of rigor mortis.

Rigor Mortis and Muscle Extensibility

Rigor mortis, the irreversible contraction of muscle due to the depletion of ATP, has long been associated in meat with a loss of extensibility, a lowered pH, and a loss in water-holding capacity. The loss of extensibility, or stiffening of the muscle, has been attributed to the formation of a complex between actin and myosin, actomyosin (Bendall, 1960). The extensibility changes have been used as a reference in defining the "phases" of rigor mortis (Bate-Smith and Bendall, 1949; Briskey, *et al.*, 1962; and Sink, 1965): (1) delay phase; virtually no change in extensibility, (2) onset phase; continuous reduction in extensibility, and (3) completion phase, complete loss of extensibility.

Bendall (1960) further classified three general patterns describing the onset of rigor mortis: (1) acid rigor; characterized in immobilized animals for a long delay period and a short fast phase, and in struggling animals by a drastic curtailment of the delay period (at body temperature, stiffening is accompanied by a shortening of the muscle), (2) alkaline rigor; characterized by a rapid onset of stiffening and by a marked shortening even at relatively low temperatures, and (3) intermediate type; characterized in starved animals by a curtailment of the delay period, but not of the rapid phase; there is some shortening.

There have been several mechanical and electrical devices developed to measure the time course of these changes in the extensibility of muscle (Bate-Smith and Bendall, 1949; DeFremery and Pool, 1960; and Briskey, _et al._, 1962), using excised strips which are loaded and unloaded at specific intervals. These "rigorometers" provide a record of post-mortem extensibility changes on a printed readout.

There are chemical changes within the muscle that are directly related to the physical phenomenon of rigor mortis. Erdös (1943) showed that the onset of stiffening appeared to be correlated with the disappearance of ATP from the muscle. Bate-Smith and Bendall (1947, 1949) and Bendall (1951, 1960) investigated the problem further and associated the time course of rigor mortis with the initial levels of ATP, glycogen and creatine phosphate. These findings are related to the post-mortem metabolism of the muscle tissue. As the oxygen supply in the muscle is decreased after exsanguination of the animal, the metabolism shifts from the highly efficient, aerobic tricarboxylic acid cycle to the inefficient, anaerobic glycolytic pathway, resulting in a decreased synthesis of ATP. This glycolytic process can continue only as long as the glycogen supply in the muscle holds out. When the glycogen runs out, there is no other major source of glucose, the raw material for the glycolytic pathway. Marsh (1954) reported that all glycolytic processes in beef muscle are completed within thirty-six hours post-mortem. DeFremery and Pool (1960) observed that the fast phase of extensibility loss in chicken muscle did not begin until the level of ATP was down to 30 percent of its initial concentration. A necessary level of ATP can, however, be maintained briefly by the synthesis of ATP from creatine phosphate. Briskey (1959) showed that creatine phosphate in muscle is broken down enzymatically soon after death. Briskey (1959) also found accumulations of lactic acid, the end-product of anaerobic glycolysis in muscle shortly after death, accounting for the drop in muscle pH as rigor mortis develops. This drop in pH also contributes to the decrease in the water-holding capacity of post-mortem muscle.

Considerable variation between animals within and between species has been reported for the time period required for complete shortening and loss of extensibility in muscle due to rigor mortis. Smith _et al._ (1969) reported that shortening due to rigor mortis was completed within three hours in chicken muscle and within five hours in turkey muscle. T-I Ma _et al._ (1971) observed a complete loss of extensibility in the pectoralis muscle of turkey within a time range of twenty-five minutes and six and one-half hours post-mortem, indicating a widespread variation between animals of the same species. Sayre and Briskey (1963) reported that shortening due to rigor mortis is complete within five hours post-mortem in porcine muscle, while Marsh (1952) observed that whale muscle maintained in vivo levels of ATP and muscle pH for as long as twenty-four hours post-mortem, indicating variation between species in the time course for the development of rigor mortis.

The environmental temperature is also of importance in determining the time course of rigor mortis as it is manifested in a loss of extensibility and in the shortening of the muscle. Lawrie (1966) stated that muscle shortening is minimal in the temperature range of 14 - 19°C. Locker and Hagyard (1963) reported that below this 14°C level, a cold shortening effect was observed, and Marsh (1962) observed a great increase in shortening, accompanied with a marked decrease in tenderness with post-mortem temperatures over 43°C.

Hot and Cold Muscle Excision

The decline in tenderness associated with rigor mortis has been closely associated with the degree of post-mortem muscular contraction (Locker, 1960). This post-mortem shortening of muscle can be decreased if the muscles are placed under tension during the development of rigor mortis (Herring, et al., 1965a). Locker (1960) and Herring, et al. (1965b) pointed out that vertical suspension on the carcass releases tension on some muscles, or places these muscles in a shortened state, and increases tension on others, placing these muscles in a stretched state, affecting the ultimate tenderness of the various muscles. Herring (1967a), in a study of the effect of shortening and stretching on bovine semitendinosus muscle, concluded that it is more important, in terms of tenderness, to prevent post-mortem shortening than to promote maximum stretch.

In a study of the effect of vertical suspension and pre-rigor muscle excision on three bovine muscles, Reddy (1962) observed more fiber distortion (degree of kinkiness) in longissimus dorsi excised pre-rigor than in the same muscle excised after a period of carcass restraint. However, the author reported an opposite effect on the gluteus medius muscle, supporting the results of Locker (1960) and Herring (1965b), that the vertical suspension of the bovine carcass results in some muscles being stretched while others are shortened.

Lowe and Stewart (1946), working with chicken breast muscle, reported that muscle excised immediately after death, before the onset of rigor was generally less tender than conventionally processed muscle. These authors also reported that the sooner the muscle was excised post-mortem, the less tender the product, and that when the muscle was excised after the onset of rigor mortis, no significant decrease in tenderness was observed. T-I, Ma <u>et al</u>. (1971) confirmed these findings by monitoring the ATP concentration of the muscle in relation to the effect of muscle excision on tenderness. The authors observed that the less ATP present in muscle, the smaller the effect of muscle excision on tenderness.

Ramsbottom and Strandine (1949) reported that bovine muscle excised before the onset of rigor was less tender than muscle chilled on the carcass, and that muscle was more tender two hours post-mortem than after six hours of aging. However, the authors also reported that the muscle excised two hours post-mortem was less tender than beef which had been aged for twelve days. Goll, <u>et al</u>. (1964) reported that muscles restrained on the carcass were least tender immediately post-mortem, but that tenderness gradually increased with aging.

Gillis and Henrickson (1968), in a study of induced tension on pre-rigor excised muscle, observed a decrease in fiber diameter up to 1000 grams tension. In addition, the authors reported that the fiber distortion (percent kinkiness) decreased as the tension on the muscle increased. These authors also associated an increase in fiber distortion to an increase in Warner-Bratzler shear force. Working with bovine longissimus dorsi, Reddy (1962) reported that fiber diameter and Warner-Bratzler shear force were not significantly affected by pre-rigor excision. However, the author did report a significant increase in fiber diameter and shear force for bovine semitendinosus, excised pre-rigor.

Buck, et al. (1970) working with longissimus dorsi from six month old Dutch Belted rabbits, measured sarcomere length, shear force (Allo-Kramer shear press) and protein solubility for muscles allowed to pass through rigor unrestrained and muscles which were maintained in the stretched state during the development of rigor. These authors reported that the stretched muscles were significantly more tender, as evidenced by lower shear values. They also observed longer sarcomeres for the muscles excised after a period of restraint, than for the muscles excised prior to the onset of rigor.

Greater amounts of total protein were extracted from stretched muscles in all but one trial, and unexpectedly, the authors reported significantly greater amounts of actomyosin for the stretched muscles. It has been suggested by several workers (Herring, et al., 1965a; Buck, et al., 1967; and Cook, et al., 1967) that actomyosin formation is directly related to toughness in meat. The authors offered as one possible explanation for the increased level of actomyosin in the stretched muscle, the hypothesis that stretching may stimulate muscle so that it uses ATP more rapidly and more completely, forming actomyosin which does not dissociate upon extraction. Free muscle, however, may contain greater amounts of residual ATP which would tend to dissociate the actomyosin during extraction.

In a study of three post-mortem holding periods (two, five, and eight hours) before "hot" muscle excision, Kastner, et al. (1973) reported that shear force was significantly greater for the muscles excised hot in the two and five hour holding periods. In the eight hour holding period, however, the difference was not significant, indicating that eight hours of restraint on the carcass was adequate in preventing excess muscle shortening. The authors also reported that in the eight hour holding period, the percent weight loss was significantly less for the muscles excised hot than for the muscles excised after a 48 hour chill. A significant difference in color was also observed between the hot and cold excised muscles, with the muscles excised hot exhibiting a darker color in the two hour holding period, and the muscles excised cold a darker color in the five and seven hour holding periods.

Buege and Stouffer (1974), working with 31 lamb carcasses and 7 beef carcasses, in four separate experiments studied in the effects of three pre-rigor tension levels on the tenderness of the longissimus dorsi muscle. In addition, these authors investigated the influence of severing the fascia tendons, and the body and spinous processes of each vertebra beginning with the ninth thoracic and continuing consecutively posterior to the last lumbar vertebra on longissimus dorsi tenderness. The authors reported no advantage in the severing of the fascia tendons or the vertebrac, but did observe a significant decrease in the Warner-Bratzler shear force in all four experiments, with each level of tension and percent stretch of the muscle. No significant differences, however, were reported among the three tension levels, supporting the work of Herring, et al. (1967a) and Gillis and Henrickson (1968) demonstrating that a level exists in stretching beyond which there is little or no advantage in decreasing shear force values.

Falk (1974) investigated the effect of hot boning the bovine carcass on several quality attributes of meat. He assigned thirty choice Angus steers to one of three post-mortem holding periods (three, five, and seven hours). Muscles from either the right or left side were excised hot after being held at 16°C for the designated holding period, while the muscles from the opposite sides were excised after a forty-eight hour chill at 1.1°C. The author measured pH, Warner-Bratzler shear force, organoleptic tenderness, color, press fluid ratios, percent cooking loss and percent fat for several representative muscles from the streamlined hind-quarter. In addition, he monitored the microbial populations in ground beef from the two post-mortem treatments. Muscle fiber diameter kinkiness and sarcomere length were also measured for three individual muscles.

The author reported small differences in shear force values between the hot and cold excised muscles, averaging less than two pounds. Shear force values were, however, significantly higher ($P < 0.05$) for the muscles excised hot in the five hour holding period for the longissimus dorsi, and at the seven hour holding period for the semimembranosus. There was no significant difference observed in sarcomere length at any of the three holding periods, indicating that the three hour post-mortem holding period was effective in reducing muscle shortening from rigor mortis. The author, however, reported significant differences between the hot and cold excised muscles in fiber diameter and kinkiness in the longissimus dorsi in all three post-mortem holding periods. There was no difference reported in organoleptic tenderness evaluation except at the seven hour holding period where the panelist preferred the muscles excised hot to those excised cold ($P < 0.05$). Although some significant differences were reported in subjective color evaluation, panelists found the color of the hot excised muscles as acceptable, or more acceptable than the muscles excised cold. The author reported no difference in the psychrophilic bacterial count at any holding period, but did state that the number of mesophilic bacteria was significantly more for the muscles excised hot ($P < 0.05$). A difference in cooler shrinkage was observed between the two treatments at all three holding periods. The author reported that the sides processed hot had a lower cooler shrinkage than the sides processed cold, and that difference was significant at the five and seven hour holding periods ($P < 0.001$). The author observed no difference in pressed fluid ratio, percent cooking loss, percent moisture, and percent fat ($P > 0.05$). The author concluded that the hot processing of the bovine carcass may be commercially feasible in the production of an acceptable product without a large discernable loss in the major quality attributes of beef.

Muscle Elasticity and Extensibility

Bate-Smith (1939) observed that muscle is truly elastic up to about 3 percent extension of muscle length, but beyond this point, the stress-strain curve is non-linear. Guth (1947) reported that elasticity in muscle is significantly different from rubberlike elasticity. He observed different stress-strain curves for resting muscle and rubber, and reported that muscle corresponds to rubber that has been stretched out so much that the chain molecules are markedly oriented rather than randomly assorted.

Hoeve and Willis (1963), working with glycerinated muscle fibers reported that elasticity at the molecular level is related to phase changes of the fibrous proteins from an oriented crystalline state to a random coil, amphorous state.

Hoyle (1968) proposed a mechanism for muscle elasticity, postulating a new sarcomere component, the T-filament. Since elasticity is present in muscle at lengths which do not stretch the sarcolemma, and elasticity is present in fibers in which the sarcolemma has been dissected, Hoyle hypothesized that individual sarcomeres must be the major source of elasticity. Both actin and myosin filaments are inelastic and therefore the T-filament, a thin filament which has been observed in the gap region between actin and myosin of heavily stretched fibers, was postulated to be the elastic element of muscle. These T-filaments run from z line to z line and may also, according to Hoyle be involved in muscle contraction.

Wang, <u>et al</u>. (1956), working with bovine longissimus dorsi and semitendinosus from animals representing selective carcass weights and grades reported correlations of -.85 and -.86 between muscle fiber extensibility and meat tenderness in the longissimus dorsi and semitendinosus, respectively. Wang measured extensibility by placing an individual muscle fiber under a dissecting microscope at 2.5 x, pulling the fiber apart from both ends with forceps, and measuring break elongation.

Hosteller and Cover (1961), working with 24 steers noted a positive relationship between fiber extensibility and increased shear force for longissimus dorsi and biceps femoris cooked to 100°C. At 61°C, the relationship was apparent only in the longissimus dorsi. In addition, the increase in extensibility was inversely related to softness to tooth pressure and loss of fragmentation. The authors also observed a greater mealiness of muscle fiber at 100°C than at 61°C.

Cover et al. (1962), working with bovine longissimus dorsi and biceps femoris reported positive correlations ($P < 0.01$) between fiber extensibility (break elongation) of single muscle fibers and Warner-Bratzler shear values. She observed a correlation of +.83 with longissimus dorsi cooked to 61°C and +.78 with longissimus dorsi cooked to 100°C. The correlations with biceps femoris were comparable, but non-significant due to a smaller sample size. Cover also noted an increase in fiber extensibility with an increase in ultimate cooking temperature.

Muscle Tensile and Shear Properties and Their Relation to Meat Tenderness

The relationship between various physical properties of meat and tenderness has been under investigation for some time. Presently, most objective measures of tenderness involve the measurement of some physical property (i.e., shear force) for gross samples of meat (Schultz, 1957; Pearson, 1963; Szezesniak and Torgeson, 1965; and Sharrah, et al., 1965), and relating these properties back to organoleptic evaluation of meat tenderness. Although a relationship between the physical properties associated with the muscle fiber and factors affecting meat tenderness was reported by Bate-Smith (1939), and Wang, et al. (1956), there has until recently been little interest in the development of methods for measuring meat tenderness, utilizing the individual muscle fiber or muscle fiber bundles. The purpose of this section of the review will be to follow the development of recent methods for measuring certain physical properties of the muscle fiber and subsequent relationships which have been established between these physical properties and meat tenderness.

The method for measuring muscle fiber extensibility or break elongation used by Wang, <u>et al.</u> (1956), Hostetler and Cover (1961), and Cover, <u>et al.</u> (1962) was replaced with the development and application of the Instron Universal Testing Machine (Burr, 1949; Hindman and Burr, 1949; and White, 1970). The Instron Universal Testing Machine is a research tool used to study the rheological properties of food materials by measuring tensile strength and related physical properties.

Stanley, <u>et al.</u> (1971) measured work of rupture, breaking strength, break elongation (extensibility), and elasticity or stress relaxation on commercially obtained beef shank and tenderloin muscle utilizing the Instron Universal Testing Machine. In addition, Stanley, <u>et al.</u>, measured these same physical properties on restrained rabbit psoas major and longissimus dorsi, in order to determine the effect of post-mortem restraint on the carcass on the texture properties of the meat. The author made these measurements on uncooked samples of individual muscle fiber bundles, 5.0 cm. in length, and 0.2 - 0.5 cm^2 in cross sectional area.

With the beef shank and tenderloin muscles, Stanley reported higher tensile properties for shank than for tenderloin, and also observed less elasticity for the beef shank muscle. The author also showed in this study, that post-mortem aging decreased tensile measurements and elasticity.

Utilizing rabbit psoas major and longissimus dorsi, Stanley reported a breaking force of 0.237 ± 7.5 percent for unrestrained muscle and

0.168 ± 9.9 percent for restrained muscle. The restrained muscle also showed a higher elasticity and break elongation. Stanley explained these results in terms of the effect of rigor on the post-mortem muscle. Contraction theoretically causes a greater degree of overlap between the thick and thin muscle filaments and leads to a higher concentration of actomyosin in the unrestrained sample (Herring, _et al._, 1967a, 1967b).

In a subsequent study, Stanley, _et al._ (1972) compared muscle tensile properties with organoleptic and objective evaluations of meat tenderness. Utilizing raw porcine psoas major muscle fiber bundles, Stanley measured shearing and breaking strength, sarcomere length, elasticity, stress relaxation and break elongation, and compared these measurements with tenderness (taste panel evaluation), chew count, Lee-Kramer Shear Press, and Warner-Bratzler Shear determinations. Again he excised muscles from one side unrestrained and from the opposite side after at twenty-four hour period of restraint on the carcass at 0 - 5^{o}C.

Stanley observed no significant correlations between the various tensile properties, but when these were associated with objective and subjective measures of meat tenderness, some highly significant correlations were observed.

A correlation of +0.81 ($P < 0.01$) was reported between Instron breaking strength and tenderness as measured by a trained panel with unrestrained sample, and the correlation between chew count and Instron breaking strength was also significant ($P < 0.05$) at +0.67. With the samples excised after the twenty-four hour period of restraint on the carcass, however, the correlations were non-significant.

Breaking strength following cycling (measured after one minute of cycling between 0 and 14 percent extension) was significantly related

($P < 0.01$) to tenderness in both the restrained and unrestrained samples ($r = +0.84$ and $+0.90$, respectively). In addition, a significant relationship ($P < 0.01$) was also observed between Instron breaking strength following cycling and chew count for the restrained and unrestrained samples ($r = +0.82$ and $+0.79$, respectively).

Instron breaking strength following extension (measured after the sample was held for one minute at 14 percent extension) was also significantly related to tenderness in the restrained and unrestrained samples. A correlation coefficient of +0.76 ($P < 0.05$) was reported for the restrained muscles and +0.95 ($P < 0.01$) was observed for the unrestrained muscles. Instron breaking strength following extension was also significantly associated ($P < 0.05$) with chew count in the restrained muscles ($r = 0.73$). In the unrestrained muscles, a correlation coefficient of +0.85 ($P < 0.01$) was reported between Instron breaking strength following extension, and chew count.

Break elongation was significantly related to tenderness in the restrained muscles ($P < 0.05$) with a correlation coefficient of +0.64, but the relationship was nonsignificant in the unrestrained muscles. Chew count and break elongation were not, however, significantly related ($P > 0.05$) either for the restrained or unrestrained muscles using parametric correlation coefficients. Neither elasticity nor stress relaxation was significantly related to tenderness or chew count.

Stanley concluded that Instron breaking strength is the best measure of meat tenderness and that longitudinal stress is more highly related to taste panel evaluation of tenderness than tangential force required to shear muscle fibers. In addition, the author cited two major structural contributions of raw muscle to cooked meat tenderness (1) a connective tissue factor, and (2) a contraction factor. He concluded that different objective measures are best suited for their evaluation.

In a study of the effect of aging on muscle textural properties, Eino and Stanley (1973a) monitored break elongation, breaking strength, elasticity, and stress relaxation for bovine psoas major aged at 0 - 5°C for 1 - 14 days. The authors reported that break elongation reaches a minimum at 2 days, but subsequently increases to about 65% of its original value. This increase in break elongation was apparent at day 4 and beyond, and the authors postulated that it may indicate a weakness of the actin-myosin interactions, allowing slippage of these elements past one another. Breaking strength was observed to drop rapidly during the first 4 days of aging and then stabilized. The authors stated that the parallel diminuation in pH, ATP concentration and sarcomere length accompanying rigor mortis, produces muscle tissue which is rigid and inflexible. These changes according to Eino and Stanley make the fiber more susceptible to longitudinal stress since they would tend to break with very little extension. The authors offered susceptibility to longitudinal stress as an explanation for the rapid decrease in breaking strength, since extension is seen to decline concomitantly.

Eino and Stanley rated minimum or maximum values for all tensile properties between days 2 and 4. Elasticity, like break elongation, reached a minimum at 2 days, but also increased to a significant percentage of its original value.

The authors concluded with a proposition that since these physical properties appear to reflect the rigidity or stiffening of the muscle, they should prove useful in following the time course of rigor mortis.

In a separate study, Eino and Stanley (1973b) investigated the effect of soaking muscle fiber bundles in a catheptic enzyme preparation and in a collogenase preparation, on surface ultrastructure and muscle tensile properties. The authors measured breaking strength and break elongation for bovine and Dutch rabbit psoas major. Again, muscle fiber bundles, 5 cm. in length by 0.2 - 0.5 cm^2 in cross sectional area were subjected to the post-mortem treatments, and certain physical properties were measured utilizing the Instron Universal Testing machine. The authors reported a 4 percent decrease in breaking strength and a 26 percent decrease in break elongation with the catheptic enzyme preparation. A similar decrease in breaking strength was observed for muscle which had been soaked in the collagenase preparation, but not in break elongation. The changes in ultrastructure and tensile properties reported in this study related well to changes observed in the aging process (Eino and Stanley, 1973a). This experiment demonstrates the usefulness of muscle tensile measurements in the investigation of chemical and physical changes that occur in meat during various post-mortem conditions.

A different approach to the measurement of meat tenderness utilizing the Instron Universal Testing Machine was described by Bouton and Harris (1972a and 1972b). This method involves the measurement of adhesion between muscle fibers, and is intended to be an index of connective tissue strength. Bouton _et al._ (1974) in an investigation of the effect of myofibillar contraction state, cooking temperature and cooking time on mechanical properties of veal, studied four post-mortem treatments. One treatment involved the excision of selected muscles within 1 hour post-mortem allowing these muscles to cold shorten at 0 - 1°C for 2 days before cooking. A second treatment was the conventional method of hanging the carcass from the Achilles tendon, and a third treatment consisted of hanging the carcass from the pelvis by the method described by Hosteller, et al. (1970). In the fourth method, the side was placed flat on a horizontal plane with the legs placed in the walking position (Herring, et al., 1965b). Selected muscles were cooked at 50 and 60°C for one hour and some were cooked at 90°C for either one or three hours.

The muscles removed one hour post-mortem showed the smallest sarcomere length values, and generally the highest adhesion and Warner-Bratzler shear values, regardless of cooking temperature and time. The muscles from the sides hung by the Achilles tendon had low sarcomere length values and generally greater adhesion and Warner-Bratzler shear values than muscles processed by the Herring, et al. (1965b) method or the pelvis hung muscles. The muscles from sides hung by the pelvis exhibited greater sarcomere length values, and generally lower adhesion and Warner-Bratzler shear values than any of the other treatments. However, there were exceptions. In some cases, the muscles with the greatest sarcomere length values and lowest adhesion values required greater amounts of Warner-Bratzler shear force than those processed 1-hour post mortem or from sides hung by the Achilles tendon, even though the muscles from the other treatments were in a deeper state of contraction. The authors pointed out that high shear force values can be obtained for samples with very low adhesion values and relatively long sarcomere lengths, indicating that shear force and adhesion measurements are influenced by different structural patterns. The authors were, however, able to conclude that increasing the cooking temperature from 50° to 60°C and increasing cooking time at 90°C from 1 to 3 hours significantly reduces adhesion values, regardless of myofibillar state. In addition, the authors observed an increase in adhesion value with an increasing myofibrillar state.

This author was part of a new approach to the investigation of physical properties of the muscle fiber. A microsensitive shear instrument, Henrickson et al. (1967), was designed to measure shear force for individual muscle fibers. Henrickson et al. (1974) described the instrument as a research tool for measuring shear force, a physical property of the muscle fiber. In a uniformity trial utilizing formalin fixed sartorius muscle fibers, Henrickson et al. (1974) reported a mean shear force of 5.04×10^{-1} g. and a mean shear stress of 2.30×10^{-4} g./cm.^{2}. In the same study, the author measured fiber diameter, degree of kinkiness, shear force, and shear stress for formalin fixed bovine sartorius muscle fibers from carcasses held two, five, and eight hours post-mortem before hot muscle excision. Sartorius muscles from the opposite sides were excised after a 48 hour period of restraint on the carcass at 2°C.

Significant differences ($P < 0.01$) were reported between the hot and cold excised muscles in fiber diameter, degree of kinkiness, shear force and shear stress, only in the two hour holding period. In the five and eight hour holding periods, the restraint on the carcass during the development of rigor was apparently adequate in preventing the differences observed in the two hour holding period between the two treatments. The authors attributed the differences in the two hour holding period to the unrestrained development of rigor due to muscle excision prior to the onset of rigor.

CHAPTER III

MATERIALS AND METHODS

This study was carried out in conjunction with a project investigating the feasability of "hot" boning the bovine carcass (Falk, 1974). Eighteen Angus steers of approximately the same weight (483.23 ± 7.46 Kg.) and market grade (choice) were utilized in this study. These animals were assigned at random to a three, five, or seven hour holding period for the side to be processed "hot". Each animal was delivered to the meat science abattior 24 hours prior to slaughter. Following the 24 hour shrinkage period, the steer was weighed and ante-mortem Federal inspection was provided. The animals were each rendered unconscious with a Cash Percussion Stunner, raised off the floor by both hind legs and bled in the traditional manner. Stunning, eviseration, splitting and Federal inspection were accomplished within 45 minutes post-mortem.

Either the right or left side of the carcass was randomly assigned to one of two treatments: (1) removing the muscles from the warm carcass ("hot" boning) or (2) removing the muscles after restraint on the carcass for a period of 48 hours ("cold" boning).

After slaughter, Federal inspection and weighing, the sides designated as "hot" were placed in a 16°C holding room for a period of three, five, or seven hours. Each side was then fabricated by first removing the chuck, and then proceeding to muscle bone the streamlined hindquarter. The tensor fascia latae, the muscle utilized in this study, was the first to be excised. The muscles were then placed in Cry-O-Vac bags (S-507) and held at 1.1°C until the side designated as "cold" had been allowed to chill for a period of 48 hours (in the same cooler).

Sampling for Fiber Shear Force, and Fiber Shear Stress, Warner-Bratzler Shear, Nip Tenderometer and Organoleptic Determinations

Two sample steaks for each determination were cut from the "hot" and "cold" tensor fascia latae muscles (Figure 1). Steaks for Warner-Bratzler Shear and Nip Tenderometer measurements, Organoleptic evaluation, and Fiber shear force and shear stress determinations were cut (Figure 2), packaged, labeled, and frozen at -30°C for analysis at a later date.

The Microsensitive Shear Instrument

The Microsensitive Shear Instrument utilized in this study (Figure 3) was described by Henrickson *et al.* (1967), Marsden (1973), and Henrickson *et al.* (1974). The instrument consists of a shear gauge equipped with a torque dial which is easily read from the top of a vertical support (Figure 4). The shear gauge is strung with a wire 1/100 inch in diameter which supports a blunt edged shearing blade (Figure 5). The top end of the wire is connected to the torque dial and the bottom to a tension arm. The amount of rotation of the dial is measured in degrees and can be read directly from the torque dial. The fiber is held, but not tightly clamped between a plexiglass and an aluminum plate (Figure 6). A shallow V-cut in the aluminum plate provides a groove to position

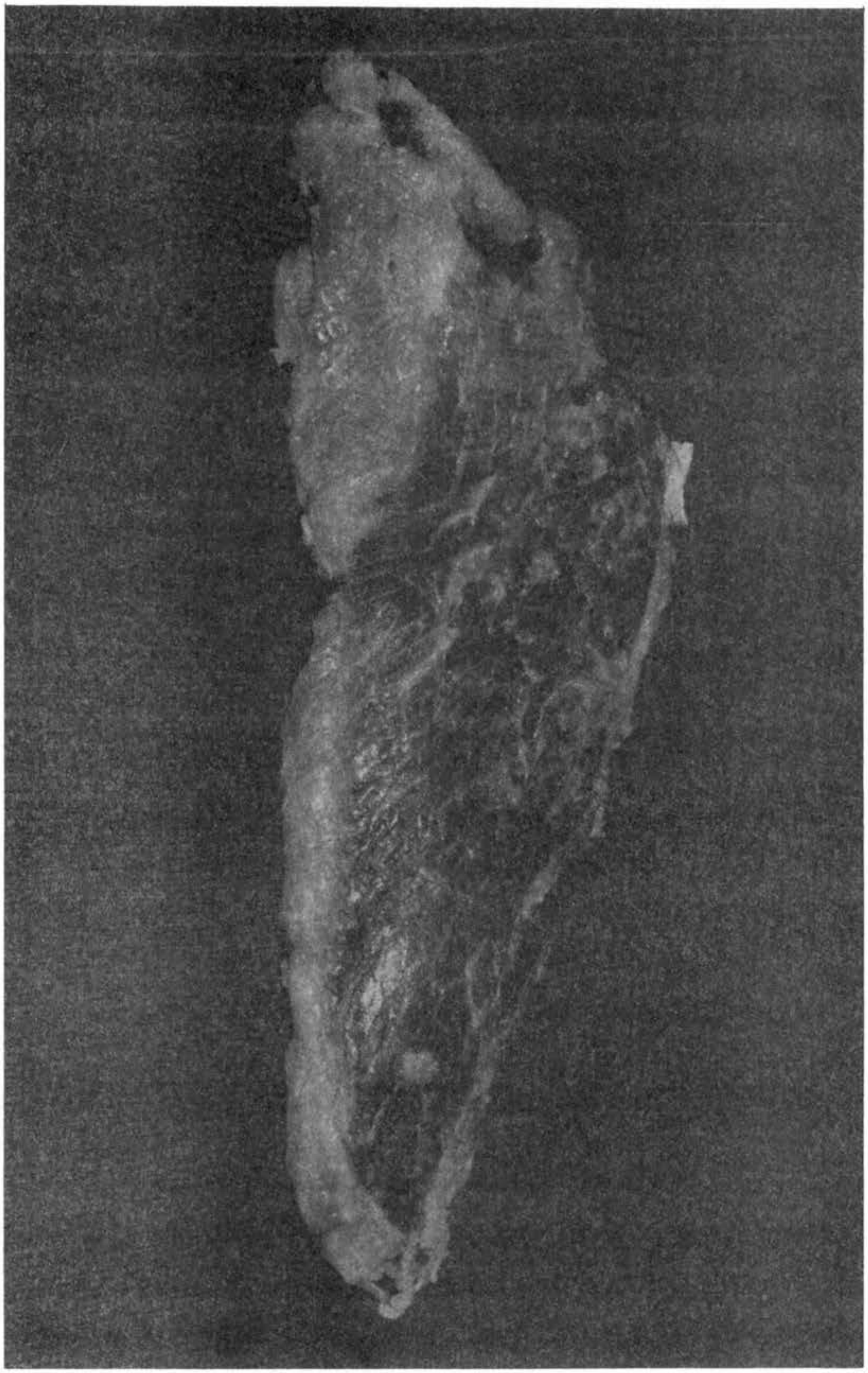

Figure 1. The Bovine Tensor Fascia Latae Muscle

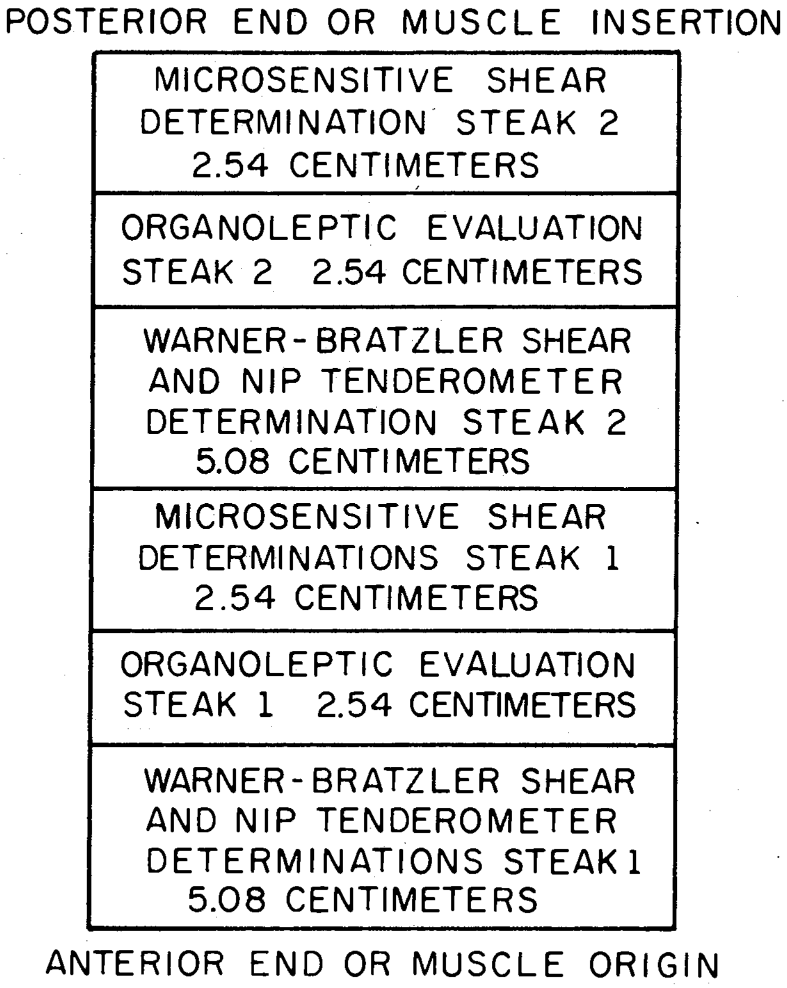

Figure 2. Sampling Procedure for Microsensitive Shear, Organoleptic, Warner-Bratzler Shear, and Nip Tenderometer Determinations

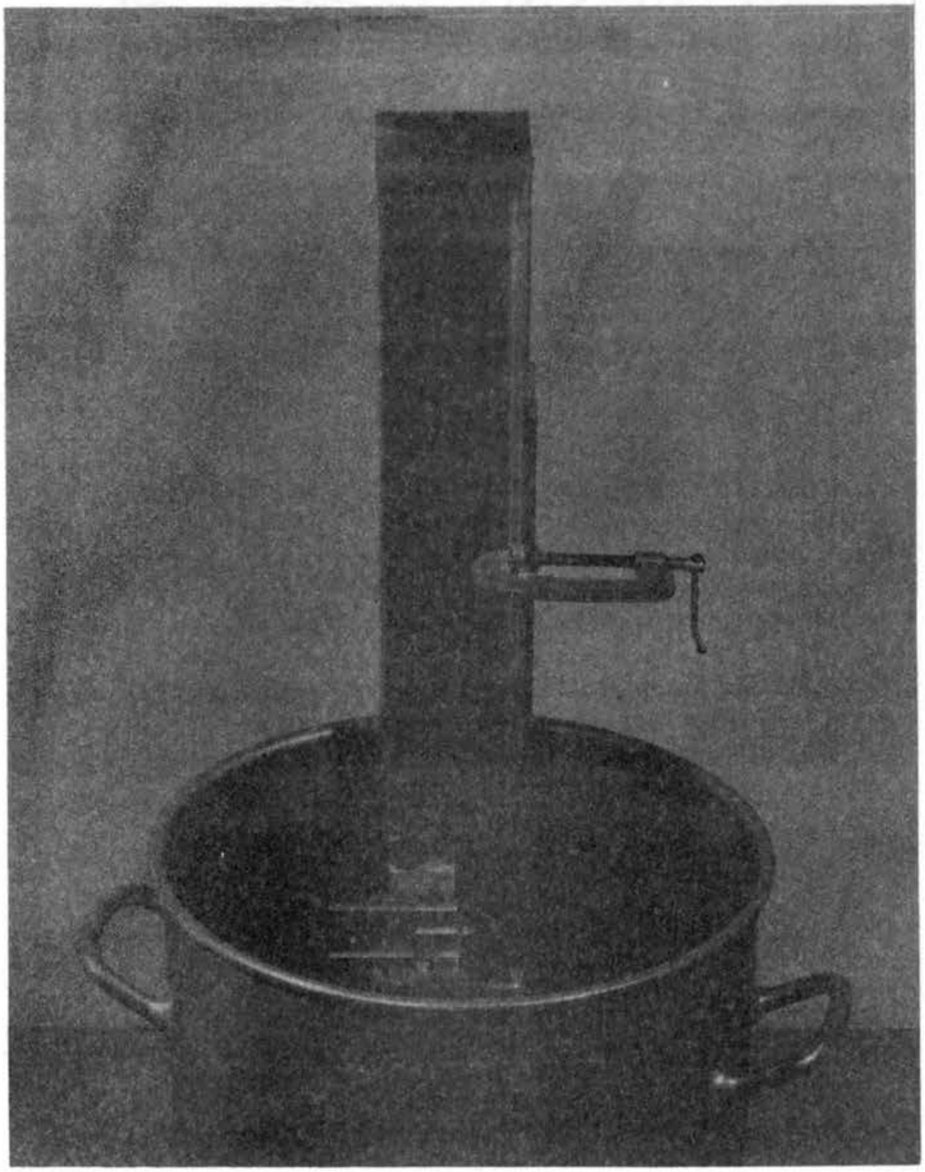

Figure 3. Microsensitive Shear Instrument Fully Assembled

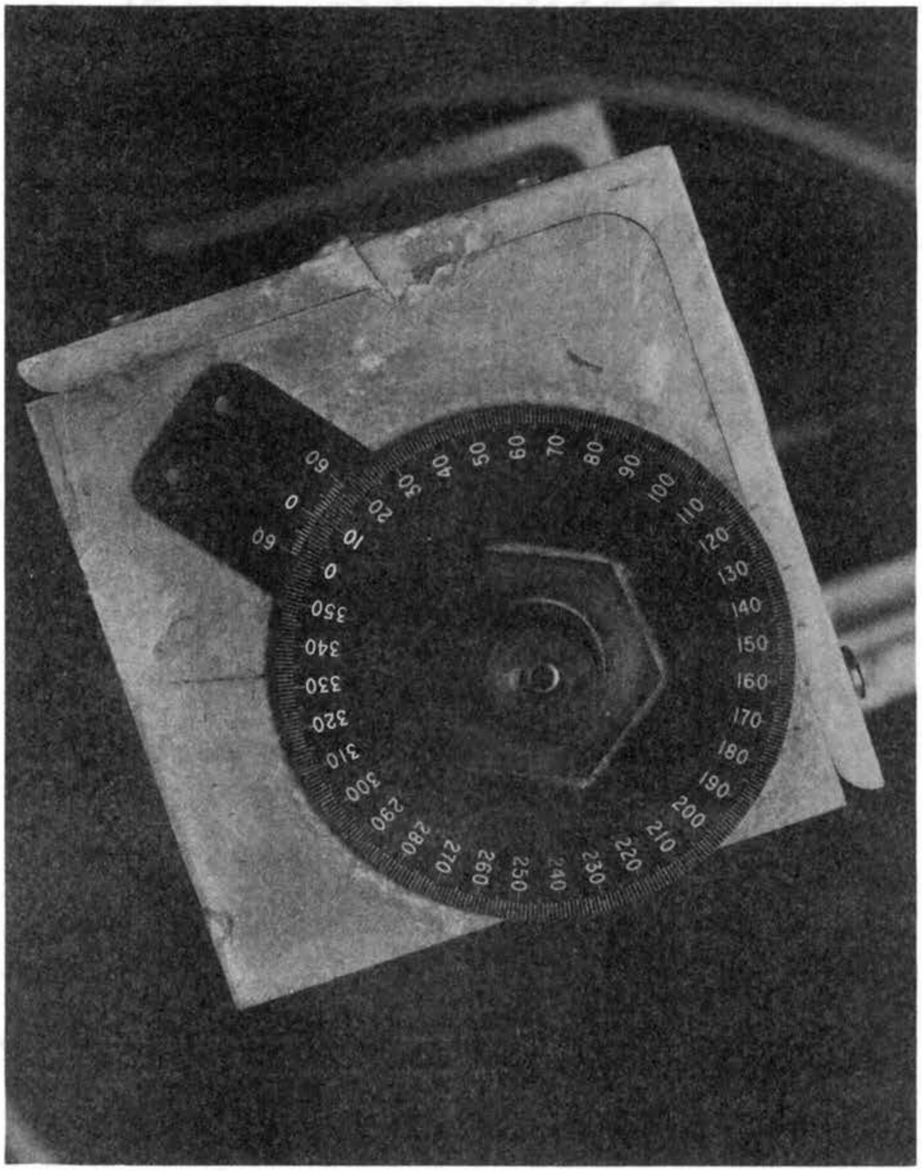

Figure 4. Torque Dial of the Microsensitive Shear Instrument

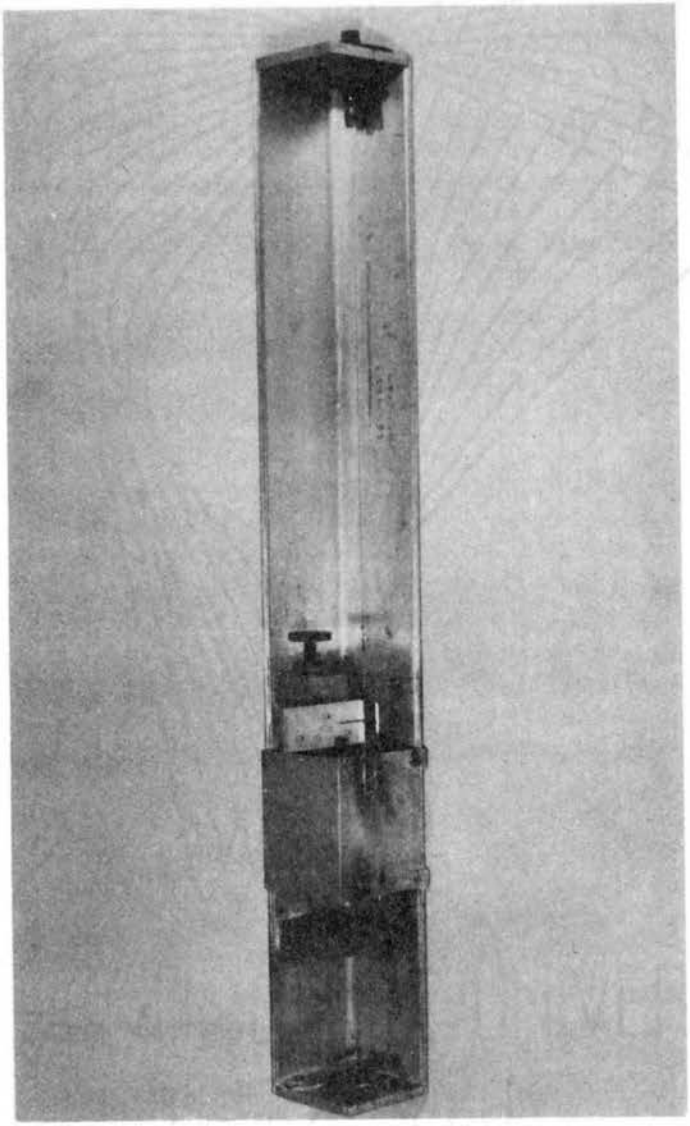

Figure 5. Assembled Shearing Mechanism and Wire Leading to Torque Dial

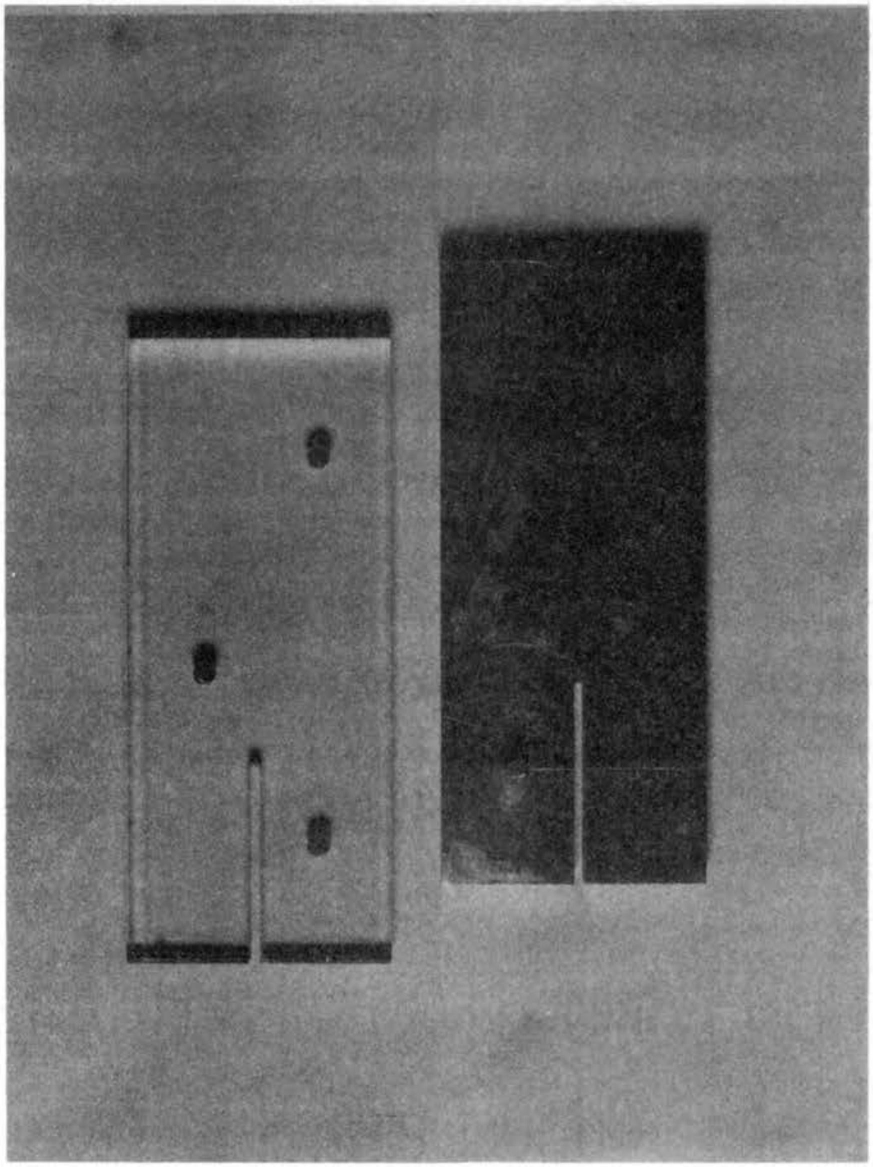

Figure 6. Plexiglass and Aluminum Holder Showing the V-Cut

the fiber. The two plates are then attached by a clamp to an adjustable specimen holder which supports the fiber in a vertical position. The holder assembly and blade are placed under water while the shear is made in order to reduce the effect of friction between the blade and the fiber.

The torque required to shear the fiber is converted to units of force by the formual (Henrickson, et al., 1967):

$$\text{Shear Force} = \text{Degrees} \times 6.094287 \times 10^{-3} \text{ grams}$$

The force per unit area or shear stress is determined by dividing the amount of rotation of the blade by the square of the diameter and then multiplying by a conversion factor, where:

$$\text{Shear Stress} = \frac{\text{Degrees}}{\text{Square of Diameter}} \times 7.759469 \times 10^{-3} \text{ g/u}^2 .$$

Harvesting Individual Muscle Fibers

Thin muscle cross sections (approximately 2.0 mm.) were cut parallel to the fiber grain from the sample steaks reserved for fiber shear force and shear stress determinations, and individual fasciculi were dissected from these thin strips. An effort was made to utilize fasciculi of approximately 25 mm. in length and 2.0 mm. in diameter. For the preparation of fibers for raw shear force and shear stress determinations, an individual fascicule was placed in a modified Waring Blender containing 200 ml. of 5% glycerin solution. The blender was operated at a rheostat setting of 40 volts for a period of one minute, to dislodge the muscle fibers from the fascicule. The suspension of fibers was then transferred to a container and held until 30 fibers had been measured for diameter and sheared with the microsensitive shear instrument (approximately one hour).

The procedure for isolation of cooked fibers was the same as described above, except that the dissected fascicule was placed in a beaker of water pre-heated to a temperature of 71.1°C for a period of one minute before being transferred to the blender.

Determination of Fiber Diameter

The fiber suspension was thoroughly shaken and a small portion was poured into a two-inch diameter petri dish. The petri dish was placed on an American Optical microscope equipped with an ocular micrometer, and the fibers were allowed to settle to the bottom of the dish. Those fibers which appeared steady, and were at least the length of the microscopic field were measured at 100X for diameter at their widest point. Thirty raw and thirty cooked muscle fibers were measured from each sample steak.

Determination of Shear Force and Shear Stress for Raw and Cooked Muscle Fibers

After each fiber was measured for diameter, it was carefully removed with forceps from the petri dish and placed between the aluminum and plexiglass holding mechanism (Figure 7) in preparation for shearing. After the fiber was firmly secured between the two components of the holding mechanism, the assembly was placed on the shearing platform of the microsensitive shear instrument. The shearing process was accomplished, under water, by slowly and steadily turning the blade until it visibly came into contact with the fiber. This reading was used as the

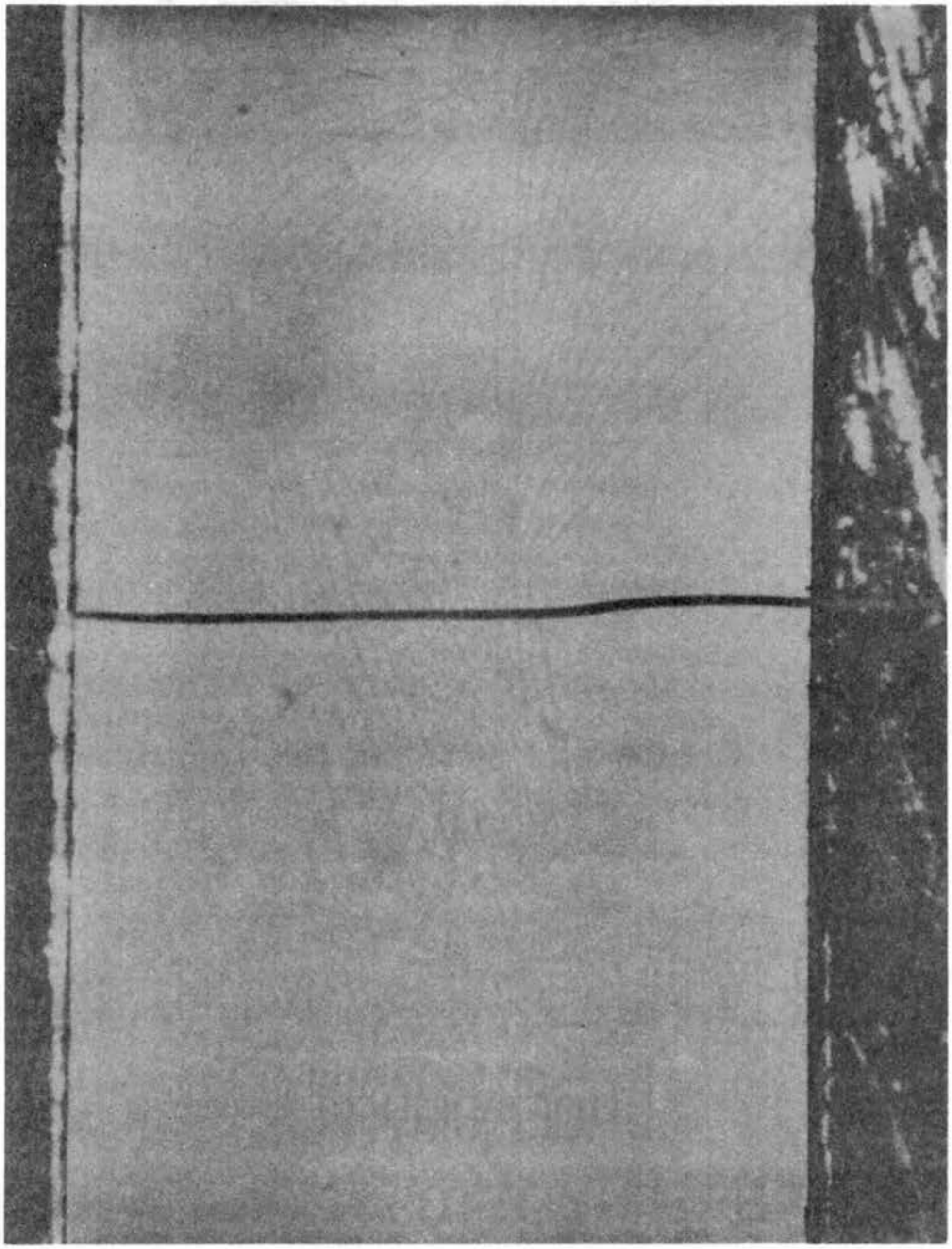

Figure 7. Individual Muscle Fiber Lying Across Holding Plate

starting point. The blade was then steadily turned by the operator until it passed through the fiber (Figure 8). At this point, the operator recorded the torque (degrees) required to shear the fiber by subtraction of the initial starting point reading from the reading on the torque dial at the point where the fiber was sheared. This procedure was repeated for thirty raw and thirty cooked muscle fibers from each sample steak. The torque required to shear each fiber was converted to units of force and to units of stress by the formulas shown on page 29.

Nip Tenderometer and Warner-Bratzler Shear Determinations

The Nip Tenderometer described by Smith and Carpenter (1973) (Figure 9) and the Warner-Bratzler Shear Instrument were used as objective measures of meat tenderness in this phase of the study. Two steaks from each tensor fascia latae muscle were evaluated with these instruments. The frozen steaks designated for Nip Tenderometer and Warner-Bratzler Shear determinations were thawed for twenty-four hours at 4°C. The thawed steaks were labeled and cooked in deep fat at a temperature of 121.1°C until an internal temperature of 65.6°C was reached. The steaks were removed from the deep fat and allowed to stand until the temperature rose to its ultimate level and then dropped to a temperature of 71°C. At this temperature, a thin slice was cut from the external surface of the steak, exposing the grain of the fibers. The jaws of the Nip Tenderometer were inserted into the steak perpendicular to the grain of the fibers. Five 71°C Nip Tenderometer readings were taken on each steak and the steaks were then allowed to cool at 4°C for 24 hours. After the cooling period, another slice was taken from the external sur-

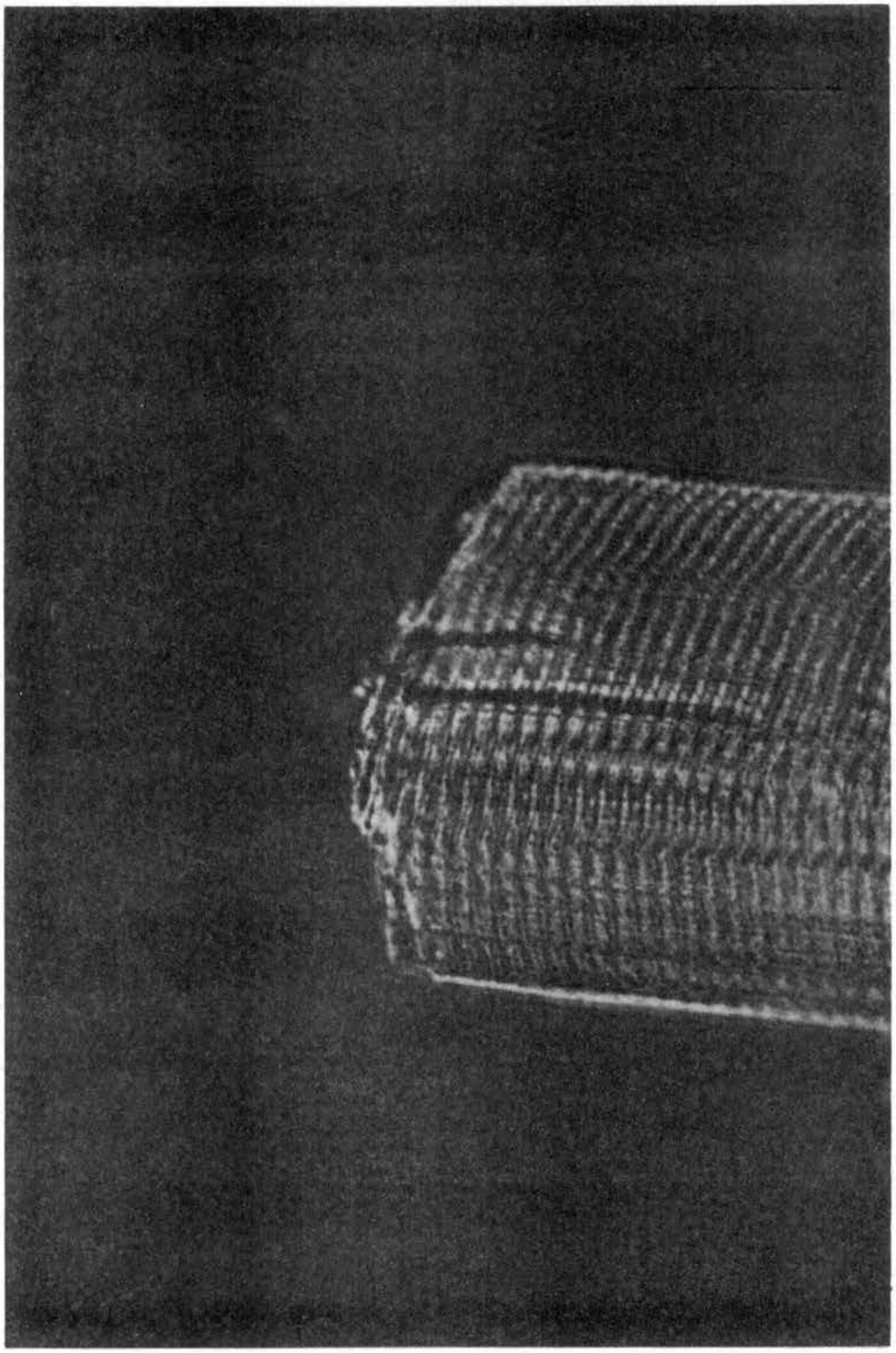

Figure 8. Sheared End of Individual Muscle Fiber

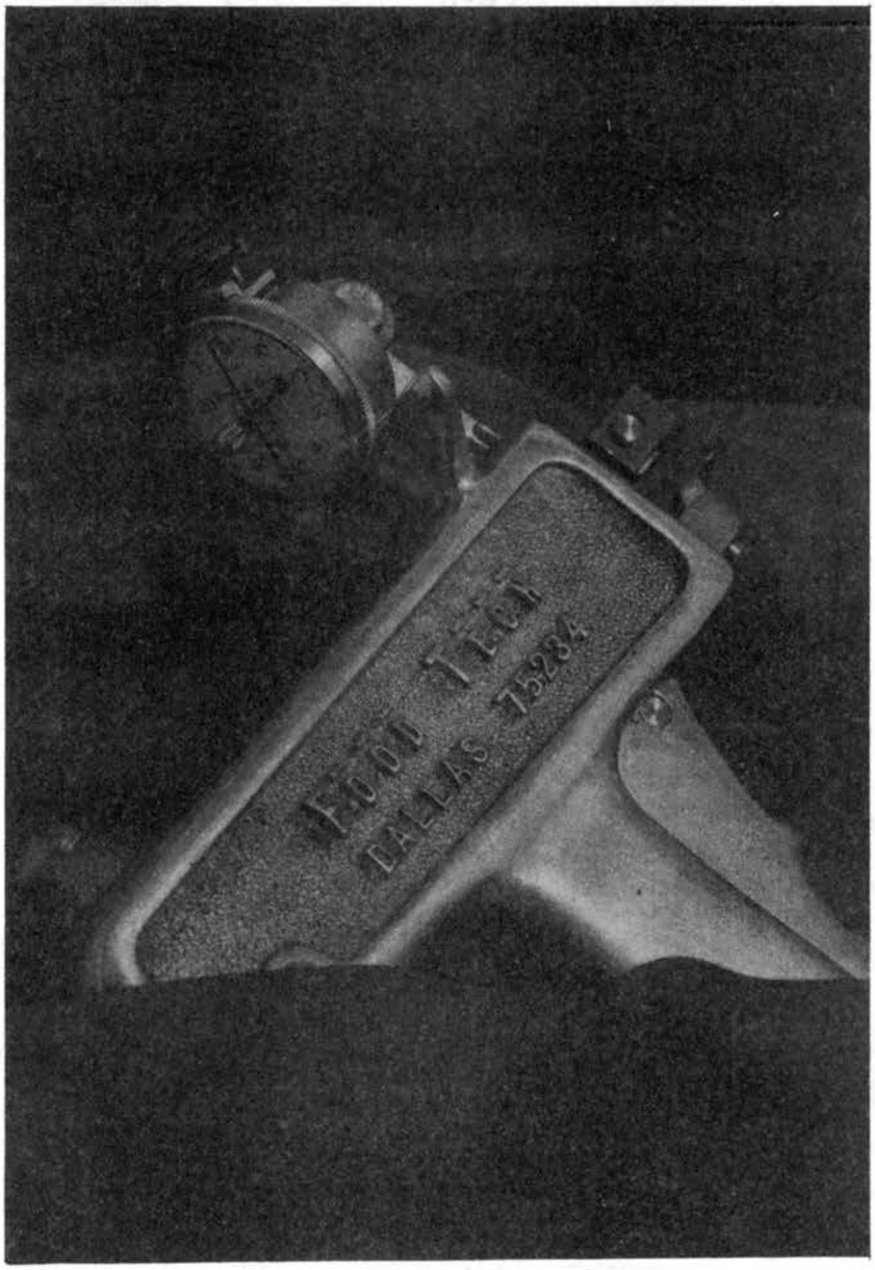

Figure 9. The Nip Tenderometer

face of the steak, again exposing the grain of the fibers. Five 4°C Nip Tenderometer readings were then taken from each steak.

Three 1.27 cm. diameter cores were extracted from the same cooked steaks using a mechanical boring device to assure uniformity (Kastner and Henrickson, 1969). Each core was then sheared three times by the Warner-Bratzler Shear Instrument. The three shear values from each core were summed and averaged, and the resulting averages of the three cores were pooled and averaged to obtain a shear value for the entire steak.

Organoleptic Evaluation

Two steaks were allotted from each tensor fascia latae muscle for organoleptic evaluation. Steak 1 (Figure 2) was designated for Difference scale evaluation and steak 2 for chew count determination. Four panelists (two males and two females) were chosen from the meat laboratory staff and were provided some training before the beginning of the actual trials. The same four panelists were used throughout the course of the study. The panelists were instructed to evaluate the samples on the basis of tenderness only. The frozen steaks designated for organoleptic evaluation were thawed at 4°C for 24 hours and then cooked in deep fat at 121.1°C to an internal temperature of 65.6°C. Four 1.27 cm. cores were randomly extracted from the steaks. Each panelist was supplied one core for Difference scale evaluation (1 = extremely tender, 9 = extremely tough), and one core for chew count determination. Figure 10 is a replication of the Difference scale and chew count score sheet.

Statistical Analysis

The Analysis of Variance and Regression procedures of the SAS com-

Date ____________________ Product ____________________

Project ____________________ Animal No. ____________________

Panel Score for Tenderness

A. Difference Scale

1. Extremely Tender
2. Very Tender
3. Moderately Tender
4. Slightly Tender
5. Neither Tender Nor Tough
6. Slightly Tough
7. Moderately Tough
8. Very Tough
9. Extremely Tough

B. Number of Chews __________

Figure 10. Difference Scale and Chew Count Score Sheet

puter programming system (Service, 1972) were used to analyze the data collected during the course of the study. The F-tests concerning the main unit analysis utilized the animal x treatment mean square with 5 degrees of freedom as the error term. The error term for the F-tests concerning the subunit analysis utilized the pooled animal x steak plus animal x treatment x steak mean square with 10 degrees of freedom. Each analysis of variance generated by the analysis of data presented in this study is shown in the Appendix (Tables XI-XLIII). The design of the hot boning investigation of which this study was a part (Falk, 1974), provided that each holding period be considered as a separate experiment. Therefore, no statistical comparison was made between the three, five, and seven hour holding periods. Partial correlation coefficients were determined between variables within each holding period after removing the effects of animal variation and treatment variation ("hot" and "cold" muscle excision).

CHAPTER IV

RESULTS AND DISCUSSION

Effect of Hot and Cold Processing -

Fiber Diameter

A difference in raw fiber diameter between the hot and cold excised Tensor fascia latae muscles for the three hour holding period was statistically significant ($P < 0.01$) (Table XI). The average raw fiber diameter for the muscles excised hot was 45.61 microns as compared with 43.17 microns for the muscles excised cold. Table I and Figure 11 illustrate that this difference in raw fiber diameter decreased in the five and seven hour holding periods; neither difference was significant ($P > 0.05$). The five hour period of restraint on the carcass before hot muscle excision was apparently adequate in preventing the increase in fiber diameter seen in the three hour holding period.

The cooked fiber diameter was significantly greater in the muscles excised hot only in the three hour holding period ($P < 0.05$) (Table XII). The average cooked fiber diameter for the muscles excised hot was 49.56 microns, while the muscles excised cold had an average fiber diameter of 47.05 microns (Table II and Figure 12). The difference in cooked fiber diameter between the muscles excised hot and cold was very small in the five and seven hour holding periods (Table II and Figure 12), indicating again that the five hour post-mortem holding period was adequate in preventing the increase in fiber diameter apparent in the three hour holding

TABLE I

MEANS AND $\sqrt{EMS/N}$ FOR RAW FIBER DIAMETER, RAW FIBER SHEAR FORCE, AND RAW FIBER SHEAR STRESS

Holding Time	3 Hour			5 Hour			7 Hour		
	Fiber Diameter u (N=360)	Shear Force x 10^{-1}g (N=360)	Shear Stress x 10^{-4} g/u^2 (N=360)	Fiber Diameter u (N=360)	Shear Force x 10^{-1}g (N=360)	Shear Stress x 10^{-4} g/u^2 (N=360)	Fiber Diameter u (N=360)	Shear Force x 10^{-1}g (N=360)	Shear Stress x 10^{-4} g/u^2 (N=360)
Processing Method									
Hot	45.61**	3.31	2.09*	43.40	3.20	2.27	43.60	3.09	2.17
Cold	43.17**	3.20	2.27*	43.00	3.17	2.28	42.70	3.03	2.31
$\sqrt{EMS/N}$	0.38	0.26	0.04	0.28	0.06	0.03	0.42	0.08	0.09
dF	5	5	5	5	5	5	5	5	5

*(P < 0.05).

**(P < 0.01).

TABLE II

MEANS AND $\sqrt{EMS/N}$ FOR COOKED FIBER DIAMETER, COOKED FIBER SHEAR FORCE, AND COOKED FIBER SHEAR STRESS

Holding Time	3 Hour			5 Hour			7 Hour		
	Fiber Diameter u	Shear Force $x\ 10^{-1}$ g	Shear Stress $x\ 10^{-4}$ g/u^2	Fiber Diameter u	Shear Force $x\ 10^{-1}$ g	Shear Stress $x\ 10^{-4}$ g/u^2	Fiber Diameter u	Shear Force $x\ 10^{-1}$ g	Shear Stress $x\ 10^{-4}$ g/u^2
Processing Method									
Hot	49.56*	3.67*	1.97	47.10	3.47	2.08	45.50	3.22	2.08
Cold	47.05*	3.50*	2.08	46.80	3.41	2.05	46.00	3.44	2.10
$\sqrt{EMS/N}$	0.65	0.08	0.04	0.46	0.14	0.05	0.44	0.13	0.03
dF	5	5	5	5	5	5	5	5	5

*($P < 0.05$).

**($P < 0.01$).

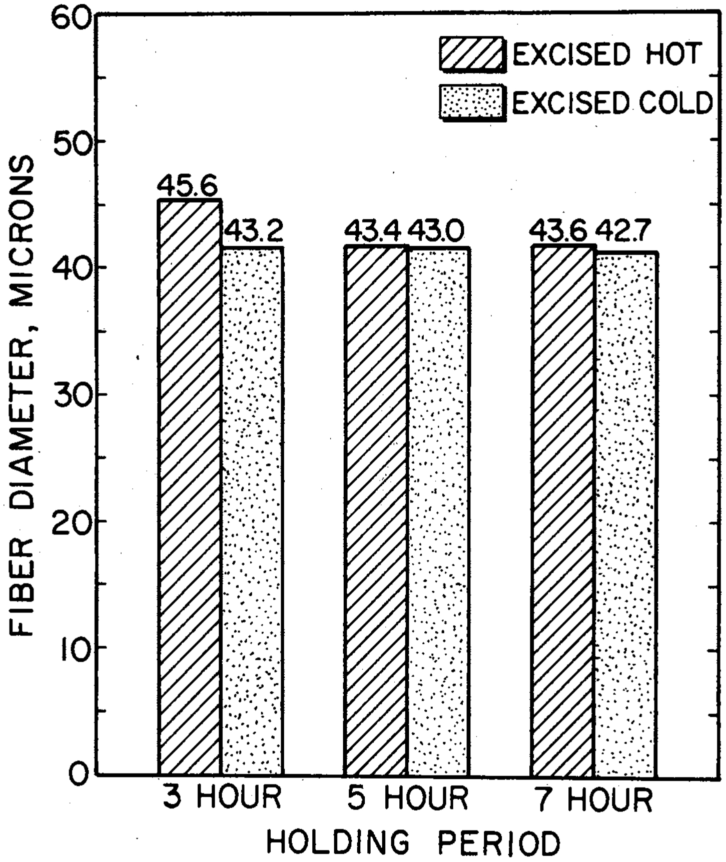

Figure 11. Effect of Chilling Method and Holding Period on Raw Fiber Diameter

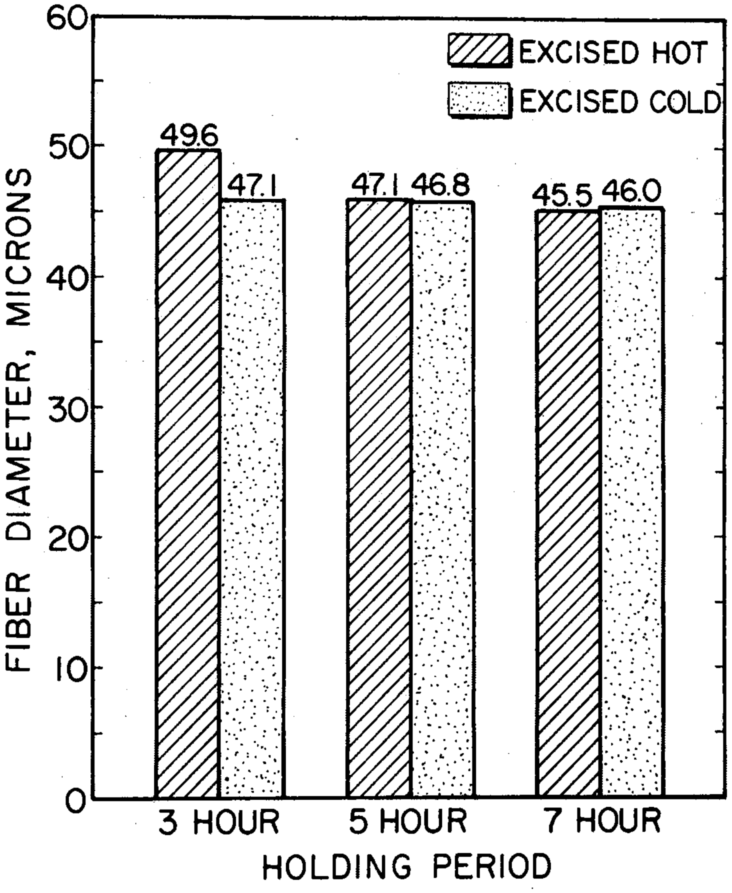

Figure 12. Effect of Chilling Method and Holding Period on Cooked Fiber Diameter

period.

The difference in fiber diameter was 2.4 microns in the raw fibers and 2.5 microns in the cooked fibers. Henrickson et al. (1974) reported a difference of 12.3 microns in formalin fixed fibers between sartorius muscles excised hot after a two hour holding period and sartorius muscles excised cold after chilling for forty-eight hours. The three hour holding period does therefore represent an improvement over shorter postmortem holding periods in terms of limiting increases in fiber diameter in hot processed muscle.

Effect of Hot and Cold Processing -
Fiber Shear Force

There were no significant differences in raw fiber shear force between the hot and cold excised tensor fascia latae muscles in the three, five, or seven hour holding periods. Table I and Figure 13 show that the difference was greatest in the three hour holding period, and least in the five hour holding period. The raw fiber shear force was greater in each holding period for the muscles excised hot, but these differences were quite small, indicating that the three hour holding period was adequate in preventing a significantly increased raw fiber shear force in the muscles excised hot.

The cooked fiber shear force was significantly greater for the muscles excised hot in the three hour holding period ($P < 0.05$) (Table XIV). The average cooked fiber shear force was 3.67×10^{-1} grams for the muscles excised hot and 3.50×10^{-1} grams for the muscles excised cold (Table II and Figure 14). The difference in cooked fiber shear force between the hot and cold excised muscles was small in the five and seven

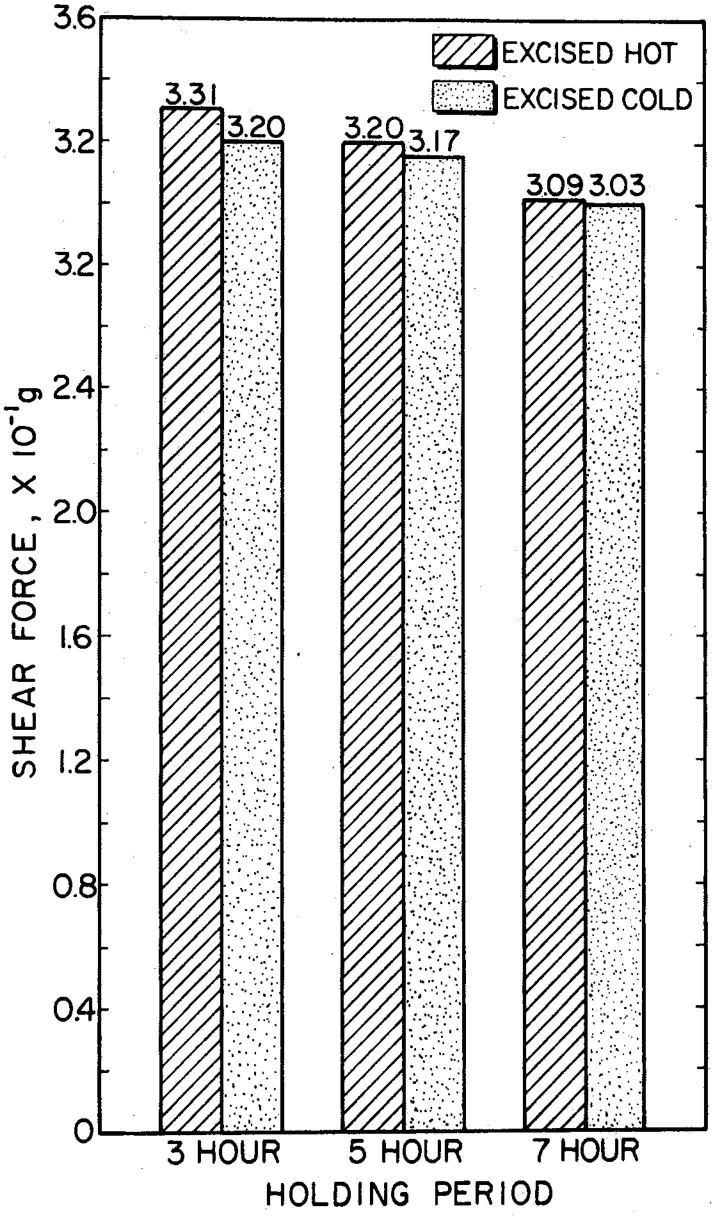

Figure 13. Effect of Chilling Method and Holding Period on Raw Fiber Shear Force

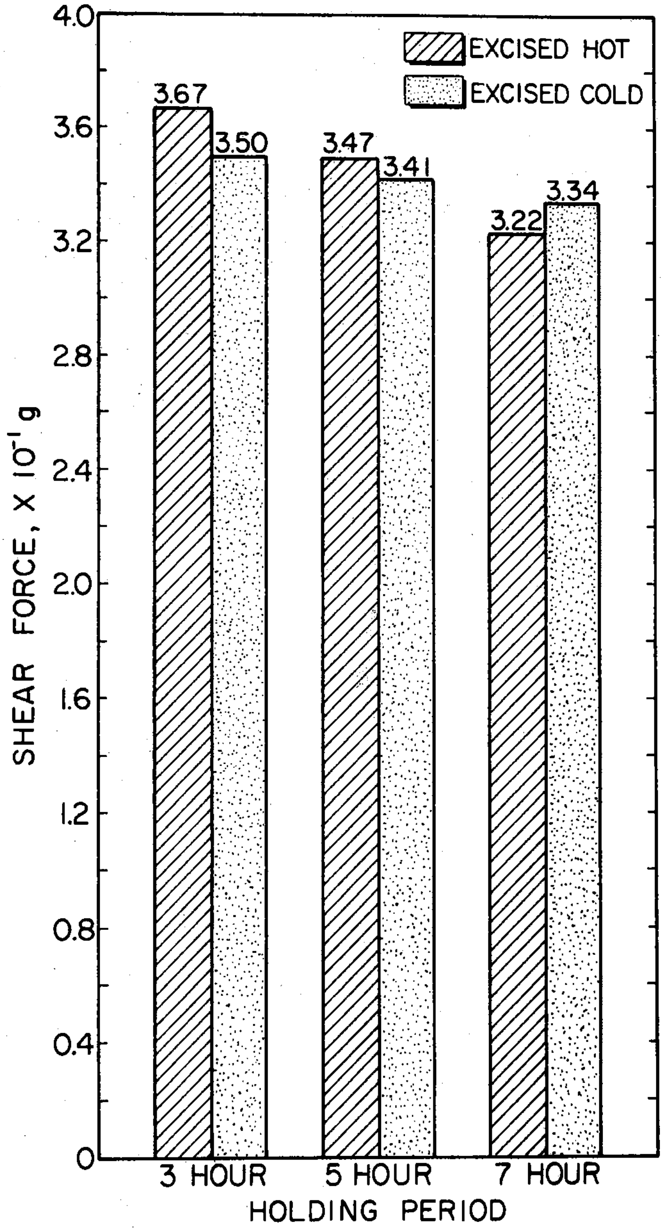

Figure 14. Effect of Chilling Method and Holding Period on Cooked Fiber Shear Force

hour holding periods and neither difference was significant. In the seven hour holding period, the muscles excised hot actually had a lower average cooked fiber shear force than the muscles excised cold (Table II and Figure 14). Although these data disagree in terms of differences between hot and cold excised muscles in the three hour holding period, it should be pointed out that in both the raw and cooked fiber shear force measurements, the greatest difference occurred in the three hour holding period.

Effect of Hot and Cold Processing -
Fiber Shear Stress

A difference in raw fiber shear stress between the hot and cold excised tensor fascia latae muscles was significant in the three hour holding period ($P < 0.05$) (Table XV). However, in this case the muscles excised cold showed a significantly higher shear stress value than the muscles excised hot (Table I and Figure 15). The average shear stress for the muscles excised hot was 2.09×10^{-4} g/u^2, as compared to 2.27×10^{-4} g/u^2 for the muscles excised cold. There were no significant differences in shear stress in the five and seven hour holding periods.

In order to interpret this apparent discrepancy in these data, the formula for computing shear stress must be analyzed. The torque required to shear an individual fiber is converted into units of force per unit area (shear stress) by first multiplying by a conversion factor and then dividing by the square of the diameter. The numerator in the equation is a rather small number compared to the denominator which is in the range of 100 - 10,000. Therefore, the diameter of the fiber becomes the most important factor in determining shear stress, and shear stress

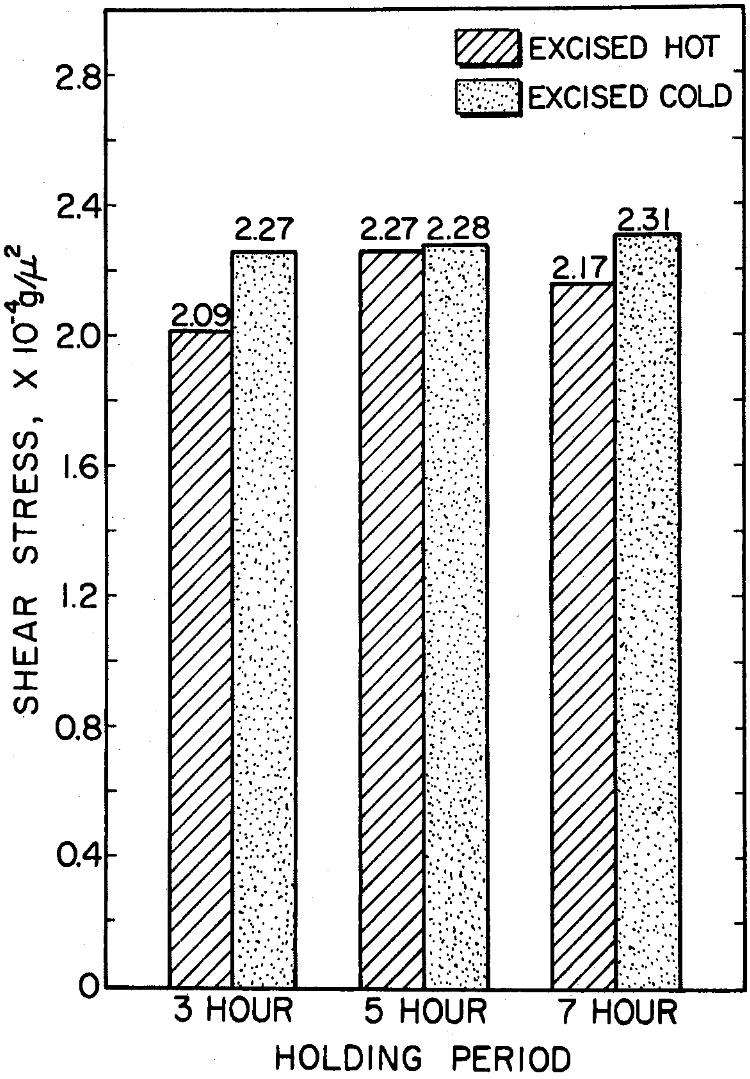

Figure 15. Effect of Chilling Method and Holding Period on Raw Fiber Shear Stress

becomes a reflection of fiber diameter. Since the muscles excised hot in the three hour holding period had a higher average fiber diameter than the muscles excised cold, the denominator in the equation for calculation of shear stress was larger for the muscles excised hot. This effect tends to mask any differences in torque which are evidenced in the earlier discussion of fiber shear force.

There were no significant differences in fiber shear stress between the hot and cold excised muscles for the cooked fibers in the three, five, or seven hour holding periods (Table II and Figure 16). The fiber shear stress value for the muscles excised cold was, however, higher than the value for the muscles excised hot in the three hour holding period, but the author again attributes this difference to the greater fiber diameter of the muscles excised hot.

Effect of Hot and Cold Processing -
Nip Tenderometer Value

There were no significant differences in the 71°C or the 4°C Nip Tenderometer values between the hot and cold treatments for the three hour holding period (Table III and Figures 17 and 18). However, both the 71°C and the 4°C Nip Tenderometer values were significantly higher ($P < 0.05$) for the five hour holding period (Tables XXXIII and XXXIV). The 71°C Nip Tenderometer value was 10.02 lbs. for the muscles excised hot, and 10.92 lbs. for the muscles excised cold. The 4°C Nip Tenderometer value was 13.30 lbs. for the muscles excised hot and 14.87 lbs. for the muscles excised cold. Again in the seven hour holding period, neither difference was significant.

Although the differences in the three hour holding period were not

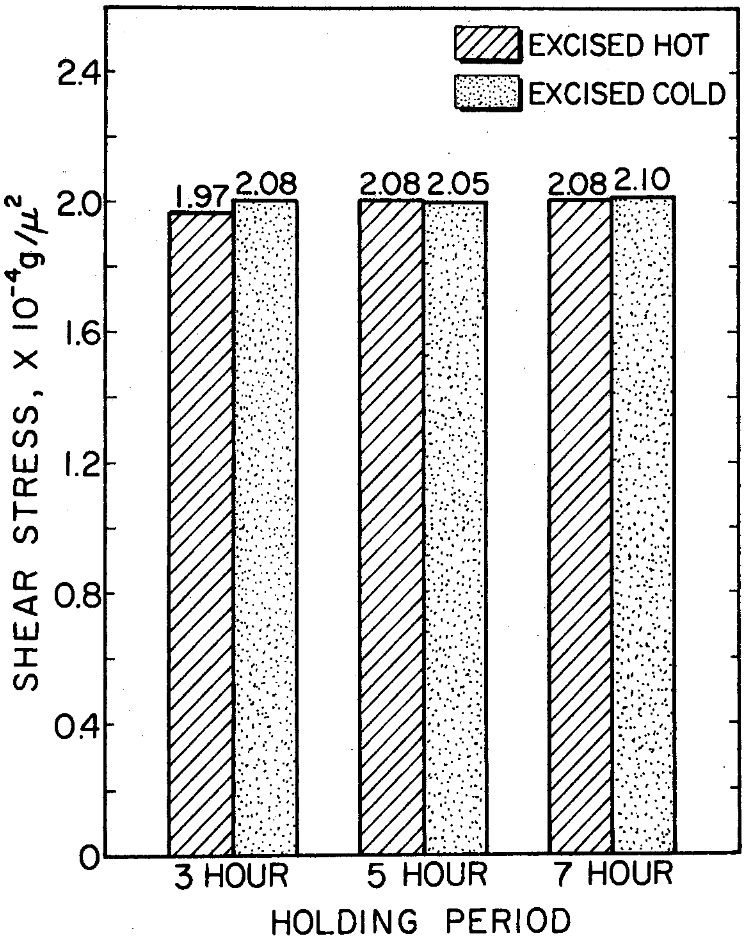

Figure 16. Effect of Chilling Method and Holding Period on Cooked Fiber Shear Stress

TABLE III

MEANS AND $\sqrt{EMS/N}$ FOR NIP TENDEROMETER AND WARNER-BRATZLER SHEAR VALUES

Holding Time	3 Hour			5 Hour			7 Hour		
	71°C Nip Value lbs. (N=60)	4°C Nip Value lbs. (N=60)	W-B Shear Value lbs. (N=108)	71°C Nip Value lbs. (N=60)	4°C Nip Value lbs. (N=60)	W-B Shear Value lbs. (N=108)	71°C Nip Value lbs. (N=60)	4°C Nip Value lbs. (N=60)	W-B Shear Value lbs. (N=108)
Processing Method									
Hot	11.28	15.33	7.54	10.02*	13.30*	7.08**	10.88	14.38	7.62
Cold	10.42	15.00	8.58	10.92*	14.87*	9.11**	11.25	15.67	8.24
$\sqrt{EMS/N}$	0.55	0.31	0.46	0.20	0.42	0.22	0.22	0.36	0.17
dF	5	5	5	5	5	5	5	5	5

*($P < 0.05$).

**($P < 0.01$).

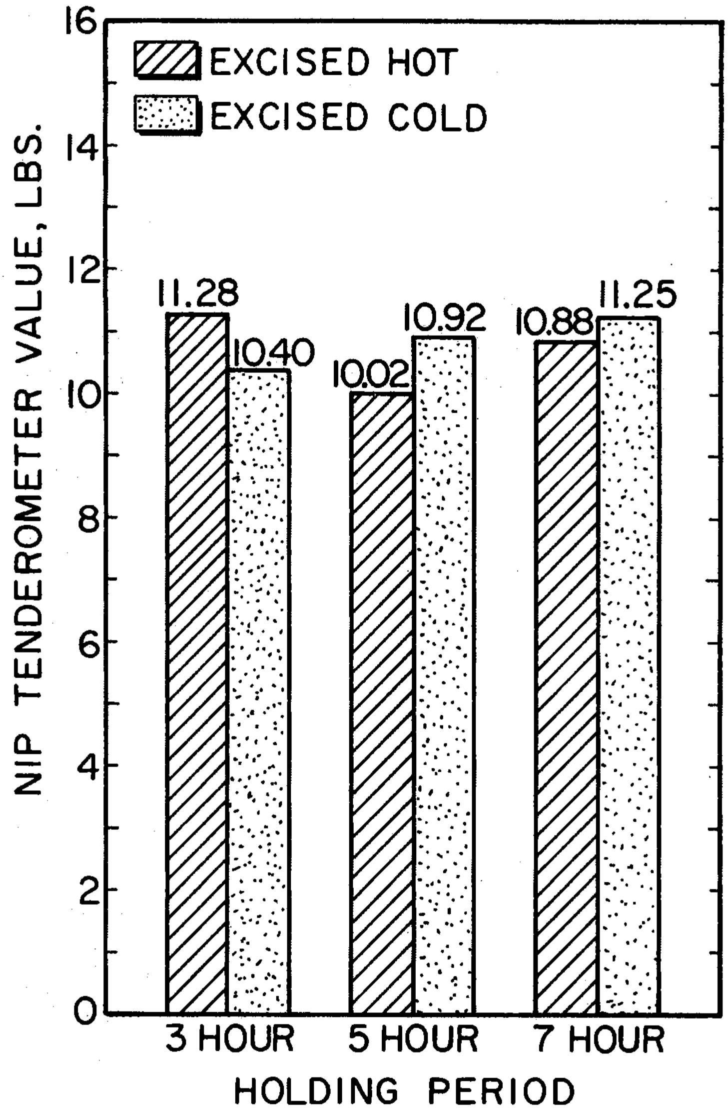

Figure 17. Effect of Chilling Method and Holding Period on 71°C Nip Tenderometer Value

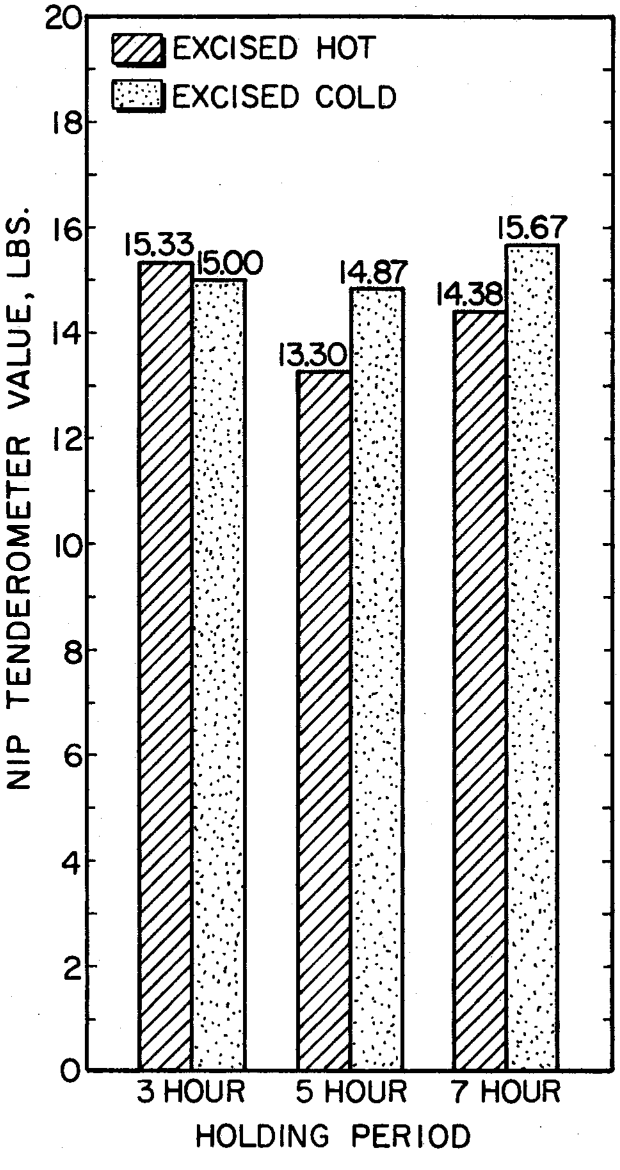

Figure 18. Effect of Chilling Method and Holding Period on 4°C Nip Tenderometer Value

significant, it is interesting to note that for both the 71°C and the 4°C Nip Tenderometer values, the muscles excised hot required more force than the muscles excised cold (Table III and Figures 17 and 18). In the five and seven hour holding periods, the muscles excised cold required more force than the muscles excised hot.

The data obtained with the Nip Tenderometer does not compare well with the measurement of shear force with the microsensitive shear instrument, except that in the three hour holding period the muscles excised hot showed slightly higher Nip Tenderometer values than the muscles excised cold. In the five and seven hour holding periods, the Nip Tenderometer values showed the muscles excised cold to require more force than the muscles excised hot, while the microsensitive shear instrument measurements of shear force showed that the muscles excised cold required slightly less force than the muscles excised hot. The explanation for this discrepancy is simply that the two instruments are measuring different physical properties, the microsensitive shear instrument, fiber shear force, and the Nip Tenderometer, a combination of various physical properties including squeezing, shearing, and tearing.

Effect of Hot and Cold Processing - Warner-Bratzler Shear Force

There was no significant difference in Warner-Bratzler shear force between the hot and cold excised muscles in the three hour holding period (Table III and Figure 19). A significant difference was, however, observed in the five hour holding period ($P < 0.01$) (Table XXXVIII). The muscles excised hot required an average shear force of 7.08 lbs.; the muscles excised cold required an average shear force of 9.11 lbs. In

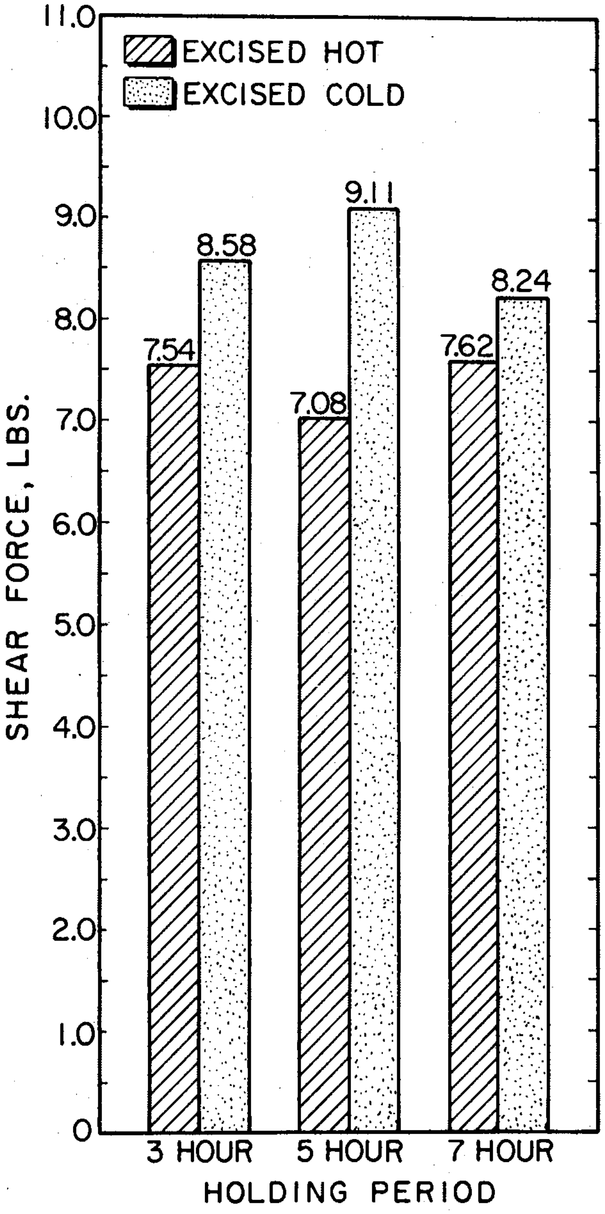

Figure 19. Effect of Chilling Method and Holding Period on Warner-Bratzler Shear Force

the seven hour holding period, the muscles excised cold again required a significantly higher shear force ($P < 0.05$) (Table XXXIX) than the muscles excised hot. The average shear force for the muscles excised hot was 7.62 pounds, while the muscles excised cold required 8.24 pounds.

The results differ with both of those obtained with the microsensitive shear instrument and the Nip Tenderometer. With the Warner-Bratzler shear instrument, the muscles excised cold required more force than the muscles excised hot in all three holding periods. With the Nip Tenderometer, the muscles excised cold in the three hour holding period showed a lower value of force than the muscles excised hot, although this difference was not significant (Table III and Figures 17 and 18). With the microsensitive shear instrument, the muscles excised hot required a greater amount of force in each holding period with the raw fibers, and in the three and five hour holding periods with the cooked fibers (Table I and Figures 13 and 14).

Again, the difference reported with the use of these various instruments must be attributed to the fact that they are each measuring different physical properties of muscle, although these properties may all be related to tenderness. The relationship of each of these instruments to meat tenderness as ascertained in this study will be discussed subsequently.

Effect of Hot and Cold Processing -
Organoleptic Evaluation

There were no significant differences observed between the muscles excised hot and cold in the three and five hour holding periods for difference scale rating or chew count (Table IV and Figures 20 and 21).

TABLE IV

MEANS AND $\sqrt{EMS/N}$ FOR TENDERNESS PANEL DIFFERENCE RATING AND CHEW COUNT

Holding Time	3 Hour		5 Hour		7 Hour	
	Difference Rating† (1-9) (N = 24)	Chew Count (N = 24)	Difference Rating (1-9) (N = 24)	Chew Count (N = 24)	Difference Rating (1-9) (N = 24)	Chew Count (N = 24)
Processing Method						
Hot	4.88	18.25	4.38	15.83	4.29*	16.88
Cold	4.79	18.96	4.38	16.63	5.00*	18.21
$\sqrt{EMS/N}$	0.24	0.96	2.45	0.40	0.19	0.47
dF	5	5	5	5	5	5

†(1 = Extremely tender, 9 = Extremely tough).

*($P < 0.05$).

**($P < 0.01$).

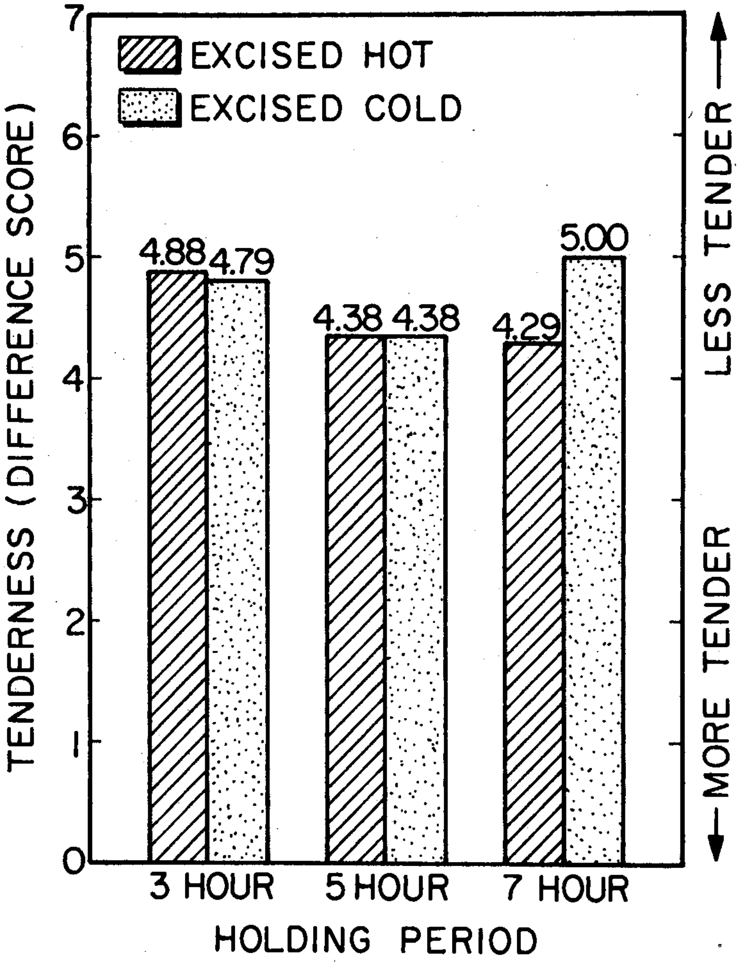

Figure 20. Effect of Chilling Method and Holding Period on Tenderness (Difference Score)

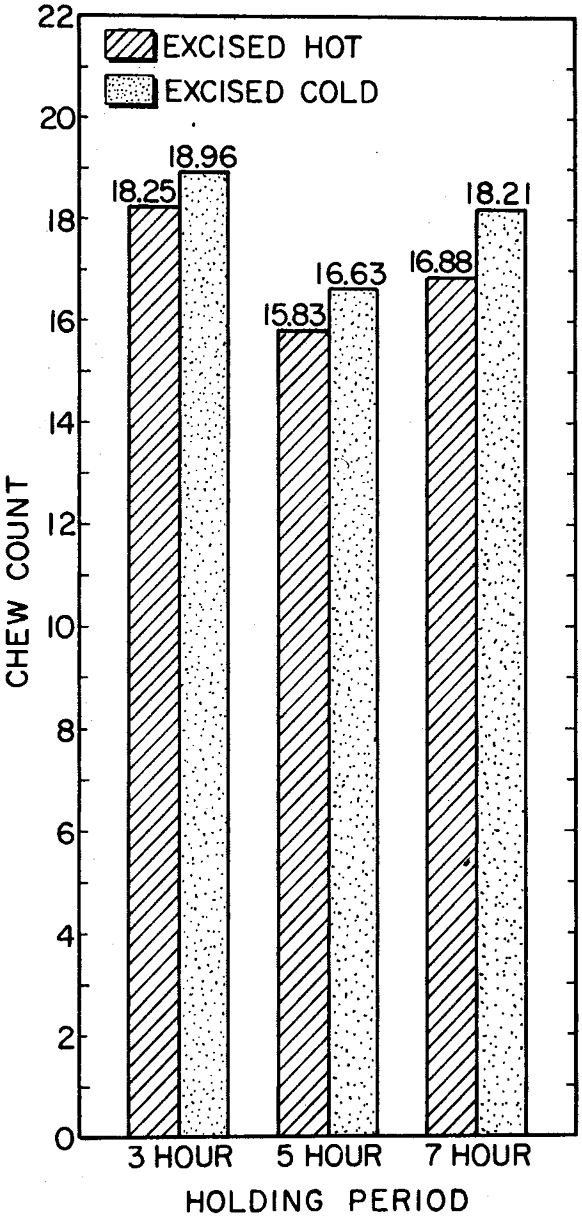

Figure 21. Effect of Chilling Method and Holding Period on Chew Count

However, in the seven hour holding period, the difference scale rating was significantly higher for the muscles excised cold ($P < 0.05$) (Table XLIV). The average difference scale rating for the muscles excised hot in the seven hour holding period was 4.29, while the average rating for the muscles excised cold was 5.00. There was no significant difference between the two treatments in the seven hour holding period for chew count.

The difference scale rating was slightly higher for the muscles excised hot in the three hour holding period, and was virtually identical for the two treatments in the five hour holding period. The chew count was lower for the muscles excised hot in the three, five, and seven hour holding periods, corresponding well with what was reported earlier for the shear force values obtained with the Warner-Bratzler shear instrument. The Warner-Bratzler Shear Instrument did not, however, compare favorably with the difference scale ratings of the three and five hour holding periods. In the seven hour holding period, the muscles excised cold were rated by the panel as being significantly less tender than the muscles excised hot ($P < 0.05$), and the shear force values obtained with the Warner-Bratzler Shear Instrument showed the muscles excised hot to have required significantly less shear force than the muscles excised cold ($P < 0.05$) (Table III and Figure 17).

The data reported earlier for the $71^{\circ}C$ and the $4^{\circ}C$ Nip Tenderometer readings correspond well with the difference scale ratings in the three and five hour holding periods in terms of general trends of the means. The chew count data is comparable with the $71^{\circ}C$ and $4^{\circ}C$ Nip Tenderometer means for the five and seven hour holding periods.

The raw fiber shear force values obtained with the microsensitive shear instrument correspond favorably with the difference scale ratings in the three and five hour holding periods, but differ significantly in the seven hour holding period where raw fiber shear force was shown to be greater for the muscles excised hot (Table I and Figure 13), while the muscles excised cold were rated by the panel as being significantly less tender than the muscles excised hot ($P < 0.05$). The cooked fiber shear force values correspond well to the difference scale ratings in the three, five, and seven hour holding periods (Table I and Figure 14). Neither the raw or cooked fiber shear force values correspond well to the general trend of means reported for chew count.

Raw fiber shear stress showed a positive relationship to the difference scale means in the five and seven hour holding periods, but the relationship was reversed in the three hour holding period. The average raw fiber shear stress values did not compare favorably to the chew count means in the three or five hour holding periods, but did show the same general trend in the seven hour holding period (Table I and Figure 15). The values for cooked fiber shear stress correspond poorly with the difference scale means in the three and seven hour holding periods (Table II and Figure 16), but both showed the hot and cold treatment means to be virtually equal in the five hour holding period. In addition, the fiber shear stress value and the chew count value for the three hour holding period both showed the muscles excised cold to be slightly less tender than the muscles excised hot, however, fiber shear stress and chew count were not positively related in the five and seven hour holding periods.

These relationships between the various physical measurements of meat tenderness and the organoleptic evaluation of tenderness will be expanded subsequently in the discussion of partial correlation coefficients between the parameters investigated in this study.

Partial Correlation Coefficients for Raw and Cooked Fiber Measurements and Objective and Subjective Tenderness Measurements

Three Hour Holding Period

There was no significant correlation observed between raw or cooked fiber shear force and any of the objective and subjective measurements of meat tenderness in the three hour holding period (Tables V and VI). A partial correlation coefficient of -0.82 was significant ($P < 0.05$) between raw fiber shear stress and chew count, and a partial correlation coefficient of -0.95 was also significant ($P < 0.01$) between cooked fiber shear stress and chew count. However, these relationships are opposite of what might be expected. The reason for these negative associations must be related back to the calculation formula for shear stress. As fiber diameter increases, shear stress decreases; partial correlation coefficients of -0.73 and -0.99 were observed between raw fiber diameter and raw fiber shear stress and cooked fiber diameter and cooked fiber shear stress, respectively, in the three hour holding period. In addition, there has been a generally positive relationship between fiber diameter and chew count observed in this study (Tables V-X), and therefore as chew count increases, possibly related to an increase in fiber diamter, fiber shear stress decreases due to the influence of fiber diameter in the calculation formula. The net result of these relationships is the negative association between chew count and

TABLE V

PARTIAL CORRELATION COEFFICIENTS FOR RAW FIBER MEASUREMENTS AND OBJECTIVE AND SUBJECTIVE TENDERNESS MEASUREMENTS FOR THE THREE HOUR HOLDING PERIOD

	RD	RSF	RSS	WB	HN	CN	DSR	CC
RAW FIBER DIAMETER (RD)	1.00							
RAW FIBER SHEAR FORCE (RSF)	0.22	1.00						
RAW FIBER SHEAR STRESS (RSS)	-0.73	0.48	1.00					
WARNER-BRATZLER SHEAR FORCE (WB)	0.10	0.62	0.30	1.00				
71°C NIP TENDEROMETER VALUE (HN)	0.39	0.20	-0.30	0.01	1.00			
4°C NIP TENDEROMETER VALUE (CN)	0.50	-0.43	-0.77	0.70	0.55	1.00		
DIFFERENCE SCALE RATING (DSR)	0.15	0.71	-0.70	0.71	0.33	0.86*	1.00	
CHEW COUNT (CC)	0.54	-0.48	-0.82*	0.16	0.56	0.67	0.56	1.00

*($P < 0.05$).

**($P < 0.01$).

TABLE VI

PARTIAL CORRELATION COEFFICIENTS FOR COOKED FIBER MEASUREMENTS AND OBJECTIVE AND SUBJECTIVE TENDERNESS MEASUREMENTS FOR THE THREE HOUR HOLDING PERIOD

	CD	CSF	CSS	WB	HN	CN	DSR	CC
COOKED FIBER DIAMETER (CD)	1.00							
COOKED FIBER SHEAR FORCE (CSF)	0.79	1.00						
COOKED FIBER SHEAR STRESS (CSS)	-0.99**	-0.72	1.00					
WARNER-BRATZLER SHEAR FORCE (WB)	-0.16	-0.21	0.12	1.00				
71°C NIP TENDEROMETER VALUE (HN)	0.59	0.47	-0.56	0.01	1.00			
4°C NIP TENDEROMETER VALUE (CN)	0.70	0.69	-0.62	0.70	0.55	1.00		
DIFFERENCE SCALE RATING (DSR)	0.44	0.28	-0.36	0.71	0.33	0.86*	1.00	
CHEW COUNT (CC)	0.95**	0.57	-0.95**	0.16	0.56	0.67	0.56	1.00

*($P < 0.05$).

**($P < 0.01$).

TABLE VII

PARTIAL CORRELATION COEFFICIENTS FOR RAW FIBER MEASUREMENTS AND OBJECTIVE AND SUBJECTIVE TENDERNESS MEASUREMENTS FOR THE FIVE HOUR HOLDING PERIOD

	RD	RSF	RSS	WB	HN	CN	DSR	CC
RAW FIBER DIAMETER (RD)	1.00							
RAW FIBER SHEAR FORCE (RSF)	-0.13	1.00						
RAW FIBER SHEAR STRESS (RSS)	-0.72	0.75	1.00					
WARNER-BRATZLER SHEAR FORCE (WB)	-0.09	-0.01	-0.17	1.00				
71°C NIP TENDEROMETER VALUE (HN)	0.15	-0.75	-0.73	0.54	1.00			
4°C NIP TENDEROMETER VALUE (CN)	0.38	-0.37	-0.61	0.68	0.53	1.00		
DIFFERENCE SCALE RATING (DSR)	-0.34	0.06	0.23	0.08	-0.19	-0.24	1.00	
CHEW COUNT (CC)	-0.60	0.22	0.35	0.81*	0.24	0.20	0.36	1.00

*($P < 0.05$).

**($P < 0.01$).

TABLE VIII

PARTIAL CORRELATION COEFFICIENTS FOR COOKED FIBER MEASUREMENTS AND OBJECTIVE AND SUBJECTIVE TENDERNESS MEASUREMENTS FOR THE FIVE HOUR HOLDING PERIOD

	CD	CSF	CSS	WB	HN	CN	DSR	CC
COOKED FIBER DIAMETER (CD)	1.00							
COOKED FIBER SHEAR FORCE (CSF)	0.28	1.00						
COOKED FIBER SHEAR STRESS (CSS)	-0.46	0.69	1.00					
WARNER-BRATZLER SHEAR FORCE (WB)	0.52	0.12	-0.13	1.00				
71°C NIP TENDEROMETER VALUE (HN)	0.46	-0.14	-0.51	0.54	1.00			
4°C NIP TENDEROMETER VALUE (CN)	0.18	0.22	0.06	0.68	0.53	1.00		
DIFFERENCE SCALE RATING (DSR)	0.77	0.50	-0.09	0.08	-0.19	-0.24	1.00	
CHEW COUNT (CC)	0.55	0.31	0.07	0.82*	0.24	0.20	0.36	1.00

*($P < 0.05$).

**($P < 0.01$).

TABLE IX

PARTIAL CORRELATION COEFFICIENTS FOR RAW FIBER MEASUREMENTS AND OBJECTIVE AND SUBJECTIVE TENDERNESS MEASUREMENTS FOR THE SEVEN HOUR HOLDING PERIOD

	RD	RSF	RSS	WB	HN	CN	DSR	CC
RAW FIBER DIAMETER (RD)	1.00							
RAW FIBER SHEAR FORCE (RSF)	0.20	1.00						
RAW FIBER SHEAR STRESS (RSS)	-0.75	-0.16	1.00					
WARNER-BRATZLER SHEAR FORCE (WB)	-0.08	-0.16	0.16	1.00				
71°C NIP TENDEROMETER VALUE (HN)	0.74	0.23	-0.24	0.30	1.00			
4°C NIP TENDEROMETER VALUE (CN)	0.53	-0.35	-0.68	0.34	0.20	1.00		
DIFFERENCE SCALE RATING (DSR)	0.06	0.72	-0.41	0.62	-0.30	0.05	1.00	
CHEW COUNT (CC)	-0.29	0.76	-0.04	0.42	-0.41	-0.29	0.90*	1.00

*($P < 0.05$).

**($P < 0.01$).

TABLE X

PARTIAL CORRELATION COEFFICIENTS FOR COOKED FIBER MEASUREMENTS AND OBJECTIVE AND SUBJECTIVE TENDERNESS MEASUREMENTS FOR THE SEVEN HOUR HOLDING PERIOD

	CD	CSF	CSS	WB	HN	CN	DSR	CC
COOKED FIBER DIAMETER (CD)	1.00							
COOKED FIBER SHEAR FORCE (CSF)	0.83*	1.00						
COOKED FIBER SHEAR STRESS (CSS)	-0.47	0.05	1.00					
WARNER-BRATZLER SHEAR FORCE (WB)	0.52	0.76	-0.05	1.00				
71°C NIP TENDEROMETER VALUE (HN)	0.43	0.58	0.28	0.30	1.00			
4°C NIP TENDEROMETER (CN)	-0.08	-0.44	-0.49	0.34	0.20	1.00		
DIFFERENCE SCALE RATING (DSR)	0.02	-0.34	-0.26	0.62	-0.30	0.05	1.00	
CHEW COUNT (CC)	0.21	-0.08	-0.26	0.42	-0.41	-0.29	0.09*	1.00

*($P < 0.05$).

**($P < 0.01$).

shear stress.

In addition to the significant relationships between shear stress and chew count and fiber diameter with shear stress and chew count discussed above, only one other significant association ($P < 0.05$) was observed. This was a partial correlation coefficient of +0.86 between the 71°C Nip Tenderometer values and the difference scale rating in the three hour holding period. This value compares favorably with a correlation of -0.80 reported by Smith and Carpenter (1973) between a 75°C Nip Tenderometer reading and panel tenderness ratings based on a 9 point scale (9 = extremely tender; 1 = extremely tough). No other relationships in the three hour holding period were significant, although a strong positive correlation was observed between raw fiber shear force and Warner-Bratzler shear force ($r = +0.62$) and raw fiber shear force and difference scale rating ($r = +0.71$). In addition, cooked fiber shear force was rather strongly correlated with 71° and 40°C Nip Tenderometer values ($r = +0.47$, and $r = +0.69$, respectively). A partial correlation coefficient of +0.57, although nonsignificant was also reported between cooked fiber shear force and chew count.

Five Hour Holding Period

There were no significant partial correlation coefficients observed between any of the raw or cooked fiber measurements and any of the objective or subjective measurements of meat tenderness (Tables VII and VIII). However, a positive partial correlation coefficient of 0.50 was observed between cooked fiber shear force and difference scale tenderness rating. The Nip Tenderometer readings (71°C and 4°C), the Warner-Bratzler Shear Instrument, and the chew count showed the muscles processed cold to be less tender than the muscles processed hot, while the raw and cooked fiber measurements of shear force and shear stress, and the difference scale ratings showed the two treatments to be approximately equal in terms of tenderness.

The only significant partial correlation coefficient ($P < 0.05$) observed in the five hour holding period was between Warner-Bratzler shear force and chew count, where a positive association of 0.81 was reported (Table VII). This partial correlation coefficient compares well with values reported by Pearson (1963) in a review of the relationship between Warner-Bratzler shear force values and various sensory methods. Pearson reported values ranging from -0.60 to -0.85 with an average of about -0.75 based on ratings where tenderness increases with increasing numbers on the scale. Since tenderness decreases with increasing numbers in a chew count study, the positive relationship reported in this study corresponds with the negative relationships reported by Pearson.

Seven Hour Holding Period

Again, none of the raw or cooked measures of fiber shear force or fiber shear stress were significantly related to any of the objective or subjective measures of meat tenderness in the seven hour holding period (Tables IX and X). Strong relationships were, however, indicated between raw fiber shear force and difference scale tenderness rating ($r = +0.72$), and raw fiber shear force and chew count ($r = +0.76$). In addition, cooked fiber shear force was strongly, but nonsignificantly related to Warner-Bratzler shear force ($r = +0.76$), and 71°C Nip Tenderometer value ($r = +0.58$). The only significant relationship ($P < 0.05$) involving a fiber measurement was the positive association ($r = +0.83$)

between cooked fiber diameter and cooked fiber shear force (Table X). The only other significant association ($P < 0.05$) was observed between the difference scale rating and the chew count value ($r = +0.90$) (Table IX).

CHAPTER V

SUMMARY AND CONCLUSIONS

Eighteen Angus steers were randomly assigned to one of three post-mortem holding periods (three, five, and seven hours). The tensor fascia latae muscle from one side of each carcass was excised hot, after having been suspended, at 16°C, for one of the three post-mortem holding periods. Tensor fascia latae muscles from the opposite sides were excised cold, after having chilled, at 1.1°C, for forty-eight hours. Each muscle was evaluated for raw and cooked fiber diameter, shear force, and shear stress, 71°C and 4°C Nip Tenderometer values, Warner-Bratzler shear force, difference scale rating, and chew count. In addition, partial correlation coefficients were determined between each of the fiber measurements and the objective and subjective measurements of meat tenderness.

In the three hour holding period, raw fiber diameter for the muscles excised hot was significantly greater than for the muscles excised cold ($P < 0.01$). In addition, diameter for the cooked fibers was also greater for the muscles excised hot ($P < 0.05$). There was no significant difference in raw fiber shear force between the two treatments, but the muscles excised hot required significantly more cooked fiber shear force than the muscles excised cold ($P < 0.05$). Raw fiber shear stress was significantly greater for the cold treatment in the three hour holding period ($P < 0.05$), but the difference in cooked fiber shear stress was nonsignificant.

Neither the 71°C and 4°C Nip Tenderometer values or the Warner-Bratzler shear values were significantly different for each of the two treatments in the three hour holding period. In addition, no significant difference was observed between the muscles excised hot and cold in either difference scale rating or chew count.

The only significant partial correlation coefficients observed in the three hour holding period were positive associations between 4°C Nip Tenderometer value and difference scale rating ($P < 0.05$), and cooked fiber diameter and chew count ($P < 0.01$), and negative associations between raw fiber shear stress and chew count ($P < 0.05$), cooked fiber diameter and cooked fiber shear stress ($P < 0.01$), and cooked fiber shear stress and chew count ($P < 0.01$).

In the five hour holding period, there were no significant differences observed between the two treatments in raw or cooked fiber diameter, shear force or shear stress. However, the 71°C and 4°C Nip Tenderometer values, and the Warner-Bratzler shear values were significantly greater for the muscles excised cold ($P < 0.05$) and ($P < 0.01$), respectively. There were no significant differences observed between the hot and cold treatments in difference scale rating or chew count.

The only significant partial correlation coefficient observed in the five hour holding period was between Warner-Bratzler shear values and chew count ($P < 0.05$). None of the fiber measurements were significantly correlated to any of the objective or subjective measurements of meat tenderness.

In the seven hour holding period, no significant differences were observed between the hot and cold treatments in raw or cooked fiber diameter, shear force or shear stress. In addition, the differences in 71°C and 4°C Nip Tenderometer values were nonsignificant between the muscles excised hot and cold. Warner-Bratzler shear values were, however, significantly greater for the muscles excised cold ($P < 0.05$). The difference scale rating for the muscles excised cold was also significantly greater ($P < 0.05$), but the difference in chew count was nonsignificant.

Cooked fiber shear force was positively associated ($P < 0.05$) with cooked fiber diameter in the seven hour holding period, but again, no significant correlations were observed between any of the fiber measurements and the objective and subjective measures of tenderness. The only other significant partial correlation coefficient observed in the seven hour holding period was a positive relationship between difference scale rating and chew count ($P < 0.05$).

It is clear, both from a comparison of the means, and the partial correlation coefficients that the fiber measurements investigated, did not measure meat tenderness as it was assessed by the various objective and subjective methods utilized in this study. However, it should be pointed out that none of the tenderness measures seemed to be closely related in all three holding periods. The experimental numbers in this study were relatively small, and perhaps an experiment with greater numbers would produce different results. However, it is felt that some progress was made in the evaluation of the microsensitive shear instrument, and that some suggestions can be made regarding possible future experiments. First, there is no useful purpose in calculating shear stress from the torque required to shear an individual fiber since the dominant role of fiber diameter in the calculation formula masks any real relationship between shear stress, or force per unit area, and the measurement of tenderness. Secondly, although the precision of the instrument seems to have improved over previous studies utilizing formalin fixed muscle fibers, instrument modifications should be made in order to increase the precision of the instrument, and to increase the ease of operation. In addition, the author would suggest that future studies be limited to cooked muscle fibers, primarily because of the decrease in fiber distortion associated with the separation of individual fibers from the fasciculi.

In conclusion, the microsensitive shear instrument failed to consistently relate fiber shear force or shear stress measurements to meat tenderness as measured by various objective and subjective means. This may have been a result of the small number of experimental units available in this study, and yet the feasability of measuring fiber shear force with this particular instrument, and relating this measurement to meat tenderness must be questioned at this point in time.

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APPENDIX

TABLE XI

ANALYSIS OF VARIANCE OF RAW FIBER DIAMETER DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	43,131.11	59.99
Main Unit Analysis	11	1,461.11	
Animal	5	119.44	23.89
Treatment	1	1,075.56	1,075.56
Animal x Treatment	5	266.11	53.22
Subunit Analysis	708	41.67	
Steak	1	13.89	13.89
Treatment x Steak	1	45.00	45.00
Animal x Steak + Animal x Treatment x Steak	10	117.78	11.78
Fiber (Animal Treatment Steak)	696	41,493.33	59.62

TABLE XII

ANALYSIS OF VARIANCE OF COOKED FIBER DIAMETER DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
<u>Total Corrected</u>	719	53,917.17	74.99
<u>Main Unit Analysis</u>	11	2514.51	
Animal	5	631.84	126.37
Treatment	1	1,127.50	1,127.50
Animal x Treatment	5	755.17	151.04
<u>Subunit Analysis</u>	708	51,402.65	
Steak	1	2.34	2.34
Treatment x Steak	1	270.11	270.11
Animal x Steak + Animal x Treatment x Steak	10	554.57	55.46
Fiber (Animal Treatment Steak)	696	50,575.63	72.67

TABLE XIII

ANALYSIS OF VARIANCE OF RAW FIBER SHEAR FORCE DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	3,523,100.17	4,900.00
Main Unit Analysis	11	142,824.18	
Animal	5	91,259.78	18,251.96
Treatment	1	20,734.42	20,734.42
Animal x Treatment	5	30,829.98	6,106.00
Subunit Analysis	708		
Steak	1	3,986.60	3,986.60
Treatment x Steak	1	2,274.85	2,274.85
Animal x Steak + Animal x Treatment x Steak	10	26,263.58	2,626.36
Fiber (Animal Treatment Steak)	696	3,347,752.95	4,809.97

TABLE XIV

ANALYSIS OF VARIANCE OF COOKED FIBER SHEAR FORCE DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	5,491,421.25	7,637.58
Main Unit Analysis	11	626,460.27	
Animal	5	561,789.28	112,357.86
Treatment	1	54,619.04	54,619.04
Animal x Treatment	5	10,051.95	2,010.39
Subunit Analysis	708	4,864,960.98	
Steak	1	1,271.49	1.271.49
Treatment x Steak	1	15,434.34	15,434.34
Animal x Steak + Animal x Treatment x Steak	10	106,346.91	10,634.69
Fiber (Animal Treatment Steak)	696	4,741,098.24	6,813.09

TABLE XV

ANALYSIS OF VARIANCE OF RAW FIBER SHEAR STRESS DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	213.89	0.30
Main Unit Analysis	11	10.28	
Animal	5	1.42	0.29
Treatment	1	5.49	5.49
Animal x Treatment	5	3.37	0.67
Subunit Analysis	708	203.61	
Steak	1	0.01	0.01
Treatment x Steak	1	1.15	1.15
Animal x Steak + Animal x Treatment x Steak	10	1.98	0.20
Fiber (Animal Treatment Steak)	696	200.47	0.29

TABLE XVI

ANALYSIS OF VARIANCE OF COOKED FIBER SHEAR STRESS DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	203.53	0.28
Main Unit Analysis	11	24.17	
Animal	5	18.47	3.69
Treatment	1	2.23	2.23
Animal x Treatment	5	3.47	0.69
Subunit Analysis	708	185.57	
Steak	1	0.13	0.13
Treatment x Steak	1	0.47	0.47
Animal x Steak + Animal x Treatment x Steak	10	6.21	0.62
Fiber (Animal Treatment Steak)		172.55	172.55

TABLE XVII

ANALYSIS OF VARIANCE OF RAW FIBER DIAMETER DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	42,319.00	58.86
Main Unit Analysis	11	1,365.35	
Animal	5	1,192.51	238.50
Treatment	1	35.11	35.11
Animal x Treatment	5	137.73	27.55
Subunit Analysis	708	40,953.65	
Steak	1	246.17	246.17
Treatment x Steak	1	0.61	0.61
Animal x Steak + Animal x Treatment x Steak	10	617.24	61.72
Fiber (Animal Treatment Steak)	696	40,089.63	57.60

TABLE XVIII

ANALYSIS OF VARIANCE OF COOKED FIBER DIAMETER DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	48,791.20	67.86
Main Unit Analysis	11	1,584.13	
Animal	5	1,191.67	238.33
Treatment	1	15.02	15.02
Animal x Treatment	5	377.44	75.49
Subunit Analysis	708	47,207.01	
Steak	1	0.80	0.80
Treatment x Steak	1	43.02	43.02
Animal x Steak + Animal x Treatment x Steak	10	281.11	28.11
Fiber (Animal Treatment Steak)	696	48,882.13	67.36

TABLE XIX

ANALYSIS OF VARIANCE OF RAW FIBER SHEAR FORCE DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	3,854,353.25	
Main Unit Analysis	11	421,339.09	
Animal	5	412,282.11	82,456.47
Treatment	1	1,508.36	1,508.36
Animal x Treatment	5	7,548.62	1,509.72
Subunit Analysis	708	3,432,974.16	
Steak	1	56.17	56.17
Treatment x Steak	1	4,861.72	4,861.72
Animal x Steak + Animal x Treatment x Steak	10	51,347.85	5,134.79
Fiber (Animal Treatment Steak)	696	3,376,748.41	4,851.65

TABLE XX

ANALYSIS OF VARIANCE OF COOKED SHEAR FORCE DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	5,465,605.66	7,601.69
Main Unit Analysis	11	570,854.51	
Animal	5	528,739.48	105,787.90
Treatment	1	8,377.67	8,377.67
Animal x Treatment	5	33,537.36	6,707.47
Subunit Analysis	708	4,874,761.15	
Steak	1	7,253.97	7,253.97
Treatment x Steak	1	427.17	427.17
Animal x Steak + Animal x Treatment x Steak	10	97,892.12	9,789.21
Fiber (Animal Treatment Steak)	696	4,789,187.89	6,881.09

TABLE XXI

ANALYSIS OF VARIANCE OF RAW FIBER SHEAR STRESS DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	350.15	0.47
Main Unit Analysis	11	5.90	
Animal	5	3.85	0.77
Treatment	1	0.00	0.00
Animal x Treatment	5	0.05	0.41
Subunit Analysis	708	334.24	
Steak	1	3.77	3.77
Treatment x Steak	1	0.47	0.47
Animal x Steak + Animal x Treatment x Steak	10	7.21	0.72
Fiber (Animal Treatment Steak)	696	332.80	0.48

TABLE XXII

ANALYSIS OF VARIANCE OF COOKED FIBER SHEAR STRESS DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	248.62	0.35
Main Unit Analysis	11	9.41	
Animal	5	5.38	1.08
Treatment	1	0.13	0.13
Animal x Treatment	5	3.90	0.78
Subunit Analysis	708	239.21	
Steak	1	0.42	0.42
Treatment x Steak	1	0.08	0.08
Animal x Steak + Animal x Treatment x Steak	10	6.67	0.67
Fiber (Animal Treatment Steak)	696	230.04	0.33

TABLE XXIII

ANALYSIS OF VARIANCE OF RAW FIBER DIAMETER DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	43,343.17	60.28
Main Unit Analysis	11	844.86	
Animal	5	357.36	70.47
Treatment	1	170.14	170.14
Animal x Treatment	5	322.36	64.47
Subunit Analysis	708	42,498.34	
Steak	1	11.25	11.25
Treatment x Steak	1	170.14	170.14
Animal x Steak + Animal x Treatment x Steak	10	620.28	62.03
Fiber (Animal Treatment Steak)	696	41,696.67	59.91

TABLE XXIV

ANALYSIS OF VARIANCE OF COOKED FIBER DIAMETER DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
<u>Total Corrected</u>	719	52,407.86	72.87
<u>Main Unit Analysis</u>	11	2,168.19	
Animal	5	1,772.36	354.47
Treatment	1	50.14	50.14
Animal x Treatment	5	345.69	69.14
<u>Subunit Analysis</u>	708	50,241.67	
Steak	1	211.25	211.25
Treatment x Steak	1	86.81	86.81
Animal x Steak + Animal x Treatment x Steak	10	1,373.61	137.36
Fiber (Animal Treatment Steak)	696	48,570.00	69.78

TABLE XXV

ANALYSIS OF VARIANCE OF RAW FIBER SHEAR FORCE DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	2,706,638.78	3,764.45
Main Unit Analysis	11	49,262.74	
Animal	5	30,964.31	6,192.86
Treatment	1	6,834.65	6,834.65
Animal x Treatment	5	11,463.78	2,292.76
Subunit Analysis	708	2,657,376.04	
Steak	1	3,595.18	3,595.18
Treatment x Steak	1	767.77	767.79
Animal x Steak + Animal x Treatment x Steak	10	29,055.91	2,905.59
Fiber (Animal Treatment Steak)	696	2,623,957.17	3,770.05

TABLE XXVI

ANALYSIS OF VARIANCE OF COOKED FIBER SHEAR FORCE DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
<u>Total Corrected</u>	719	4,584,688.67	6,376.48
<u>Main Unit Analysis</u>	11	329,360.90	
Animal	5	272,627.18	54,525.44
Treatment	1	27,942.74	27,942.74
Animal x Treatment	5	28,790.98	5,758.26
<u>Subunit Analysis</u>	708	4,255,327.78	
Steak	1	3,760.46	3,760.46
Treatment x Steak	1	1,862.18	1,862.18
Animal x Steak + Animal x Treatment x Steak	10	81,217.66	8,121.77
Fiber (Animal Treatment Steak)	696	4,168,487.48	5,987.21

TABLE XXVII

ANALYSIS OF VARIANCE OF RAW FIBER SHEAR STRESS DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	1,551.28	2.16
Main Unit Analysis	11	38.34	
Animal	5	20.00	4.04
Treatment	1	3.53	3.53
Animal x Treatment	5	14.61	2.92
Subunit Analysis	708	1,512.95	
Steak	1	4.43	4.43
Treatment x Steak	1	6.10	6.10
Animal x Steak + Animal x Treatment x Steak	10	19.44	1.94
Fiber (Animal Treatment Steak)	696	1,482.98	2.13

TABLE XXVIII

ANALYSIS OF VARIANCE OF COOKED FIBER SHEAR STRESS DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	719	266.34	0.37
Main Unit Analysis	11	6.63	
Animal	5	4.83	0.97
Treatment	1	0.14	0.14
Animal x Treatment	5	1.66	0.33
Subunit Analysis	708	259.72	
Steak	1	0.53	0.53
Treatment x Steak	1	0.13	0.13
Animal x Steak + Animal x Treatment x Steak	10	7.29	0.73
Fiber (Animal Treatment Steak)	696	251.77	0.36

TABLE XXIX

ANALYSIS OF VARIANCE OF 71°C NIP TENDEROMETER DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	119	811.30	6.82
Main Unit Analaysis	11	351.10	
Animal	5	236.90	47.38
Treatment	1	22.53	22.53
Animal x Treatment	5	91.67	18.33
Subunit Analysis	108	460.20	
Steak	1	1.20	1.20
Treatment x Steak	1	5.63	5.63
Animal x Steak Animal x Treatment x Steak	10	314.57	31.46
Residual	96	138.80	1.45

TABLE XXX

ANALYSIS OF VARIANCE OF 4°C NIP TENDEROMETER DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	119	510.67	4.29
Main Unit Analysis	11	220.47	
Animal	5	188.67	37.73
Treatment	1	3.33	3.33
Animal x Treatment	5	28.47	5.69
Subunit Analysis	108	290.20	
Steak	1	5.63	5.63
Treatment x Steak	1	28.03	28.03
Animal x Steak Animal x Treatment x Steak	10	38.93	3.89
Residual	96	217.60	2.27

TABLE XXXI

ANALYSIS OF VARIANCE OF 71^{o}C NIP TENDEROMETER DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	119	551.87	4.64
Main Unit Analysis	11	311.87	
Animal	5	275.37	55.07
Treatment	1	24.30	24.30
Animal x Treatment	5	12.20	2.44
Subunit Analysis	108	240.00	
Steak	1	5.63	5.63
Treatment x Steak	1	0.00	0.00
Animal x Steak Animal x Treatment x Steak	10	98.37	9.84
Residual	96	136.00	1.42

TABLE XXXII

ANALYSIS OF VARIANCE OF 4°C NIP TENDEROMETER DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	119	923.17	7.76
Main Unit Analysis	11	533.57	
Animal	5	405.87	81.17
Treatment	1	73.63	73.63
Animal x Treatment	5	54.07	10.81
Subunit Analysis	108	389.60	
Steak	1	2.13	2.13
Treatment x Steak	1	0.00	0.00
Animal x Steak Animal x Treatment x Steak	10	123.87	12.39
Residual	96	263.60	2.75

TABLE XXXIII

ANALYSIS OF VARIANCE OF 71°C NIP TENDEROMETER DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	119	407.47	3.42
Main Unit Analysis	11	155.57	
Animal	5	137.57	27.51
Treatment	1	4.03	4.03
Animal x Treatment	5	14.27	2.85
Subunit Analysis	108	251.60	
Steak	1	4.03	4.03
Treatment x Steak	1	3.33	3.33
Animal x Steak Animal x Treatment x Steak	10	102.23	10.22
Residual	96	142.00	1.48

TABLE XXXIV

ANALYSIS OF VARIANCE OF 4°C NIP TENDEROMETER DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	119	618.93	5.20
Main Unit Analysis	11	270.03	
Animal	5	182.48	36.50
Treatment	1	49.41	49.41
Animal x Treatment	5	38.14	7.63
Subunit Analysis	108	348.91	
Steak	1	0.01	0.01
Treatment x Steak	1	1.88	1.88
Animal x Steak Animal x Treatment x Steak	10	107.02	10.70
Residual	96	240.00	2.50

TABLE XXXV

ANALYSIS OF VARIANCE OF WARNER-BRATZLER SHEAR DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	215	791.75	3.68
Main Unit Analysis	11	228.23	
Animal	5	57.30	11.46
Treatment	1	58.39	58.39
Animal x Treatment	5	112.54	22.51
Subunit Analysis	204	563.52	
Steak	1	6.10	6.10
Treatment x Steak	1	0.32	0.32
Animal x Steak Animal x Treatment x Steak	10	48.56	4.86
Residual	192	508.55	2.65

TABLE XXXVI

ANALYSIS OF VARIANCE OF WARNER-BRATZLER SHEAR DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	215	794.47	3.70
Main Unit Analysis	11	354.25	
Animal	5	106.21	21.24
Treatment	1	222.85	222.85
Animal x Treatment	5	25.19	5.04
Subunit Analysis	204	440.22	
Steak	1	22.43	22.43
Treatment x Steak	1	6.83	6.83
Animal x Steak Animal x Treatment x Steak	10	104.60	10.46
Residual	192	306.36	1.60

TABLE XXXVII

ANALYSIS OF VARIANCE OF WARNER-BRATZLER SHEAR DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	215	471.25	2.19
Main Unit Analysis	11	74.99	
Animal	5	45.15	9.03
Treatment	1	20.66	20.66
Animal x Treatment	5	9.18	1.84
Subunit Analysis	204	396.27	
Steak	1	28.75	28.75
Treatment x Steak	1	3.84	3.84
Animal x Steak Animal x Treatment x Steak	10	61.11	6.11
Residual	192	302.56	1.58

TABLE XXXVIII

ANALYSIS OF VARIANCE OF DIFFERENCE SCALE RATING DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	47	102.67	2.18
Animal	5	49.67	9.93
Treatment	1	0.08	0.08
Animal x Treatment	5	6.92	1.38
Residual	36	46.00	1.27

TABLE XXXIX

ANALYSIS OF VARIANCE OF CHEW COUNT DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	47	1,721.48	36.63
Animal	5	404.85	80.97
Treatment	1	6.02	6.02
Animal x Treatment	5	109.85	21.97
Residual	36	1,200.75	33.35

TABLE XL

ANALYSIS OF VARIANCE OF DIFFERENCE SCALE RATING DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	47	111.25	2.37
Animal	5	46.75	9.35
Treatment	1	0.00	0.00
Animal x Treatment	5	2.00	0.40
Residual	36	62.50	1.74

TABLE XLI

ANALYSIS OF VARIANCE OF CHEW COUNT DATA AT THE FIVE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	47	448.48	10.39
Animal	5	127.85	25.57
Treatment	1	7.52	7.52
Animal x Treatment	5	19.35	3.87
Residual	36	333.75	9.27

TABLE XLII

ANALYSIS OF VARIANCE OF DIFFERENCE SCALE RATING DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	47	72.98	1.55
Animal	5	3.35	0.67
Treatment	1	6.02	6.02
Animal x Treatment	5	4.35	0.87
Residual	36	59.25	1.65

TABLE XLIII

ANALYSIS OF VARIANCE OF CHEW COUNT DATA AT THE SEVEN HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" EXCISED TENSOR FASCIA LATAE

Source	DF	Sum of Squares	Mean Square
Total Corrected	47	923.92	19.66
Animal	5	75.67	15.13
Treatment	1	21.33	21.33
Animal x Treatment	5	26.42	5.28
Residual	36	800.50	22.24

VITA

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Doctor of Philosophy

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