FEASIBILITY OF "HOT" PROCESSING

THE BOVINE CARCASS

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1970

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1972

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
July, 1974

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ACKNOWLEDGEMENTS

The author expresses sincere appreciation to Dr. R. L. Henrickson, Professor, for his invaluable guidance, assistance, and professional example during the entire period of graduate study.

Appreciation is also extended to Dr. R. D. Morrison, Professor of Mathematics and Statistics, for his assistance with the analyses and interpretation of the data.

The author is also indebted to Dr. C. G. Beames, Jr., Professor of Veterinary Physiology, Dr. R. R. Frahm, Associate Professor of Animal Science, Dr. J. J. Guenther, Professor of Animal Science, and Dr. G. V. Odell, Professor of Biochemistry for their advice and assistance during the entire course of study and in the preparation of this manuscript.

Grateful appreciation is also extended to Mr. L. Kimbrell, Mr. R. W. Givens, Mr. B. Mullinix, and fellow graduate students, Mr. J. L. Marsden and Mr. P. A. Will for their technical assistance and cooperation.

The author is grateful to his parents for their thoughtfulness and assistance throughout his college study.

An expression of sincere gratitude goes to his wife, Elizabeth, for her ever present encouragement, faith, and love.

Acknowledgement is made of the Statistical Analysis System (SAS), the development of which was partially supported by the Oklahoma Agricultural Experiment Station through regional project S-94.

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CHAPTER I

INTRODUCTION

Since 1939, ample evidence has been compiled to illustrate that muscle, excised before the onset phase of rigor mortis, will shorten considerably. More importantly, the extent to which muscle shortens has a dramatic influence upon the ultimate quality of the final product. In order to overcome this shortening effect, various attempts were made to control environmental conditions, as well as, the method of application and amount of tension exerted upon muscle undergoing rigor. Kastner (1972) proposed to alleviate the shortening effect by allowing muscles to remain on the carcass for two, five, or eight hours post-mortem prior to excision. Results of the earlier study indicated that "hot" boning (removal of muscles before chilling) was feasible as early as five hours post-mortem without a large decrease in quality. However, muscles excised at two hours post-mortem did exhibit a significant quality diminution.

This study was proposed to evaluate the feasibility of "hot" boning the beef carcass and to determine the minimum conditioning time before "hot" boning could be initiated. Three holding times were proposed: three, five, and seven hours post-mortem. Should the three hour holding period be unfeasible, the investigation would add further evidence to evaluate the desirability of utilizing a later conditioning period before excising the muscles.

"Hot" boning of the beef carcass results in the removal of bone and excess fat before chilling, thus, eliminating unnecessary cooling. Processors would benefit from increased efficiency resulting from the utilization of on-the-rail boning (Brasington and Hammons, 1971), shorter refrigeration time, and increased yield of boneless meat which would allow maximum utilization of refrigerative space. A boneless, closely trimmed product, as would be produced by "hot" boning, would lend itself well to portion control. Furthermore, the shelf life of the final product would be enhanced as a result of rapid entry into the chill cooler in combination with a more rapid rate of chilling as compared to refrigerating the whole carcass prior to fabrication.

The objective of this study was to evaluate the feasibility of "hot" boning beef carcasses with respect to tenderness, color, microbial population, product yield, and juiciness.

CHAPTER II

REVIEW OF THE LITERATURE

Kastner (1972) compiled an extensive review of the literature concerning the major aspects of meat quality, most notably tenderness, juiciness, flavor, and color. It shall be the purpose of this review to develop a detailed description of rigor mortis and its effect upon meat components. The latter portion of the review will focus upon research concerning "hot" processing porcine and bovine carcasses.

Bate-Smith (1939), an early investigator of the phenomenon of rigor mortis, reported that muscle in full rigor had a uniform pH of 5.8 throughout the tissue. Conversely, muscle from a freshly slaughtered animal was found to vary with respect to location in the carcass. Using rabbit psoas muscle, it was demonstrated that the change in modulus as the pH decreased from 7.4 to 6.3 was extremely small. As the pH continued to fall, the modulus changed very rapidly, usually beginning at pH 6.2. It was further noted that if the glycogen content of the muscle was altered by starvation, fatigue, or by the administration of insulin, the pH seldom reached a value of less than 6.3. Rigor was reported to be rapid at the outset, and even though little change in pH occurred, the amount of modulus produced by muscle shortening could have a high value in the glycogen depleted tissue. Thus it was demonstrated that rigor could take place without acidification.

Bate-Smith and Bendall (1947) observed that there was considerable

variation in the time after death at which rigor mortis began. In animals that were relatively passive before stunning, the delay before the onset of rigor was longer than in animals which struggled violently. Two factors emerged to explain the observed variation: 1) the actual production of lactate in the muscle as a result of struggling, 2) a subsequent and sustained increase in the rate of glycolysis. These sources of variation indicated that any factor which had an effect upon the metabolic rate of production of lactate immediately post-mortem affected the period of delay before the onset of rigor.

The aforementioned conditions were explained by Bate-Smith and Bendall (1947) on the basis of whether or not glycolysis occurred. When the glycolytic cycle was unable to operate, owing to the total absence of glycogen, the breakdown of polyphosphate by Myosin-Adenosine triphosphatase (ATPase), unaccompanied by any resynthesis, was rapid from the moment of death. The rate of breakdown of polyphosphate slowed when 50 percent of the labile phosphate had disappeared. It was reported that even after 24 hours, 25 percent of the original polyphosphate was still present in the muscle. On the other hand, when glycolysis was fully operating, there was a balance between breakdown and synthesis. Conditions at this stage still favored breakdown, which proceeded slowly for about four hours, but rapidly at the outset. After this lag period, the rate of breakdown increased five-fold at pH 6.5. It was during this period of breakdown, not during the lag period, that a significant change in modulus occurred. If the glycogen in the muscle was exhausted, so that the pH remained near 6.0, the breakdown of polyphosphate appeared to proceed rapidly to completion. But, if the pH fell further, the reaction slowed and appreciable amounts of polyphosphate remained after

24 hours. These findings led Bate-Smith and Bendall (1947) to conclude that the destruction of glycogen, leading to the production of lactate and a decrease in pH, was not directly responsible for the increase in modulus. However, the moment of increased tension, as well as its rate of increase, were clearly dependent upon the pH of the system and the prevailing rate of glycolysis. Realizing that these were also the factors on which the rate of destruction of Adenosine triphosphate (ATP) depends, the authors stated that it was the destruction of ATP and this alone with which the onset of rigor could be associated, whether or not accompanied by glycolysis.

Bate-Smith and Bendall (1949) defined two phases of rigor mortis: 1) a delay period in which the modulus of elasticity either does not change at all or increases slightly, 2) a rapid phase in which the modulus increases rapidly to its maximum which may be 10 to 40 times higher than the initial value. The delay period was described as a phase in which the system of breakdown by myosin and myokinase was in balance with the system of resynthesis of ATP via glycolysis. The duration of this period was determined solely by the maximum fall of the pH post-mortem. Therefore, as long as the "backpressure" of ATP resynthesis from the glycolytic cycle was sufficiently high, the muscle did not pass into rigor. Adenosine triphosphate was broken down in excess of its resynthesis as soon as the muscle was exhausted or seriously depleted of glycogen and there was sufficient production of lactate. At this point, muscle extensibility decreased, and the rapid phase of rigor onset began. The duration of the rapid phase was determined by the relative rate of resynthesis and breakdown of ATP. At pH values at which ATP turnover was slow, it was expected that breakdown would slowly over-

take the resynthesis, a considerable time being necessary for the ATP to fall from 85 to 20 percent of its initial value. With fast rates of turnover, breakdown of ATP overtook resynthesis.

Bate-Smith and Bendall (1949) further stated that an ultimate pH of 5.3 appeared to be a limiting value, beyond which, glycolysis was completely inhibited. Thus, as with Bate-Smith and Bendall (1947), this study confirmed that the turnover of ATP provided a satisfactory explanation of events leading to rigor mortis, and that the rapid disappearance of ATP from muscle coincided with the change in extensibility during the rapid phase of rigor.

In 1951, Bendall showed that creatine phosphate was the first chemical compound to be broken down during the course of rigor mortis in rested muscles at 37°C and 17°C. ATP appeared to start breaking down when 70 percent or more creatine phosphate had disappeared. As with earlier investigations, ATP was found to diminish relatively quickly, depending upon how vigorously glycolysis proceeded. It was also shown that the average rate of ATP turnover was approximately 26 times as rapid at 37°C than at 17°C when the pH of the muscle was 7.1. At 37°C active shortening of the muscle occurred after, but never before, the ATP had begun to fall below its resting level. The critical level of ATP at which shortening began depended upon the ultimate pH of the muscle, falling from 0.40 mg P_{7},/g at pH 7.2 to 0.28 mg P_{7},/g at pH 5.8. Shortening was complete when the ATP had fallen to 0.10 mg P_{7},/g. In comparison, the loss of extensibility at 17°C bore a similar relation to the ATP and creatine phosphate level of muscle at 37°C. The critical level of ATP fell more rapidly with ultimate pH. In conclusion, Bendall (1951) suggested that the fall in the ratio of the rate of resynthesis to the

rate of breakdown of ATP bore a closer relationship to the shortening and extensibility change than the fall in ATP level itself. Shortening in rigor was explained as a very low, irreversible contraction, and it was suggested that the disappearance of ATP from the muscle was a fundamental prerequisite for both shortening in rigor and for physiological contraction. Creatine phosphate was regarded as a means for resynthesizing ATP in both rigor mortis and contraction.

In similar studies, Marsh (1953) examined changes which occurred during the onset of rigor mortis at temperatures from 7°C to 37°C using muscle strips from the longissimus dorsi (LD). Marsh found that increased shortening was accompanied by a smaller decrease in extensibility. Further work by Marsh (1954), Marsh and Thompson (1958), Bendall (1960), Cook and Langsworth (1966a), and Cassens and Newbold (1967) gave evidence that the rate of pH fall depended upon the temperature and was not the same in all muscles. For example, Bendall (1960) illustrated with rabbit psoas muscle, the lower the temperature in the range of 0 - 37°C, the more slowly the pH fell. On the other hand, Cassens and Newbold (1967) and Newbold and Scopes (1967) found that the pH of ox sternomandibularis muscle will decrease more slowly as the temperature is lowered in the range of 5 - 37°C; however, the pH fell more rapidly at 1°C than at 5°C during the first few hours post-mortem.

The importance of post-mortem changes in skeletal muscle was realized as early as 1949 by Ramsbottom and Strandine, who noted that the shear reading of cooked bovine muscle excised for eight to 72 hours post-mortem was much higher than muscle in the pre- or post-rigor state. Muscle was described histologically during the first few hours following slaughter as having fibers which were straight or slightly wavy. Follow-

ing this pre-rigor period, "hard lumps" began to appear in the muscle, eventually involving the whole muscle. Again microscopic evaluation of the tissue in these hard lumps revealed that the muscle fibers had been thrown into many sharply defined waves which resembled a "washboard". Similar results were reported by Harrison et al. (1949). Hiner et al. (1953) accomplished further work with the histology of post-mortem muscle by showing that as the fiber diameter of a muscle increased, the tenderness decreased.

Locker (1959) further characterized post-mortem bovine muscle by noting that ox muscle in rigor mortis offered a selection of myofibrils which were fixed in varying degrees of contraction. In this characterization, four distinct, successive patterns of contraction were revealed. Locker (1960) reported that the final state of a muscle was probably determined by the strain which was imposed on it in the hanging carcass. In addition, muscles of the ox went into rigor in widely differing states of contraction as defined by the striation patterns of the myofibrils. In this study, relaxed muscles were found to be more tender than partially contracted muscles. To generalize, Locker (1960) concluded that there was a relationship between post-mortem shortening and tenderness. Huxley and Hanson (1960) discussed the contractile structure and sliding mechanism of striated muscle, including the overlapping filaments which contained primarily actin and myosin. In addition it was observed that as a muscle proceeds into rigor, it hardens or loses its extensibility, that is, it becomes inelastic. Hostetler and Cover (1961) showed that greater muscle fiber extensibility was closely related to higher shear force.

Further investigation by Infante and Davies (1962) showed that the

onset of shortening in rigor mortis after the release of Ca^{++} into the sarcoplasm, could be attributed to cyclic formation and breakage of actin and myosin cross-links which were accompanied by the enzymatic hydrolysis of ATP by calcium activated actomyosin ATPase. Rigor mortis continued to develop until ATP was depleted by the ATPase activity of the muscle fiber due to inhibition of net ATP production via glycolysis and respiration, in combination with reduced creatine phosphate levels. As the ability to produce ATP was altered, the cross-links which were once able to break and reform, no longer had the energy source to perform relaxation and contraction. Similar results were obtained by Briskey et al. (1962) whose investigation revealed that rigor mortis onset, as defined by the rigorometer, could vary from two minutes to eight hours in porcine muscle. This variation was primarily due to: 1) variation in membrane resistance to autolytic processes or acidification, 2) deviations in post-mortem release of Ca^{++} or other ions by muscle proteins, 3) differences in the relation between the velocity of glycolytic ATP resynthesis and its breakdown.

Locker and Haygard (1963) found that isolated fresh sternomandibularis muscle shortened more from $0^{o}C$ to $2^{o}C$ than at $37^{o}C$ and that minimum shortening occurred from four to $19^{o}C$. At temperatures greater than this range, shortening coincided with the onset phase of rigor mortis, but at lower temperatures, shortening began almost immediately. Goll et al. (1964) studied post-mortem changes in tenderness and protein solubility of the semitendinosus (ST) muscle. Those muscles excised immediately post-mortem were compared with muscles left attached to the skeleton which were least tender immediately after death, gradually increasing in tenderness during post-mortem aging. Excised muscles were found

to be least tender six to 12 hours post-mortem, and thereafter became progressively more tender. Similar results, showing that tenderness decreased following muscle excision after death, were reported by Love (1962) in fish muscle, Lowe (1948) in poultry, and by Ramsbottom and Strandine (1949) and Paul et al. (1952) in beef.

In further work with sarcomere length and tenderness, Herring et al. (1965a) noted that sarcomere lengths of excised ST and psoas major (PM), when altered by treatment, were associated with tenderness. Herring et al. (1965b) noted that sarcomere lengths, particularly in the PM were due to stretching which resulted from vertical suspension (tendon of Achilles). The shorter sarcomeres appeared to be reduced in length as a result of tension release. Muscles whose sarcomeres lengthened due to vertical suspension were the PM, latissimus dorsi, and the rectus femoris. Muscles in which the sarcomere length shortened as a result of vertical suspension were the longissimus dorsi (LD), gluteus medius, biceps femoris, and ST. It was further demonstrated that as the sarcomere length increased, there was a decrease in fiber diameter, a decrease in shear force, and an increase in tenderness. Conversely, when the muscles shortened, there were corresponding decreases in sarcomere length, increases in fiber diameter, and decreases in tenderness. Differences in both fiber diameter and sarcomere length were reported to be highly related to differences in tenderness. In addition, Herring et al. (1965b) also noted that vertically suspended sides may show tension differences due to vertebral splitting, external fat and fat firmness, as well as, differences in weight distribution on the sides.

In a similar experiment, Eisenhunt et al. (1965) studied the fiber arrangement and microstructure of the LD using horizontally (either bone

down on a flat surface with the flexible flank area supported by metal supports and the limbs oriented and fixed perpendicular to the long axis of the sides; or horizontal with the limbs securely fastened together, producing arching of the vertebral column) and vertically (tendon of Achilles) suspended sides. It appeared that vertical suspension released some of the tension on the LD and allowed rearrangement of its internal construction in comparison to the horizontal placement. With vertical suspension, the sarcomere length decreased 23 percent as compared with the horizontal placement. The most important factors contributing to the ultimate sarcomere length apparently were: 1) tension on the muscle imposed by skeletal and connective tissue attachments and 2) a combination of glycolytic rate, time course of rigor mortis, and immediate post-mortem temperature conditions.

Sink et al. (1965), in agreement with previous investigations found a close correlation between the mean sarcomere length in porcine LD and the duration of the delay phase of rigor. The study demonstrated that the amount of contraction may be related to post-mortem changes in muscle. The relationship of sarcomere length with the duration of the onset phase was nonsignificant, however, the association between sarcomere length and the duration of the delay phase was highly significant. The data illustrated that the shortening which occurred during the onset of rigor mortis was quite severe when the delay phase was of short duration. However, if the delay phase of rigor was of long duration, the sarcomere shortening that occurred was much less. These findings led Sink et al. (1965) to conclude that the amount of sarcomere shortening or contraction coincident with rigor onset was highly dependent upon the time course of rigor mortis. It was speculated that the ATP breakdown

occurred when the developed tension caused relatively inward movements of the actin and myosin filaments which resulted in sarcomere shortening.

Herring et al. (1966) again noted the relationship between sarcomere length and tenderness. Shear force was found to increase linearly with increased fiber diameter, however, shear force increased curvilinearly with decreased sarcomere length. A curvilinear relation also existed between sarcomere length and fiber diameter. Gothard et al. (1966) noted a similar relationship between bovine muscle sarcomere length and tenderness. They also noted that many of the samples excised soon after stunning contracted greatly upon cutting, however, as rigor mortis approached, the muscles lost their irritability and very little response to cutting occurred after three hours post-mortem. Newbold (1966) presented an excellent review of the current status of "normal" rigor and thaw rigor. In addition, differences in response between beef sternomandibularis and rabbit psoas muscle to changes during rigor were discussed. Cook and Langsworth (1966a) noted that minimum shortening of unfrozen ovine muscle occurred at temperatures between five and 20°C. In a subsequent article, Cook and Langsworth (1966b) found that ovine LD had lower shear force values with increased incubation temperatures from zero to 10°C. Shear force values from muscle incubated from 15 - 30°C remained constant. It was also observed that exudation and cooking losses increased with increasing incubation temperatures. Studies by Marsh and Leet (1966) added considerable evidence to the role of rigor mortis in the conversion of muscle to meat. Using beef sternomandibularis muscle it was determined that the extent of cold shortening during the early post-mortem period affected meat tenderness to a remark-

able degree. A decrease in muscle length up to about 20 percent caused little or no decrease in tenderness, however, from 20 to approximately 40 percent shortening, the toughness increased several fold. Beyond 40 percent, the meat became rapidly more tender and at 60 percent it had a tenderness similar to meat in which no shortening had occurred. The experiments demonstrated that a coincidence in the time of onset of rigor and shortening is not an essential requirement for the development of toughness. No strong evidence was provided that the extent of shortening affected tenderness, however, an almost identical relationship was found to exist between shortening and fluid exudation. The authors were not able to explain their findings at a molecular level.

Nauss and Davies (1966) provided a workable mechanism for the relationship of shortening and rigor mortis. As in many of the previous experiments with this subject, it was shown that the period of shortening coincided with the period of rapid ATP loss. Furthermore, it was shown that the onset of shortening in rigor followed the release of Ca^{++} into the sarcoplasm, as demonstrated by Hasselbach (1964), and that this shortening could be accounted for by the cyclic formation and breakage of cross links between actin and myosin. These events were accompanied by the enzymatic hydrolysis of ATP by actomyosin ATPase. The authors made the general statement that a further breakdown of ATP occurred owing to the action of ATPase in the sarcoplasmic reticulum which was due to the continuous activation of the calcium pump during development of rigor. The calcium pump continued to operate until ATP disappeared. Nauss and Davies (1966) further explained the physical changes which occurred during rigor as a transformation from a system of actin and myosin filaments which could slide freely along each other to a rigid

system consisting of actomyosin joined by cross bridges between actin and heavy meromyosin. These cross linkages which were able to break and reform while shortening occurred, could not be broken in the absence of ATP.

In 1967 Stromer and Goll added further evidence to the findings of Marsh and Leet (1966). Their experiment involved bovine ST muscles which were sampled immediately after death and at 24 hours with storage at two, 16, and 37°C. Muscle was again excised after 312 hours and held at two and 16°C. Bovine muscle was supercontracted after 24 hours storage at 2°C but was only slightly contracted after storage at 16°C for 24 hours. The ST held for 24 hours at 37°C was slightly less supercontracted than 2°C muscle. Furthermore, muscle stored at 16°C for 24 hours showed only slight shortening. The studies demonstrated that shortening at 2°C began within three hours after death while ATP levels were still above 1.0 mM. Shortening at 37°C began about five to eight hours after death when ATP levels were below 0.2 mM. When measured by isometric tension development, the ability to maintain tension was gradually lost after 24-48 hours at 2°C, but the ability to maintain tension at 37°C remained constant until bacterial decomposition destroyed the muscle strip. The authors hypothesized that post-mortem shortening at 2°C represented a true contraction initiated by either 1) a lowering of ATP to a level that permitted actomyosin interaction in the presence of five to ten millimolar Mg^{++}, 100 - 150 mM KCl, and low (10^{-6} to 10^{-7} M) levels of Ca^{++}, or 2) a gradual efflux of Ca^{++} from the membranes of the sarcoplasmic reticulum caused by a lowering of ATP to a level insufficient to fully maintain the activity of the Ca^{++} pump. The shortening which occurred at 37°C was thought to be a different process, possibly initi-

ated by low pH values (5.5) which occur rapidly in post-mortem muscle at 37°C. The authors found it surprising that any shortening could occur at the low ATP levels existing in post-mortem muscle if one is to believe accepted theories regarding the role of ATP in the dissociation of actin and myosin.

Galloway and Goll (1967) investigated the structural and biochemical properties of porcine muscle strips and myofibrils immediately after death and again after eight hours post-mortem at two, 16, 25 and 37°C. The muscle strips shortened or developed tension at all post-mortem storage temperatures, however, shortening and isometric tension were maximal at two and 37°C and were minimal at 16°C. The shortening or tension development at 2°C occurred much sooner after death than shortening or tension development at other temperatures. It was interesting to note that myofibril preparations from muscle immediately after death or eight hours post-mortem at any of the temperatures studied were in a relaxed state. Similar findings were discussed by Busch et al. (1967) who found that tension development of bovine muscle was maximal at 2°C, minimal at 16°C, and at 37°C, the tension was approximately one-half that developed at 2°C.

Newbold and Scopes (1967) found that the enzymes involved in glycolysis would be expected to decrease with lower temperatures. But in the period of 3.5 to seven hours post-mortem enzyme activities were no lower at 5°C than at 15°C, and were somewhat greater at 1°C. Thus it was apparent that the decrease in metabolic rate, as a result of lowering the temperature, was counteracted by some factor(s) that accelerated the metabolism. The phosphorylase step was accelerated the most as was evidenced by increases in hexose monophosphate concentrations at lower

temperatures. In addition, the AMP concentration rose slightly at 15°C, but more at 5°C, and even more at 1°C. Cyclic AMP is a known activator of phosphorylase b and will stimulate phosphofructokinase in vitro. The increase in AMP may be the factor responsible for accelerating the phosphorylase and phosphofructokinase steps at low temperatures. Thus, the acceleration of glycolysis at lowered temperatures may be a result of a stimulation of total ATPase activity, and if one assumes that shortening always involves myofibrillar ATPase, it can be concluded that myofibrillar ATPase was activated at the lower temperatures. This fact explains why total ATPase activity was not less at these temperatures than at 15°C. Hence, Newbold and Scopes (1967) demonstrated that an acceleration of glycolysis above a basal rate in either resting or post-mortem muscle appeared to be closely related to the activation of myofibrillar ATPase. Busch et al. (1967) supported the findings of Newbold and Scopes (1967) by showing that ATP levels changed very little in muscle at 2°C during large tension development, and that the ATP level at 2°C did not differ from the ATP level at 16°C which developed very little tension. Similar results were also obtained by Cassens and Newbold (1967).

Herring et al. (1967) gave further evidence that shortening is related to tenderness and, in addition, that these changes occur at the molecular level. As in previous articles it was shown that a decrease in muscle length gave rise to a large increase in fiber diameter. As sarcomere length decreased fiber diameter increased and there was a doubling of shear force as sarcomere length decreased to 50 percent. Furthermore, a large change in shear force was found with sarcomere lengths up to 2.0 μm but between 2.0 and 3.5 μm, little change in shear

force occurred with increased sarcomere length. Buck and Black (1967) used seven pairs of muscle strips from the bovine LD and subjected them to two degrees of stretch tension during rigor. Results indicated that muscle fiber extensibility was significantly less, shear force was significantly less, and a significantly smaller fiber diameter existed in stretched strips. The decrease in shear force in stretched strips was due to decreased extensibility. Shear force was probably more closely related to the intrafiber molecular arrangement as influenced by tensions during rigor rather than to the fiber diameter during shearing. These varying degrees of tension were felt to be due to normal carcass attachments and hanging practices which exist in different locations within a muscle during rigor. As a result of the differences in tenderness between stretched and unstretched muscle strips, the authors emphasized the need of carefully considering the effect of pre-rigor cutting on muscle.

Howard and Judge (1968) reported that correlations between sarcomere length and juice loss suggested that the contraction state of bovine muscle influences its water-holding capacity. It was further emphasized that it is possible that the contraction state of muscle is highly associated with tenderness, however, the observation of sarcomere length at a single point does not adequately reflect the overall contraction state of a muscle.

Gillis and Henrickson (1970) subjected the semimembranosus (SM) and ST muscles to four levels of tension (0g, 1000g, 2500g, 5000g). The muscles were excised 45 minutes post-mortem and then placed under tension at 1.1°C for 48 hours post-mortem. Fiber diameter was found to be smaller with the 1,000g pull treatment than when there was no tension.

In fact, increased tension did not significantly change fiber diameter. Sarcomere length increased to the 2,500g pull treatment and then leveled off. The percent kinkiness or degree of rigor in both muscles was less to the 1,000g treatment. As greater amounts of tension were applied, the ST increased, whereas, the SM decreased in kinkiness. Similar results were observed for shear force in both muscles to the 1,000g pull treatment, but after this point small increases in shear force were noted only in the ST muscle. Similar results were reported by Cagle and Henrickson (1970) in work with porcine LD.

Hostetler et al. (1970) compared sarcomere lengths in five muscles taken from one side of eight carcasses suspended by the Achilles tendon to muscles from the remaining side suspended by the obturator foramen. Between treatments, greater tenderness was obtained in muscle with longer sarcomeres. Suspension by the obturator foramen improved the tenderness of the LD and SM while keeping an acceptable tenderness of the PM. The response of the ST was variable, but was generally improved by the experimental technique. Mean length of sarcomeres from the LD was 1.93 μm for the Achilles tendon method and 2.41 μm for the obturator foramen suspension. Hostetler et al. (1970) postulated that each muscle had its own characteristic resting sarcomere length. Shortening of the sarcomere below resting length resulted in increased toughness while stretching the sarcomere beyond resting length caused little or no change in tenderness. It was stated that sarcomere length usually reflects the amount of actomyosin which has been formed. Similar work to Hostetler et al. (1970) was accomplished by Arango et al. (1970), Harris and Macfarlane (1971), Hostetler et al. (1972), and Hostetler

et al. (1973). In general, these last series of experiments illustrated that the degree of muscle shortening depends on the position of the carcass during the development of rigor mortis.

Busch et al. (1972) used strips of bovine semitendinosus muscle immersed in dilute saline solution. It was found that in the range of two to 37°C bovine semitendinosus develops the most isometric tension at two and the least at 16 - 25°C. More importantly it was demonstrated that bovine muscle strips at 16°C began to develop isometric tension within three hours after death. This report did not agree with Busch et al. (1967), as the earlier investigation showed isometric tension began to develop about seven hours after death. The author felt that the discrepancy was due to the greater sensitivity of the instrumentation used in the more recent experiment. Isometric tension at 16°C appeared to reach a maximum between nine and 24 hours post-mortem. At 37°C tension development began at three hours, reaching a maximum at approximately five hours post-mortem. Busch et al. (1972) indicated that post-mortem isometric tension was closely analogous to post-mortem shortening on unrestrained muscle. Post-mortem isometric tension and post-mortem shortening probably commenced simultaneously and reached a maximum at the same time. In addition, it was evident that maximum isometric tension development must always precede complete loss of extensibility, although at 37°C the time between these two events is very short.

Bouton et al. (1973a) showed that the muscles of a normal pH (5.4 - 5.6) had shear force values that were highly dependent upon muscle fiber contraction state. Connective tissue strength was significantly increased for samples which contained predominantly contracted fibers as compared to samples containing mainly stretched fibers. As the pH in-

creased so did the water holding capacity. This is in agreement with Bouton et al. (1971). Furthermore, even though there was a trend toward shorter sarcomeres at high pH it probably did not influence shear force values when sarcomere lengths were greater than 2.0 μm. In addition, even though the contraction state of uncooked muscle has been related to the tenderness of cooked meat, simple relationships between sarcomere length and tenderness cannot always be assumed since changes in fiber length produced by cooking will vary with both ultimate pH and sarcomere length and may be related to shear force. In a subsequent article Bouton et al. (1973b) showed that, as in previous articles, measurements of water holding capacity showed a highly significant relationship with pH. Both shear force and taste panel evaluation with LD from sides hung by the Achilles tendon showed maximum toughness at pH 5.8 - 6.0. Most objective and subjective measurements on other muscles showed that tenderness increased linearly with increasing pH. However, the authors cautioned that with so many factors affecting tenderness in normal animals it would be surprising if there were always a direct relationship between pH and tenderness with ultimate pH values less than 6.0.

In conclusion, recent investigations when compared with earlier works, have made it difficult to accurately describe the time course of rigor mortis. Drawing conclusions from work accomplished on muscle strips in vitro and applying the results to muscle in vivo may be erroneous. A reevaluation of the techniques utilized to characterize rigor mortis appears to be necessary in order to assess the validity of the research to date. Furthermore, a need also exists to accurately characterize the time course of rigor mortis in the more economically important muscles of the various meat animals.

"Hot" Processing

One of the earliest articles concerned with the excision of muscle soon after slaughter was by Ramsbottom and Strandine (1949) who investigated the effect of boning beef before chilling on quality. One of the benefits of chilling beef in the form of boneless cuts, rather than as sides, should be a faster rate of chilling. This hypothesis was confirmed in tests made on two choice grade carcasses and two commercial grade carcasses. The chilling curves for the choice grade carcasses showed that the internal temperature of the LD muscle rose from about 100°F immediately after slaughter to 102°F one hour later, then dropped when the carcasses were moved to a chilling cooler at 35°F. The boneless loin section, excised about one hour following slaughter, showed a maximum difference in temperature as compared to the bone-in loins at two to eight hours post-mortem showing a difference of 10-15°F. The effect of boning beef before chilling was estimated by cutting steaks from the LD at three, six, nine, and twelve days post-mortem. The steaks were then broiled and rated for tenderness. Muscles which were excised from carcasses prior to chilling were less tender than those which remained intact in the carcass until it was chilled. Beef that was cooked soon after slaughter (two hours) was more tender than at two days. Furthermore, freezing and thawing tended to mask the change in tenderness that was shown in unfrozen beef. Changes that occurred in the histology of post-mortem muscle have been previously described.

Reddy (1962) reported that bovine muscle exhibited a decrease in tenderness in the semitendinosus muscle processed pre-rigor, but the gluteus medius and longissimus dorsi muscles did not increase nor decrease in tenderness. Trautman (1964) found that pork muscle processed

pre-rigor had a greater emulsifying capacity and more salt-soluble proteins than post-rigor muscle.

Hams which were "hot" processed were found to have higher bacterial counts than in conventionally processed hams when evaluated prior to smoking, but after smoking bacterial counts were low in both groups. In contrast, Barbe et al. (1966) and Barbe and Henrickson (1967) found less total contamination in "hot" processed ham. It was hypothesized that the more rapid processing of the "hot" hams as compared to conventional processing presented less opportunity for undesirable bacterial growth to occur. Mandigo and Henrickson (1966) evaluated the yield, tenderness, juiciness, flavor, and moisture content of "hot" processed hams, cured and smoked prior to chilling. Comparisons with conventional processing indicated that the "hot" processed product was of equal or superior quality.

Henrickson (1968) evaluated the tenderness of "hot" processed pork using the Warner-Bratzler shear instrument and percent kinkiness. No evidence was found to discriminate against "hot" processing. Henrickson (1968) also noted that "hot" porcine muscle was darker than muscle chilled conventionally. However, after chilling no difference could be detected between the two processes.

Cagle (1969) noted that slicing pre-rigor pork muscle decreased tenderness. In addition, the LD exhibited decreased tenderness when located in the carcass side on which the leg was used for suspension during bleeding. Acton and Safle (1969) showed that pre-rigor processed beef showed a greater emulsifying capacity than did the same property on post-rigor beef chuck.

Schmidt and Gilbert (1970) excised muscles from six carcasses (three steers, two young bulls, and one old bull) at approximately two hours post-mortem. These "hot" muscles were then aged for 24 or 48 hours at

15°C in gas impermeable bags and frozen at -14°C. Muscles for the "cold" treatment were excised from the remaining side of the carcass which was suspended for 24 hours at 9°C. The "hot" processed muscles aged for 24 hours were shown to be similar to the controls in tenderness while "hot" muscles aged for 48 hours were significantly more tender than muscle from the control side. There appeared to be no treatment effect on the SM, whereas the ST toughened after being excised pre-rigor. Mean bacterial numbers were held within the range of 10^2 to $10^5/cm^2$ of muscle surface after 48 hours storage at 15°C in a sealed gas, impermeable bag. The authors concluded that their procedure for the pre-rigor excision of bovine muscle could produce an organoleptically acceptable product of a satisfactory microbial standard.

The hypothesis that "hot" boning the beef carcass is economically favorable was supported by Brasington and Hammons (1971) who indicated that on-the-rail boning resulted in lower costs due to the use of semi-skilled workers during a portion of the operation. In addition to showing favorable yield tests, the operation was reported to be more flexible as to line arrangement, more sanitary, and less fatiguing to workers.

Kastner (1972) utilized 18 Hereford steers to study the effects of "hot" processing at 2, 5, and 8 hours post-mortem. The "hot" side was fabricated into muscles, muscle systems, bone, fat, and lean trim after being held intact for the assigned period (two, five, or eight hours). The corresponding sides were fabricated identically to the "hot" boned sides after chilling 48 hours at 2°C ("cold" boned). "Hot" boned steaks were compared to "cold" boned steaks for percent loss (shrink), shear force, color value notation, flavor, cooking loss, water binding capacity, percent moisture, and fat. No significant differences were found

in shrinkage between the two processes at the two hour holding period. However, at the five and eight hour holding periods the "hot" boned side had a significantly smaller average percent loss. The tenderness of the "hot" boned product was evaluated by the Warner-Bratzler shear instrument. The "hot" boned two hour steaks taken from the LD muscle were found to be significantly less tender than their "cold" boned counterparts. The same result was obtained for the five hour treatment, however, no significant difference was found between the eight hour and control treatments. The author felt that the eight hour holding period appeared to alleviate the shear force difference between "hot" and "cold" steaks. Differences at the two and five hour holding period and the control were not thought to be economically important. The "hot" boned steaks evaluated for color were found to be statistically different from their controls at all three holding periods. At the two hour holding period, the "hot" boned steaks were darker than the controls but in the five and eight hour holding period, the reverse was true. When the color was evaluated by a sensory panel, a significant difference was observed between the two hour holding period and the control, however, no significant difference was detected for either the five or eight hour holding period. Pressed fluid ratios were statistically different for all holding periods. In a test for percent cooking loss no significant difference was found to exist between any of the holding periods and their corresponding controls. Nor was any significant difference detected in flavor between the two, five, and eight hour holding periods versus the 48 hours controls.

Marsh et al. (1972) accomplished further research in response to work done by Mandigo and Henrickson (1966) with "hot" processing the

pork carcass. The authors felt that prior research raised the possibility of inadvertent toughness production if wholesale cuts were exposed to a chiller temperature in a pre-rigor state. Results indicated that the effect of excising pork muscle from the "hot" carcass and exposing it to 0°C twenty minutes after exsanguination toughened the muscles as compared to routine processing of the entire carcass. However, the magnitude of the mean induced toughening was not great. In another series of experiments, complete loosening of the LD, with the exception of the caudal insertion, resulted in a small improvement in tenderness relative to the control muscle. In a third experiment seven muscles, (LD, BF, ST, triceps brachii, PM, gluteus medius and rectus femoris) were excised from one side of ten carcasses and transferred to a 0°C cooler 45 minutes post-mortem. Statistically significant toughening was observed in the LD, dark ST, triceps brachii and rectus femoris. Toughening, though not quite to a significant level, occurred in the light ST and gluteus medius, and practically no change was found in the BF and PM. The authors concluded that muscle excision pre-rigor followed by fairly rapid cooling causes a significant toughening. These results were not surprising in view of previous research which illustrated that both ovine and bovine muscles toughen significantly when freed from skeletal restraint and are exposed to near freezing temperatures. The authors estimated that ox and sheep muscles treated in this manner would increase in toughness by 200 - 400 percent.

Behnke et al. (1973) proposed that it would be advantageous in terms of bacteriological quality and ease of cutting to utilize a -3°C holding treatment following freezing in place of a normal chilling procedure prior to freezing. Thus, beef carcasses could be frozen immediately

following slaughter and then cut up in a room at perhaps five to 10°C. The temperature would then rapidly rise and remain near -3°C, thereby allowing glycolysis to proceed rapidly without undesirable consequences. Following cutting and the minimum holding period (14 hours), the beef would be returned to normal frozen storage.

Schmidt and Keman (1974) evaluated the effect of "hot" processing on six Angus steer carcasses. The right side of each carcass was "hot" boned one hour after slaughter whereas the left side was placed in a 1°C room. The boneless wholesale cuts from the right side were weighed and kept at 7°C for four hours, after which they were placed in a 1°C room overnight. They were then vacuum packaged and replaced in the cold room for seven days. "Cold" boning of the "cold" side was initiated after each side was chilled for eight days at 7°C.

Taste panel evaluation of the anterior longissimus dorsi (ALD), posterior longissimus dorsi (PLD), psoas major (PM), gluteus medius (GM), semitendinosus (ST), semimembranosus (SM), biceps femoris (BF), and quadriceps femoris (QF) as well as evaluation by Warner-Bratzler shear did not indicate a significant difference between "hot" versus "cold" processing. Measurements of fiber diameter showed that most "hot" boned muscles increased in fiber diameter compared with the control. A significant increase was observed in fiber diameter for the PLD, PM, GM, and ST. A nonsignificant increase was found in the other muscles observed.

CHAPTER III

MATERIALS AND METHODS

Thirty Angus steers of approximately the same grade (choice), ranging in weight from 405 to 555 kg with a mean weight of 483 $\pm$ 60 kg were utilized in this study. Each animal was delivered to the Meat Science abattior 24 hours prior to slaughter. The assignment order of the conditioning period (three, five, or seven hours post-mortem) for the "hot" side was randomly determined for the course of the experiment prior to the delivery of the first animal. Following the 24 hour shrinkage period, the steer was weighed and given antemortem Federal inspection. Care was exercised in handling the animals to avoid any adverse effect upon post-mortem metabolic reactions, as well as, ultimate product quality. Each animal was stunned with a Cash percussion stunner, raised from the floor by both legs and bled. The time of death was recorded. During the conventional dressing operation extreme care was exercised to assure accurate splitting for even weight distribution on the vertically (tendon of Achilles) suspended sides. In addition, the carcass was carefully washed to minimize bacterial contamination. The slaughter and dressing operations proceeded as rapidly as possible so that Federal inspection was given within 45 minutes post-mortem. Following inspection of the split carcass, the hot weight of both the right and left side was recorded. Either the right or left side of the carcass was randomly assigned to one of two treatments: 1) removing the muscles while the

carcass was still warm ("hot" boning) or 2) removing the muscles after a 48 hour chilling period ("cold" boning) at 1.1°C.

"Hot" Boned Side

Immediately after being weighed, the "hot" side was placed in a 16°C holding room. The side was suspended from a rail via a roller and hook through the Achilles tendon. Thermocouples were inserted into the three test muscles, namely, the longissimus dorsi (LD), semimembranosus (SM), and semitendinosus (ST). Each thermocouple was in turn connected to a Honeywell recording potentiometer. Following the expiration of a three, five, or seven hour holding period the side was fabricated into a streamlined hindquarter.

This fabrication consisted of chuck removal at the fifth thoracic vertebra with the flank and plate removed as in the commercial trade (Figure 1). After the streamlined hindquarter was weighed, on-the-rail dissection of muscles and muscle systems was initiated in the 16°C holding area. First, excess fat was carefully stripped from the muscle so that the epimysium remained intact on the muscle surface. Excision of the muscles from the streamlined hindquarter was found to be the most efficient if they were removed in the following order: tensor fascia latae, sartorius, SM, ST, biceps femoris, quadriceps complex, psoas major (PM), gluteus complex, and lastly, the LD. The remaining lean and small muscles were excised and utilized for lean trim. As soon as the excision of a given muscle was completed, it was placed into a Cry-O-Vac bag (S-507) to prevent surface desiccation. Other components (bone, fat, and lean trim) were treated in an identical manner. The dissection of the streamlined hindquarter was completed approximately one hour after

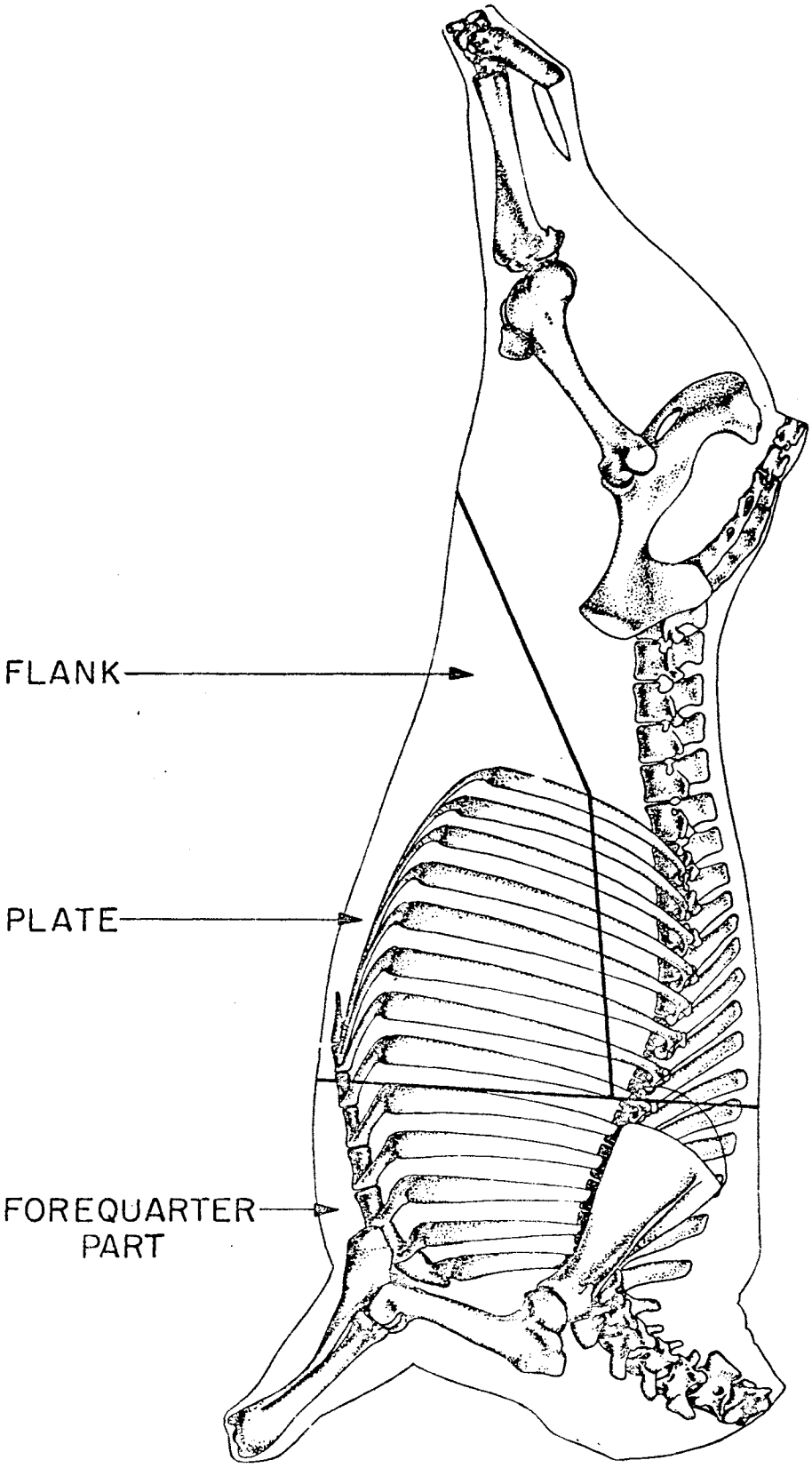

Figure 1. Diagram of Carcass Preparation for "Hot" and "Cold" Boning

initiation. The components were then removed to a 1.1°C cooler for the remaining portion of the 48 hour period (same cooler as the "cold" side).

"Cold" Boned Side

Immediately after obtaining the hot weight, the side to be "cold" boned was placed into a 1.1°C chill cooler for 48 hours. Following the expiration of this time period, the "cold" boned side was reweighed and broken down into a streamlined hindquarter. The side was then removed to the 16°C holding area and an identical procedure to that of the "hot" side was followed.

pH Determination

Measurements of pH were taken from one through five hours post-mortem and then again at 24 and 48 hours post-mortem from the PM of both the "hot" and control sides. The PM was used in order to avoid cutting the test muscles which would result in tension loss and could possibly influence product tenderness. The procedure at each measurement period involved excising a freshly cut, transverse section from the same general area on each side, using the skeleton as a guideline. Ten grams of finely minced muscle were weighed into a beaker containing 50 milliliters of distilled water. The solution was mixed thoroughly and allowed to stand for one minute at which time mixing was repeated. The pH was then estimated using a Corning Model 12 research pH meter and a Corning semimicro combination electrode. Before reading the pH, the Corning instrument was calibrated using two pHydrion buffers of pH 5.60 and 7.00. The recorded pH was used as an index of the extent and rate of post-mortem glycolysis in the "hot" as compared to the "cold" boned side.

Yield

At the expiration of 48 hours post-mortem the "cold" boned side was reweighed and the yield or percent loss calculated as follows:

$$\frac{A - B}{A} \times 100 = \text{Percent Loss}$$

A = Hot side weight,

B = Shrunk side weight.

The "hot" boned streamlined hindquarter components were removed, with the exception of the lean trim, and weighed. The lean trim was weighed in the bag to avoid undue microbial contamination. One-tenth of a pound was subtracted from the lean trim weight to allow for the weight of the Cry-O-Vac bag. The yield or percent loss of the "hot" boned side was calculated as follows:

$$\frac{A - B}{A} \times 100 = \text{Percent Loss}$$

A = Intact "streamlined" hindquarter weight,

B = Sum of "streamlined" hindquarter components.

Sections of psoas major which were removed for pH determination were weighed and then "figured back into" the yield determination.

Microbial Determination

The lean trim from both "hot" and "cold" sides was ground separately in a washed and sanitized grinder. Each sample was ground twice, once through a coarse plate and a second time through a fine plate. Then separate 25 gram aliquots were weighed and placed into 225 milliliters of sterile distilled water in a sterile Waring Blender jar. Each sample

was blended for one minute at high speed (120 on the rheostat). This constituted a 10^{-1} dilution. Next, ten milliliters of the 10^{-1} dilution were placed in 90 milliliters of sterile distilled water to constitute a 10^{-2} dilution. A 10^{-4} dilution was prepared by placing one milliliter of the 10^{-2} dilution into a 99 milliliter dilution blank. By using the appropriate pipettes, the following dilutions were applied in duplicate to labeled, disposable plastic petri dishes: 10^{-2}, 10^{-3}, 10^{-4}, and 10^{-5}. Sterile DIFCO Nutrient agar, held at 45°C to avoid resolidification, was poured into each plate. The petri dishes were then swirled for adequate mixing of the agar and diluted sample. The duplicate plates containing the "hot" and "cold" boned diluted samples were incubated at 34°C for three days and a second set of plates at 10°C for seven days. Only duplicates which had colony numbers in the range of 30-300 per plate were counted.

Sampling for Color, Pressed Fluid, Percent Moisture, Percent Fat, Histological Examination, Organoleptic Evaluation, Percent Cooking Loss, Shear Force, and Chemical Determinations

Immediately after determining the yield, the following three muscles were selected for quality evaluation by both subjective and objective measures: longissimus dorsi (LD), semimembranosus (SM), semitendinosus (ST). These three muscles were chosen because they represented much of the "streamlined" hindquarter weight and value, and also due to the fact that there was much variation in tenderness within this group of select-

ed muscles. The muscles were cut into steaks following the schedule presented in Figure 2 in order to compare both the "hot" and "cold" treatments. During the sampling procedure the muscles were held at 1.1°C.

Steaks for the organoleptic evaluation, shear force, percent cooking loss, and chemical determinations were packaged, labeled, and frozen (-10°C) for analysis at a later date. The steaks for histological examination, photovolt evaluation, pressed fluid, percent moisture, and percent fat determinations were held fresh at 1.1°C until evaluated.

Organoleptic Evaluation (Tenderness Panel)

The LD and SM muscles were utilized for appraisal by a tenderness panel. Because of its size, the ST was not used. Steaks one and two (Figure 2) from the LD and SM muscles of both right and left sides of the carcass were thawed for 24 hours at 1.1°C. Six trained panel members were used for each trial, although all six members were not the same from trial to trial. The judges consisted of both men and women of different ages selected from the employees of the Meat Science Laboratory.

The duo-trio test (Kramer and Twigg, 1966; Amerine et al., 1965) was used to determine whether differences in tenderness existed between "hot" and "cold" boning. The test is organized such that one of the samples serves as the reference, the remaining two samples are unknown. The judge is asked to choose which of the unknowns best matches the reference sample. As may be noted from Figure 2, two sample steaks from each muscle were available for each treatment side (i.e., steak number one and two; "hot" or "cold"). Thus a given panel session was run in two shifts so that both "hot" and "cold" steak number one or two were

POSTERIOR END OR MUSCLE INSERTION

CHEMICAL DETERMINATIONS
ORGANOLEPTIC EVALUATION AND PERCENT COOKING LOSS STEAK 2-2.54 CENTIMETERS
PRESSED FLUIDS, PERCENT MOISTURE AND FAT, AND HISTOLOGICAL EXAMINATION STEAK 2-2.54 CENTIMETERS
SHEAR FORCE STEAK 2-5.08 CENTIMETERS
PHOTOVOLT COLOR EVALUATION STEAK 2-2.54 CENTIMETERS
MIDLINE OF THE MUSCLE
ORGANOLEPTIC EVALUATION AND PERCENT COOKING LOSS STEAK 1-2.54 CENTIMETERS
PRESSED FLUIDS, PERCENT MOISTURE AND FAT, AND HISTOLOGICAL EXAMINATION STEAK 1-2.54 CENTIMETERS
SHEAR FORCE STEAK 1-5.08 CENTIMETERS
PHOTOVOLT COLOR EVALUATION STEAK 1-2.54 CENTIMETERS
CHEMICAL DETERMINATIONS

ANTERIOR END OR MUSCLE ORIGIN

Figure 2. Schedule for Removing Steaks for Quality Determinations on Test Muscles

evaluated at one of the two shifts. A coin toss was used to determine which steak (one or two, "hot" and "cold") was evaluated first. After randomizing the evaluation order, a second coin toss was made to determine which process ("hot" or "cold") would serve as the pair (reference and corresponding unknown) and which would be designated as the single (odd sample). The steaks from a given muscle were weighed and then cooked in Frymax oil at 135°C to an internal temperature of 72°C as determined by a Weston meat thermometer whose sensing tip was placed in the geometric center of each steak. After cooking, the steaks were blotted, reweighed, and prepared for sample extraction. A 1.27 centimeter diameter bore was used to remove two cores from the steak used as the pair and one core from the steak serving as the single. The steaks (steak one, "hot" and "cold", for example) were carefully oriented so that the cores were removed from the same position up and down the steak on both the pair and single steak for a given judge. In the case of the single steak, the odd core was removed from a point midway between the position that the pair cores were sampled on the corresponding steak. Each core was placed into a plastic medicine vial which fit into the sample tray sketched in Figure 3. As may be noted, three symbols were imprinted on the tray: $, &, and ! The dollar sign always served as the reference, whereas the ampersand and exclamation point always were unknown. A coin toss was used to determine which of the two symbols representing the unknown samples would serve as the second member of the pair, matching the reference ($) sample, for an individual panel member. The randomizations, as discussed, were accomplished before each panel and recorded on a protocal sheet to increase the efficiency of panel preparation. After the sample vials were placed in the holder, they

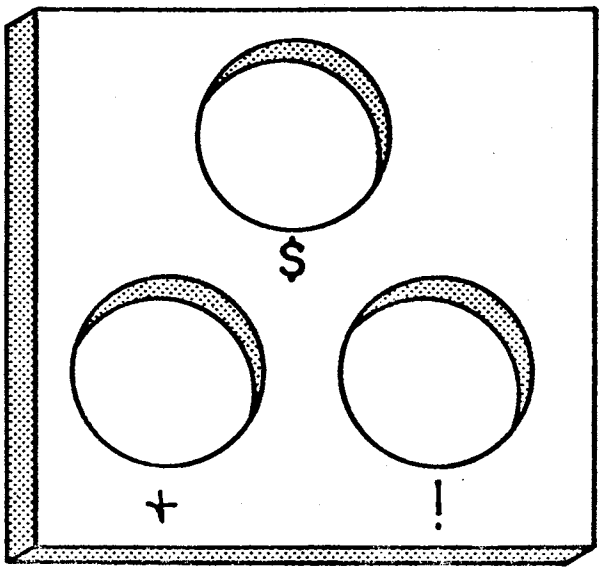

Figure 3. Sample Tray Used in the Duo-Trio Analysis

were covered with aluminum paper and placed in an electric oven and held at 49°C until evaluated. The oven was used to insure that the samples in each tray were at a uniform temperature when they were presented to the judges.

Upon receiving a tray with the three samples, each judge was asked to evaluate the samples using the form shown in Figure 4. As may be noted, the duo-trio test was performed first, then each judge was asked to indicate a preference for one of the two unknowns. If there was no preference, the judge was asked to flip a coin. Lastly, each judge assigned each unknown a level of acceptability based on a six point hedonic scale (the larger the number, the higher the level of acceptability). Care was taken to assure that the evaluation room was dimly illuminated with red light to avoid identification of the samples because of color differences. In addition, positive air pressure was utilized so that no extraneous odors from the preparation room would influence the panelists.

The duo-trio panel was evaluated by means of Table 85 as shown in Kramer and Twigg (1966) such that 73/120 correct responses were required for significance at the 0.05 level. Analysis of the preference selection was accomplished by assigning the preferred treatment a value of two and the remaining treatment a value of one. The hedonic scale was evaluated similarly such that the treatment receiving the higher level of acceptability was ranked with a two and the remaining treatment with a value of one. In case of a tie, each treatment received a value of 1.50. Both the preference and hedonic evaluation were analyzed by the Friedman test (Conover, 1971).

TENDERNESS EVALUATION

PRODUCT _____ NAME _____

PANEL NO. _____ DATE _____

The $ is the reference sample. One of the two remaining samples is identical to the reference sample. Circle the sample which is like the reference sample, then check a preference for either the & or the ! sample.

Circle the sample which is like the reference sample $:

$

& !

Check your preference:

/_/ & Sample /_/ ! Sample

RATE FOR TENDERNESS ONLY: Circle the appropriate level of acceptability for the & and the ! sample.

& Sample	! Sample
(1) Highly Unacceptable	(1) Highly Unacceptable
(2) Unacceptable	(2) Unacceptable
(3) Slightly Unacceptable	(3) Slightly Unacceptable
(4) Slightly Acceptable	(4) Slightly Acceptable
(5) Acceptable	(5) Acceptable
(6) Highly Acceptable	(6) Highly Acceptable

COMMENTS:

Figure 4. Score Sheet Used for Tenderness Panel

Percent Cooking Loss

Pre- and post-cooked weights were taken on each of the "hot" and "cold" LD and SM steaks used for the tenderness panel, as was previously discussed, in order to compare the difference in percent cooking loss between the two processes. The formula for calculating percent cooking loss was:

$$\frac{A - B}{A} \times 100 = \text{Percent Cooking Loss}$$

A = Raw steak weight,

B = Cooked steak weight.

Organoleptic Evaluation (Color Panel)

Color evaluation was accomplished similarly to the tenderness panel by using steak two ("hot" and "cold") of the organoleptic evaluation as shown in Figure 2. Before tenderness panel preparation, a 1.27 x 5.08 x 2.54 centimeter slice was removed from the dorsal end of each steak. Each slice was cut in half, the halved slice was then trimmed to remove the slight discoloration caused by freezing the sample steaks. As with the tenderness panel, the utilization of "hot" or "cold" steak two as the pair (reference and corresponding unknown) was randomized by a coin toss. Each of the samples was then trimmed to a size of 1.3 x 2.4 x 0.7 centimeters and placed on an aluminum tray covered with white freezer paper, labeled with the $, &, and ! in the same array as shown in Figure 3. The samples were lighted by two General Electric F40SW flourescent tubes with the height above the sample platform adjusted so that 100 foot candles of light illuminated the meat surface. Before the samples

were evaluated, they were allowed to oxygenate for 15 minutes.

The same six trained judges used for a given tenderness panel session were utilized for the color evaluation. Scoring of the color panel was accomplished by using an evaluation sheet shown in Figure 5 and as may be noted it is similar to the tenderness score sheet shown in Figure 4. As before, the panelist was asked to choose the unknown which was the most like the reference ($). Then the panelist designated a preference for one of the two unknowns. If a preference did not exist, the judge was asked to flip a coin. Lastly the judge assigned each unknown his appropriate level of acceptability.

Analysis of the duo-trio test was accomplished by utilizing Table 85 as shown in Kramer and Twigg (1966). It may be noted that 38/60 correct responses were necessary for significance at the 0.05 level. The preference and hedonic scale scores were analyzed in the same manner as the tenderness panel data.

Shear Force

The steaks from the LD, SM, and ST muscles as sketched in Figure 2 were thawed at 1.1°C for 24 hours. Two steaks from each of the three test muscles were evaluated for both "hot" and "cold" boning; thus 12 steaks were analyzed from each of the 30 carcasses. The thawed steaks were labeled and cooked in deep fat until an internal temperature of 72°C was reached. The cooked steaks were chilled for 24 hours at 1.1°C to provide adequate firmness to insure uniform cores (Kastner and Henrickson, 1969). Each steak yielded three 1.90 centimeter cores and each core was sheared three times by the Warner-Bratzler shear instrument. A 1.90 centimeter bore was preferred to a 2.54 centimeter bore to facili-

COLOR EVALUATION

PRODUCT _____ NAME _____

PANEL NUMBER _____ DATE _____

The $ is the reference sample. One of the two remaining samples is identical to the reference sample. Circle the sample which is like the reference sample, then check a preference for either the $ or the ! sample.

Circle the sample which is like the reference sample $:

$

& !

Check your preference:

/_/ & Sample

/_/ ! Sample

RATE FOR COLOR ONLY: Circle the appropriate level of acceptability for the & and the ! sample.

& Sample	! Sample
(1) Highly Unacceptable	(1) Highly Unacceptable
(2) Unacceptable	(2) Unacceptable
(3) Slightly Unacceptable	(3) Slightly Unacceptable
(4) Slightly Acceptable	(4) Slightly Acceptable
(5) Acceptable	(5) Acceptable
(6) Highly Acceptable	(6) Highly Acceptable

COMMENTS:

Figure 5. Score Sheet Used for Color Panel

tate the removal of three cores from each steak. Paul and Bratzler (1955) found that there was close agreement between shears of 1.27 and 2.54 centimeters in diameter and suggested that either size may be used to measure shear force. Therefore, no loss of accuracy was anticipated as a result of using the smaller diameter bore.

Histological Evaluation

Fiber Diameter and Degree Rigor (Kinkiness Score)

One 1.27 centimeter core was removed from the center of steaks one and two of "hot" and "cold" LD, SM, and ST. Cores from the two steaks of a given muscle (Figure 2) and process ("hot" or "cold") were combined and placed in a labeled sample bottle containing 10 percent buffered formalin and stored at 1.1°C until the muscle fibers were isolated. The formalin was changed after 24 hours to insure adequate fixation.

Samples were prepared by removing a small longitudinal section from both cores contained in the sample bottle, placing them in fresh 10 percent formalin, and blending at a slow speed (30 on the rheostat) in a Waring Blender jar with reversed blades to dislodge, but not break the muscle fibers. After isolation, each sample was checked to insure that little or no damage had ensued to the fibers. The resulting suspension was placed in a glass bottle and maintained at 1.1°C until the fibers were measured. At the time of microscopic observation, a portion of the fiber suspension was poured into a 10.16 centimeter diameter petri dish. The fibers were allowed to settle to the bottom and the petri dish was placed on the stage of an American Optical Microscope equipped with an ocular micrometer and a built-in light source. The

diameter of ten fibers was measured for the one petri dish. The fibers were returned to the bottle and the process repeated until a total of 25 fibers had been measured. The only fibers measured were those which appeared in the field of a constant course and were at least the length of the field. All fibers were measured at their widest point.

The degree rigor or kinkiness score was observed at the same time as fiber diameter. A subjective score for kinkiness was assigned to each fiber. The scoring was based on a photographic scale ranging from 1 to 7 depending upon the contraction state of the fiber. Score assignments were as follows: (1) straight, (2) straight-plus, (3) wavy, (4) wavy-plus, (5) twisted, (6) twisted-plus, (7) kinky (Cagle et al., 1970).

Sarcomere Length

Because of the intricacy involved in measuring sarcomere length, a limited study was accomplished using the previously discussed fibers isolated from "hot" and "cold" LD muscles of the first four carcasses in each holding period (three, five, or seven hours). The suspension of fibers contained in a sample jar was placed in a Waring Blender jar with reversed blades and blended at high speed (100 on the rheostat) for one minute to isolate the myofibrils. The suspension was then returned to the glass jar. Five myofibrils per jar were individually photographed using a Zeiss phase-contrast microscope equipped with a Polaroid camera and Zeiss light meter at 1250 magnifications. Thus a total of 120 myofibrils (20 "hot" and 20 "cold" for each holding period) were photographed. The individual myofibril on each photomicrograph was evaluated by measuring the length of ten sarcomeres by use of a caliper. The caliper was then placed on a metal ruler with one-hundreth inch gradua-

tions, and the value was converted to millimeters. Sarcomere length was then calculated as follows:

$$\frac{A}{(B)\ (C)} = \text{Sarcomere Length in Microns}$$

A = Number of millimeters measured,

B = Number of sarcomeres measured = 10,

C = Magnification of myofibril = 1250.

Pressed Fluid

Twelve steaks per carcass (two steaks per muscle for each boning method) were used for the determination of pressed fluid (Figure 2). Three cores (1.27 centimeters in diameter) were removed from each steak. Using a scalpel, a transverse section of approximately 300 milligrams was sectioned from the center of each core. The muscle tissue section was then placed on a Whatman No. 1 qualitative filter paper which was 18.5 centimeters in diameter. Care was exercised to avoid moisture evaporation from the samples prior to pressing. The filter paper and sample were placed between two clean plexiglass plates and pressed five minutes at 2,268 kilograms load on the ram of a Carver Laboratory press. Prior to use, the filter paper was held in a desiccator jar which contained a small amount of potassium chloride. This assured that the filter paper was of a constant humidity (Carr, 1970). Once the samples were pressed, the resulting meat ring was traced with a pencil and the pressed sample was discarded. The filter papers containing the traced meat ring and the moisture ring were dried for 24 hours at room temperature. Each area (meat ring and moisture ring area) was measured twice using a Compensating Polar Planimeter. Therefore, each area was the result of

averaging the two readings. The measured areas were used to calculate a dimensionless ratio which represented the pressed fluid in that sample (Sayre et al. 1963).

$$\frac{\text{Moisture Ring Area}}{\text{Meat Ring Area}} = \text{Ratio}$$

Thus, the larger the ratio, the more pressed fluid per unit area of sample.

The steaks used for pressed fluid sampling were immediately trimmed of residual exterior fat and blended to a paste consistency for percent moisture and percent fat analysis. The rheostat controlled Sorvall Omni-Mixer cannister was placed in an ice water bath to prevent the sample from overheating during blending. The blended samples were placed in sterile plastic bags and frozen at -10°C until analyzed. At the time of analysis, the samples were thawed at 1.1°C and reblended.

Percent Moisture

Duplicate determinations were made on each blended sample; thus, 24 determinations were conducted on each carcass. Approximately a two gram sample was weighed into a dry, tared aluminum planchet. The samples were spread into a thin layer to insure thorough drying and then dried for 24 hours at 110°C. The dried planchet and sample were cooled to room temperature in a desiccator jar and reweighed. The formula for calculating percent moisture was:

$$\frac{A - B}{A} \times 100 = \text{Percent Moisture}$$

A = Sample weight,

B = Dry sample weight.

Percent Fat

Because "hot" processing should have no effect upon percent fat, a limited study was accomplished using the LD, SM, and ST muscles from the first four animals of each holding period (12 animals total). Approximately a four gram sample was weighed into a dry, tared fat thimble which was stopped with non-absorbant cotton. Cotton was also placed on top of the sample after weighing. A dried ether extraction beaker was also weighed for each sample. The thimble containing the wet sample was dried for 24 hours at 110°C, cooled in a desiccator, and then placed on the ether extraction apparatus (Goldfisch) along with the companion beaker. Each sample was extracted for 24 hours. After extraction, the excess ether was collected by vaporization and condensation and the beaker containing the fat was dried for 30 minutes at 110°C to completely remove all the ether. The beaker and fat were cooled in a desiccator and reweighed. The formula for calculating percent fat was:

$$\frac{\text{Fat Weight}}{\text{Sample Weight}} \times 100 = \text{Percent Fat}$$

Photovolt Color Evaluation

The objective evaluation of color was accomplished on the LD, SM, and ST to compare "hot" versus "cold" boning at all three holding periods. The evaluation was conducted in a manner similar to that of Kastner (1972), with the exception that hue and chroma were also measured. A computer program is currently being developed to handle the

data. Therefore, the objective color evaluation will not be presented.

Chemical Determinations

The samples which were taken for chemical analysis (Figure 2) were not analyzed since no differences in flavor were noted by the judges.

Statistical Analysis

The SAS computer programming system (Service, 1972) was used to analyze all data presented in this study. Organoleptic panels were evaluated by using the ranking procedure described by Conover (1971) in conjunction with the Chi-square test. The Analysis of Variance was used in the remainder of the statistical evaluations. F- tests concerned with the main unit analysis utilized the animal x process mean square with nine degrees of freedom as the error term. The subunit analysis F-tests were conducted using the pooled animal x steak plus animal x process x steak mean square with 18 degrees of freedom. An example of the statistical analysis is presented in the Appendix (Table, XXXVII) showing the Analysis of Variance for Warner-Bratzler shear data at the three hour holding period for "hot" versus "cold" boned LD. Furthermore, it is important to note that each holding period was considered as a separate experiment. Thus no statistical comparison was made between the three, five, and seven hour treatments.

CHAPTER IV

RESULTS AND DISCUSSION

Effect of "Hot" Processing on Meat Tenderness

--Evaluation by Warner-Bratzler Shear--

Longissimus Dorsi (LD) Muscle

The problem of a significant reduction in tenderness as indicated by Kastner (1972) between muscles excised "hot" at two hours post-mortem and conventionally processed muscles was, for the most part, eliminated by allowing the muscles to remain on the carcass for an additional hour before being excised. As shown in Table I, and Figure 6, no significant difference ($P > .05$) in shear force occurred between the three hour boned LD and its corresponding 48 hour control. Although not practically important, LD excised from the "hot" side at five hours post-mortem exhibited a significant ($P < .05$) difference in tenderness when compared to the 48 hour control side (Table I and Figure 6). Similar results were also observed by Kastner (1972) in muscles "hot" boned at five hours post-mortem. The shear force of the LD muscle excised at seven hours post-mortem was not statistically different ($P > .05$) from its control.

Although the "hot" boned LD had a higher shear force than the "cold" boned LD, as may be noted from Figure 6, little difference between the two processes existed at seven hours post-mortem. Furthermore, as shown in Figure 6, the two steaks sampled from the anterior and

TABLE I

MEAN SHEAR VALUES OF "HOT" AND "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	"Cold" Shear Force (lb)	"Hot" Shear Force (lb)	Std. Error of Treatment Mean (lb)
3	15.14	16.44 NS	0.47
5	13.47	15.25*	0.45
7	14.33	14.60 NS	0.47

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boning.

TABLE II

MEAN SHEAR VALUES OF "HOT" AND "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	"Cold" Shear Force (lb)	"Hot" Shear Force (lb)	Std. Error of Treatment Mean (lb)
3	19.65	20.74 NS	0.44
5	19.29	20.02 NS	0.34
7	19.75	21.43*	0.47

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boning.

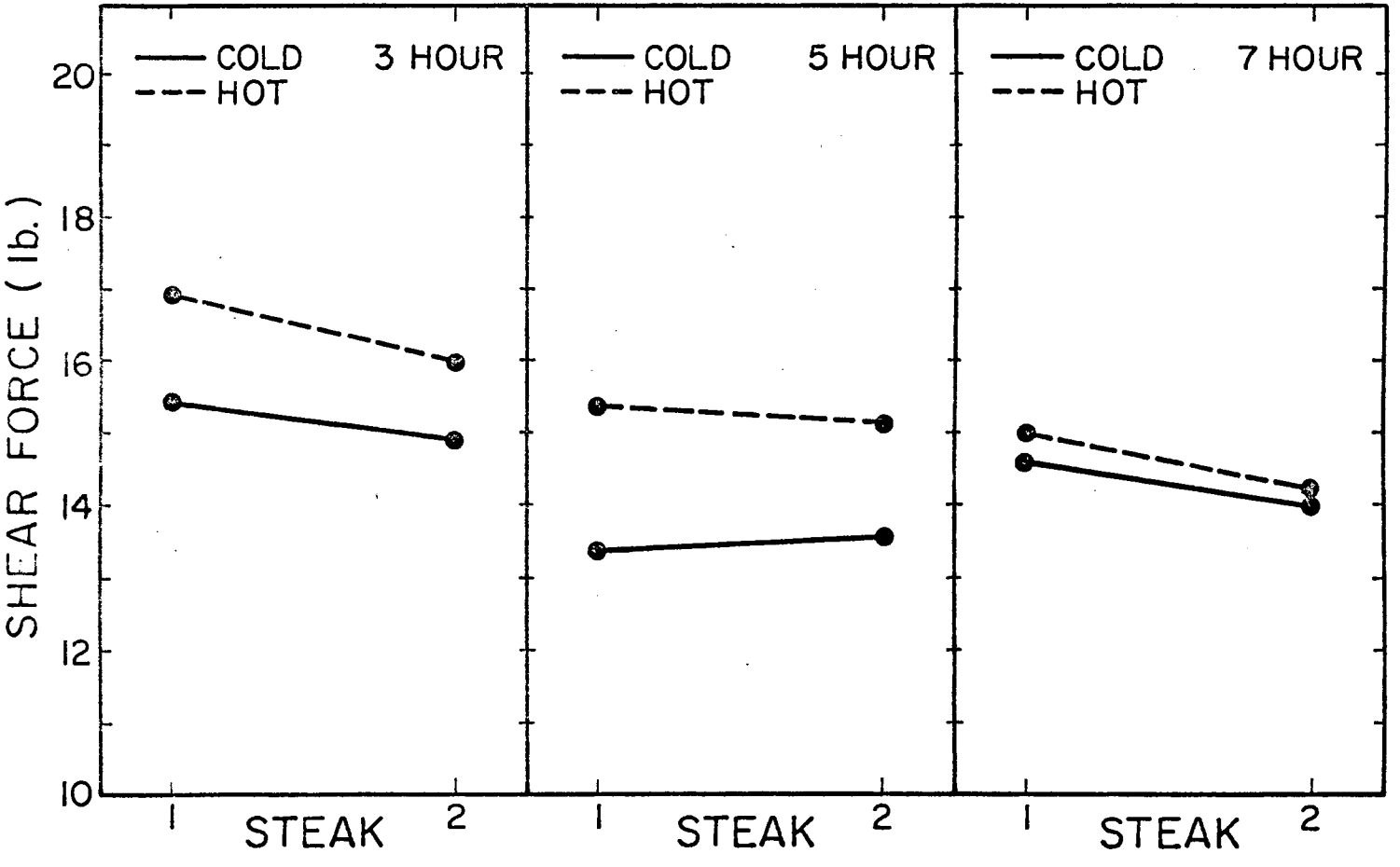

Figure 6. Tenderness Evaluation of Longissimus Dorsi by Warner-Bratzler Shear

posterior positions (steaks one and two, respectively) of the LD responded similarly regardless of processing method as evidenced by the nonsignificant ($P > .05$) process x steak interaction which occurred in all three holding periods. Further examination of Figure 6 reveals that steaks excised near the posterior portion of the LD were not influenced by "hot" boning, as much as, steaks from the anterior end. The variable response within a given muscle to "hot" processing may be due in part to connective tissue content, mode of attachment, and/or the amount of tension upon the muscle at a particular location. The difference in shear force between steaks regardless of processing method, was nonsignificant ($P > .05$) in all holding periods. Similar variations in shear force with respect to steak location in the LD were observed by Weir (1953), Cover et al. (1962), Kastner (1972), and Hansen (1973).

Semimembranosus (SM) Muscle

As shown in Table II and Figure 7, no significant difference ($P < .05$) in shear force existed between "hot" and "cold" boned SM at either the three or five hour holding period. Although the process x steak interaction was nonsignificant, if one compares the difference between processing methods, "hot" processing affected steaks sampled nearer the origin of the SM to a greater extent than steaks taken from nearer the insertion (Figure 7). In both the three and five hour holding periods, "hot" processed steaks required a slightly greater amount of shear force than "cold" boned steaks. Additionally, steak one was significantly ($P < .001$) more tender than steak two. Semimembranosus removed from the "hot" side at seven hours post-mortem had a significantly ($P < .05$) greater shear force than the 48 hour control. The process x steak

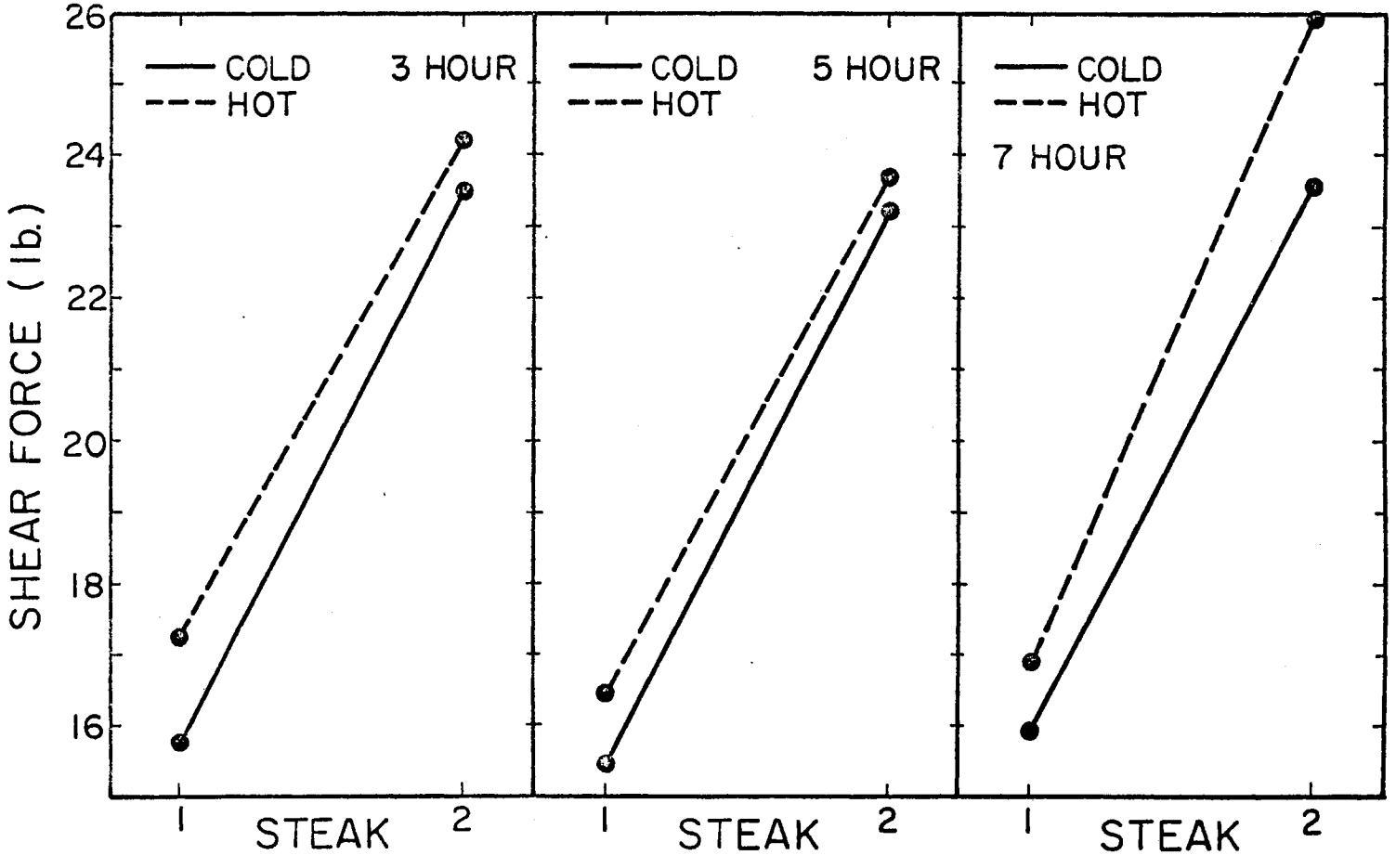

Figure 7. Tenderness Evaluation of Semimembranosus by Warner-Bratzler Shear

interaction was nonsignificant ($P > .05$). Comparing the difference between processing methods, the "hot" process apparently affected the shear force of steak two to a greater extent than steak one. Steak two was significantly ($P < .001$) less tender than steak one in both holding periods regardless of the processing method. Similar variations in the tenderness of the SM were reported by Paul and Bratzler (1955), by Ginger and Weir (1958), and Kastner (1972).

Semitendinosus (ST) Muscle

An analysis of the shear values from "hot" versus "cold" boned ST revealed that no significant difference ($P > .05$) existed for either the three, five, or seven hour holding periods as compared to their corresponding 48 hour controls (Table III). In addition, no significant ($P < .05$) process x steak interaction existed for the three, five, or seven hour holding periods, however, a larger difference was noted between steaks which were nearer the origin of the ST, comparing "hot" to "cold" processing, than steaks taken closer to the insertion, as shown in Figure 8. The increase in shear force, comparing steak one to steak two, was highly significant ($P < .001$) regardless of the processing method.

Overall, if one compares "hot" to "cold" processing for the three muscles evaluated, it may be seen (Tables I, II, and III) that the mean difference between the two processes was always less than two pounds, a value which has questionable practical significance. In fact, it is generally accepted that a minimum difference of at least two pounds of shear force must exist before detection is possible by sensory panel evaluation. Sharrah et al. (1965) further clarifies the magnitude

TABLE III

MEAN SHEAR VALUES OF "HOT" AND "COLD" BONED SEMITENDINOSUS

[a]Holding Period (Hr)	"Cold" Shear Force (lb)	"Hot" Shear Force (lb)	Std. Error of Treatment Mean (lb)
3	20.90	21.68 NS	0.34
5	21.20	21.23 NS	0.27
7	21.76	22.44 NS	0.32

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

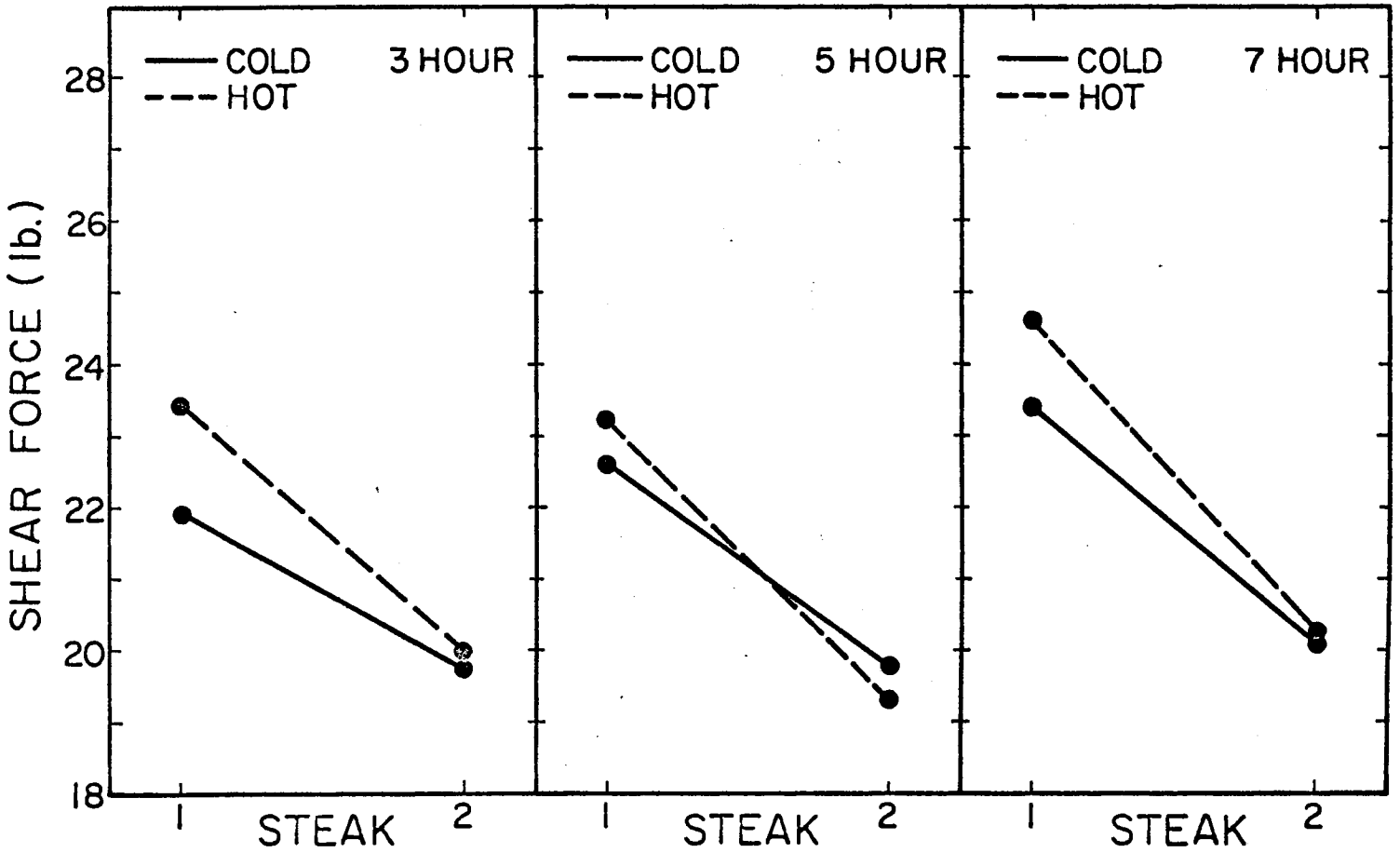

Figure 8. Tenderness Evaluation of Semitendinosus by Warner-Bratzler Shear

of this small difference in that sensory discrimination among samples was more acute within a lower range of shear force values than within a higher range. That is, it is conceivable that two versus four pounds of shear force would be more easily detected by a sensory panel than six versus eight pounds.

Evaluation by Histological Techniques (Sarcomere Length, Fiber Diameter, and Kinkiness Score)

Longissimus Dorsi (LD) Muscle

The effect of "hot" processing on sarcomere length was estimated only in the longissimus dorsi. As discussed in Chapter II, when a muscle shortens, fiber diameter increases, sarcomere length decreases, shear force increases, and tenderness decreases.

Results indicated that the difference in sarcomere length between the "hot" and "cold" boned LD was nonsignificant ($P > .05$) for each of the three holding periods. However, as shown in Table IV and Figures 9 and 10, the sarcomere length of the "cold" boned LD was always slightly greater than the "hot" boned LD. This indicated that muscles excised from the carcass at three, five, or seven hours post-mortem did undergo a slightly greater amount of shortening, as compared to muscles removed at 48 hours post-mortem. Herring et al. (1966; 1967) reported that shear force increased curvilinearly with decreased sarcomere length. As was discussed previously, the slight increase in the shear force value of the "hot" processed LD agreed well with the small decrease in sarcomere length.

Further evidence of shortening was illustrated by an increase in fiber diameter, as well as, an increase in the kinkiness score for the

TABLE IV

ANALYSIS OF SARCOMERE LENGTH IN "HOT" VERSUS "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	Mean "Cold" Sarcomere Length(μm)	Mean "Hot" Sarcomere Length(μm)	Std. Error of Treatment Mean(μm)
3	2.58	2.45 NS	0.05
5	2.48	2.40 NS	0.02
7	2.70	2.57 NS	0.03

[a]Post-mortem holding period for "hot" side.

NS = Nonsignificant.

TABLE V

ANALYSIS OF FIBER DIAMETER IN "HOT" VERSUS "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	Mean "Cold" Fiber Diameter (μm)	Mean "Hot" Fiber Diameter (μm)	Std. Error of Treatment Mean (μm)
3	63.72	69.84*	1.52
5	63.52	67.16 NS	1.34
7	64.48	66.04 NS	1.88

[a]Post-mortem holding period for "hot" side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned sides.

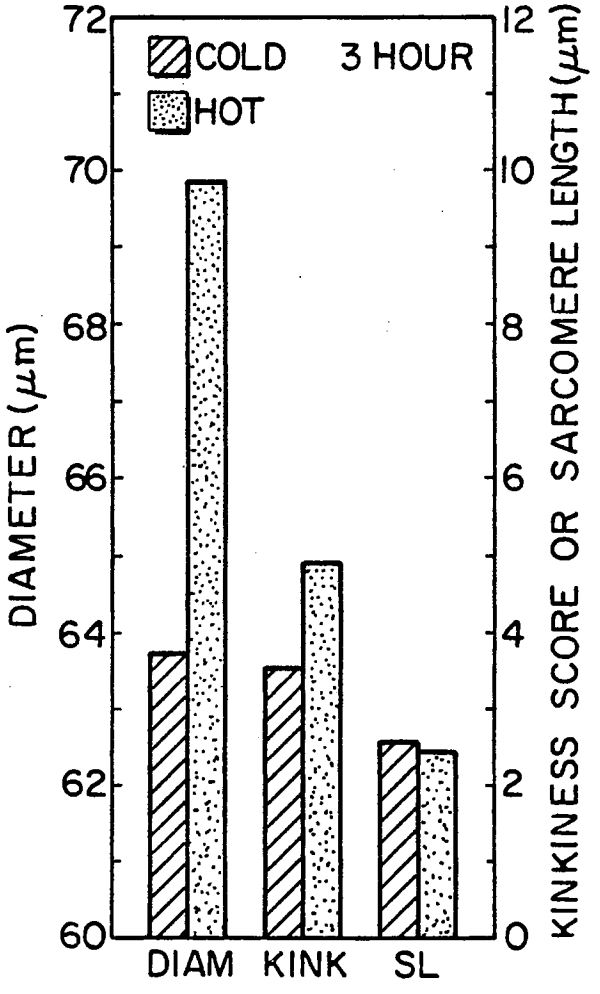

Figure 9. Fiber Characteristics of Bovine Longissimus Dorsi Excised "Hot" and "Cold"

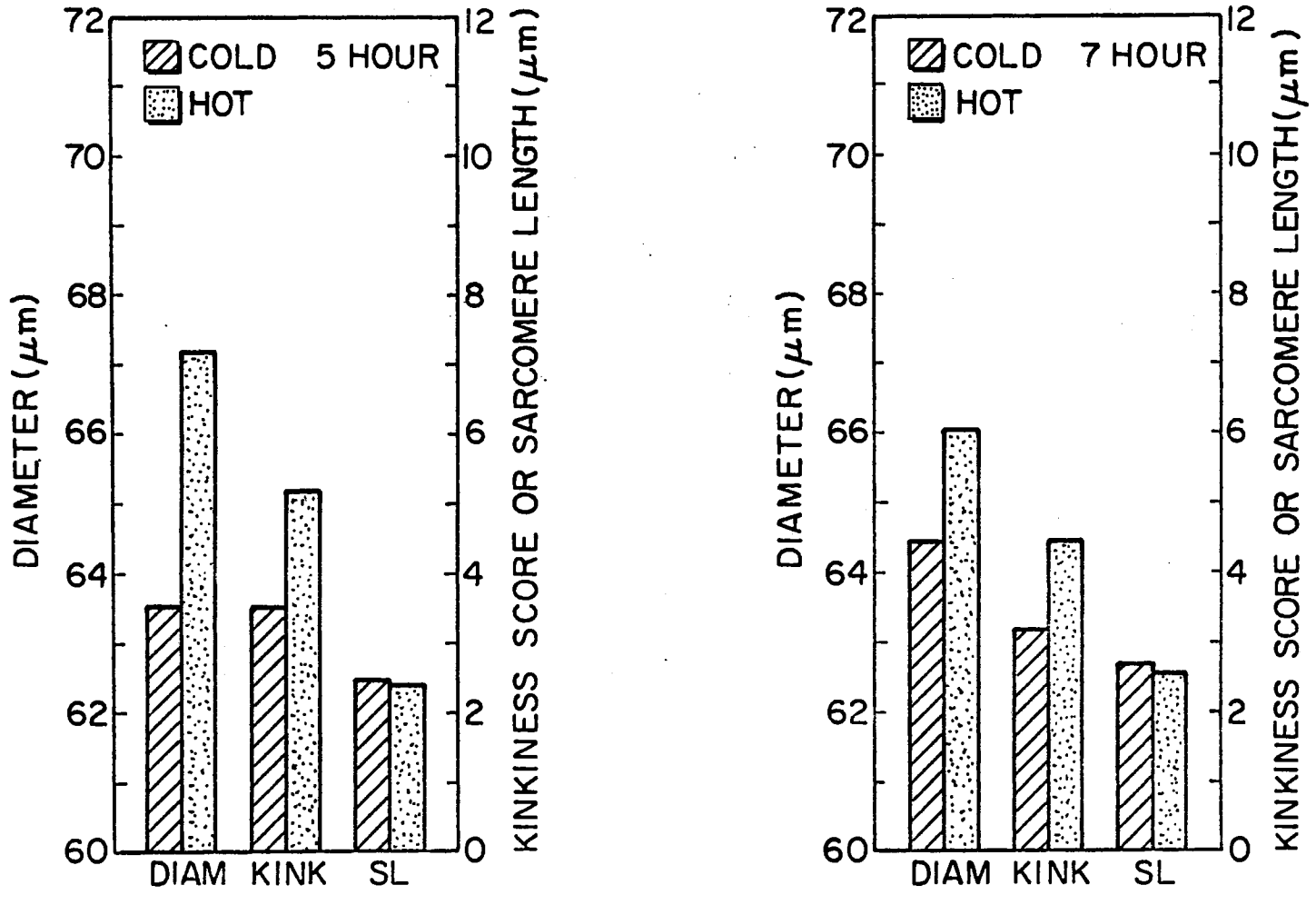

Figure 10. Fiber Characteristics of Bovine Longissimus Dorsi Excised "Hot" and "Cold"

"hot" boned LD as compared to LD processed conventionally. As shown in Table V and Figures 9 and 10, differences in fiber diameter at the five and seven hour holding periods versus the corresponding 48 hour controls were not statistically different ($P > .05$). Measurement of fiber diameter for the three hour holding period showed a significant difference ($P < .05$) between the "hot" and "cold" boned muscles. The observations of increased fiber diameter in "hot" LD muscles agreed well with both the shear force and sarcomere length studies, as well as, with Herring et al. (1967) who showed that shear force increased and sarcomere length decreased with increased fiber diameter. In addition, the relationship of fiber diameter to muscle shortening and tenderness was also demonstrated by Ramsbottom and Strandine (1949), Hiner et al. (1949), Herring et al. (1965; 1966), Buck and Black (1967), Gillis and Henrickson (1970), and Cagle and Henrickson (1970).

Measurement of fibers for kinkiness score was shown by Gillis and Henrickson (1970) and Cagle and Henrickson (1970) to be another estimate of the contraction state of a muscle. The higher a muscle fiber is scored for kinkiness, the more severely contracted the muscle, the higher the shear force, and the less acceptable the tenderness. The analysis of variance indicated that the "hot" processed LD had a significantly higher ($P < .05$) kinkiness score than the corresponding 48 hour controls at all holding periods as shown in Table VI and Figures 9 and 10. However, the largest difference in fiber diameter between "hot" versus "cold" boned LD was 6.12 μm. In addition, kinkiness scores for both "hot" versus "cold" boned LD were in the range of three to five, indicating that the contraction state of the fibers ranged from wavy to twisted. If severe contraction and subsequent shortening had occurred

TABLE VI

ANALYSIS OF KINKINESS SCORE IN "HOT" VERSUS "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	Mean "Cold" Kinkiness Score	Mean "Hot" Kinkiness Score	Std. Error of Treatment Mean
3	3.54	4.90*	0.35
5	3.52	5.16*	0.33
7	3.18	4.46*	0.28

[a]Post-mortem holding period for "hot" side.

* = Significant difference ($P < .05$) between "hot" and "cold" boned sides.

in the "hot" boned LD, one would expect the fibers to show kinkiness scores in the range from six to seven, that is, from twisted-plus to kinky.

Semimembranosus (SM) Muscle

Mean fiber diameters of "hot" versus "cold" SM showed the opposite effect that was demonstrated in the LD, that is, the fiber diameter was larger for the "cold" processed than for "hot" processed SM. Statistical analysis revealed that the fiber diameter of the 48 hour control was larger ($P < .05$) than the three hour "hot" processed SM, however, as may be observed in Table VII and Figure 11 the difference between the two processes was only 4.0 μm. Fiber diameters between the two processes at the five and seven hour holding periods were not statistically different at the five percent level of probability. A large difference in contraction state was not anticipated, as work by Herring et al. (1965a) and Hostetler et al. (1970; 1972; 1973) demonstrated that suspending the side by the Achilles tendon does not exert a stretching effect on the SM, therefore, removal of the intact muscle should not adversely influence its tenderness. Differences in fiber kinkiness score between the experimental and control treatments were nonsignificant ($P > .05$) for all three holding periods. As may be seen in Table VIII and Figure 11, scores ranged from wavy to wavy-plus, thus adding further evidence that the difference in the degree of contraction in the two processes was slight. As with the LD, the minor variations between the two processes with respect to shortening were reflected by small differences in shear force as were previously discussed.

TABLE VII

ANALYSIS OF FIBER DIAMETER IN "HOT" VERSUS "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	Mean "Cold" Fiber Diameter(μm)	Mean "Hot" Fiber Diameter(μm)	Std. Error of Treatment Mean(μm)
3	62.00	58.00*	0.69
5	62.24	61.16 NS	1.48
7	61.36	60.04 NS	1.09

[a]Post-mortem holding period for "hot" side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" processed sides.

TABLE VIII

ANALYSIS OF KINKINESS SCORE IN "HOT" VERSUS "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	Mean "Cold" Kinkiness Score	Mean "Hot" Kinkiness Score	Std. Error of Treatment Mean
3	4.66	3.98 NS	0.29
5	4.30	4.38 NS	0.27
7	4.91	4.47 NS	0.25

[a]Post-mortem holding period for "hot" side.

NS = Nonsignificant.

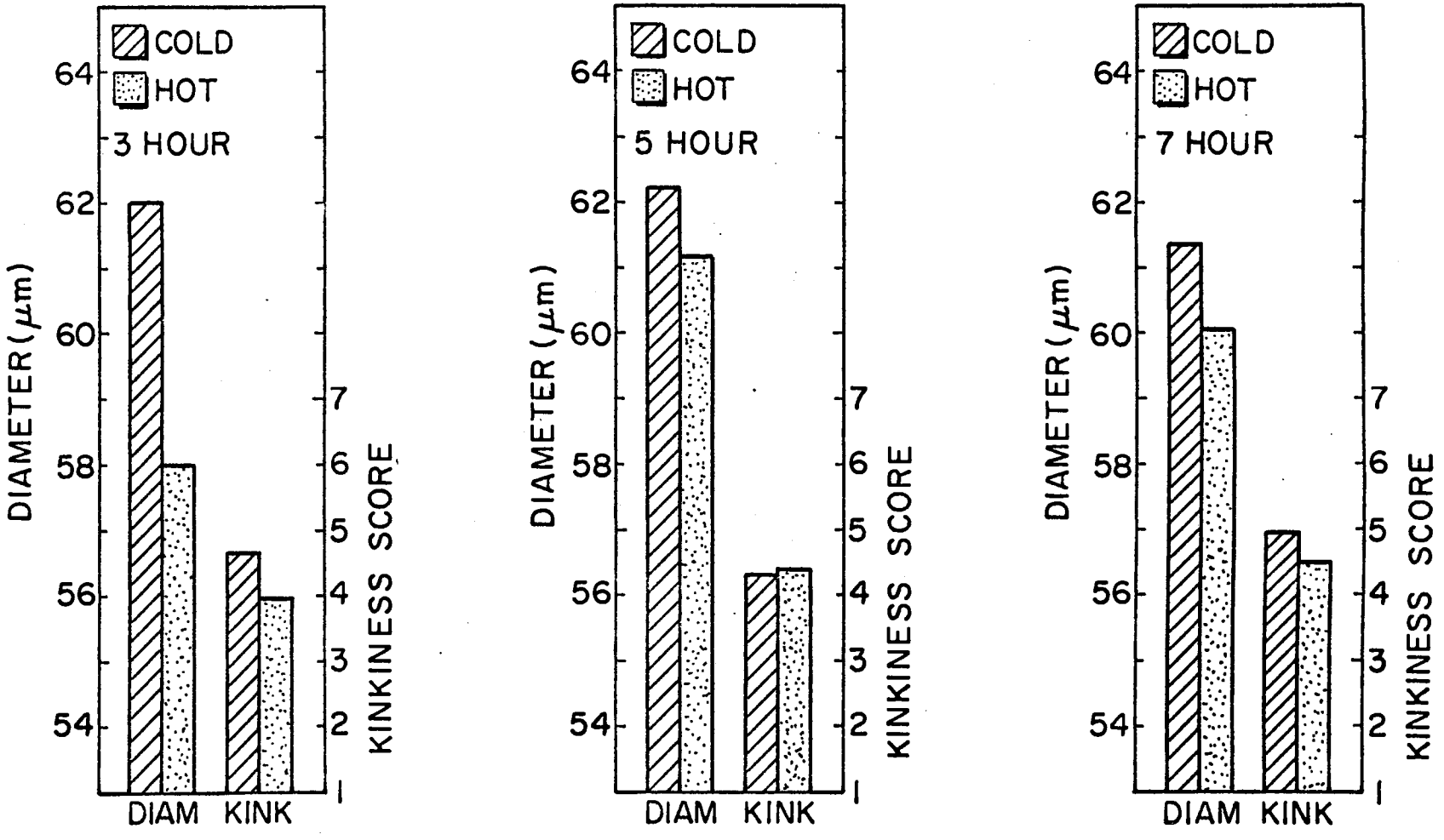

Figure 11. Fiber Characteristics of Bovine Semimembranosus Excised "Hot" and "Cold"

Semitendinosus (ST) Muscle

As with the LD muscle, the mean fiber diameter was always greater for "hot" processed ST than for the "cold" processed muscle. However, as shown in Table IX and Figure 12, the largest difference in fiber diameter was only 7.0 μm, occurring at the three hour holding period. Although the mean difference was significant ($P < .05$), there was no significant decrease in tenderness as estimated by shear force. Differences in fiber diameter between "hot" and "cold" processed ST were not statistically different ($P > .05$) at the five and seven hour holding periods. Kinkiness score analysis (Table X and Figure 12) revealed that the differences were nonsignificant ($P > .05$) for all holding periods. The histological evaluation of the ST was in good agreement with the previously discussed shear values.

Evaluation by Sensory Panel

Longissimus Dorsi (LD) Muscle

A review of Table 85 as shown in Kramer and Twigg (1966), revealed that 73/120 correct duo-trio pairings are required in order to achieve a significant difference at the five percent level. Thus, as shown in Table XI, this criterion was met only at the seven hour holding period. The test at the three and five hour holding periods was nonsignificant ($P > .05$) indicating that the judges could not distinguish differences in tenderness between "hot" and "cold" processed LD.

Preference analysis for the three hour holding period (Table XII) revealed that the panelists preferred the "cold" LD with a slightly higher frequency than LD which was "hot" processed, however, the differ-

TABLE IX

ANALYSIS OF FIBER DIAMETER IN "HOT" VERSUS "COLD" BONED SEMITENDINOSUS

[a]Holding Period (Hr)	Mean "Cold" Fiber Diameter(μm)	Mean "Hot" Fiber Diameter(μm)	Std. Error of Treatment Mean(μm)
3	58.64	65.12*	1.64
5	59.48	61.00 NS	2.05
7	54.76	54.88 NS	1.28

[a]Post-mortem holding period for "hot" side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" versus "cold" processed sides.

TABLE X

ANALYSIS OF KINKINESS SCORE IN "HOT" VERSUS "COLD" BONED SEMITENDINOSUS

[a]Holding Period (Hr)	Mean "Cold" Kinkiness Score	Mean "Hot" Kinkiness Score	Std. Error of Treatment Mean
3	3.62	3.00 NS	0.26
5	3.63	3.01 NS	0.27
7	3.88	3.27 NS	0.28

[a]Post-mortem holding period for "hot" side.

NS = Nonsignificant.

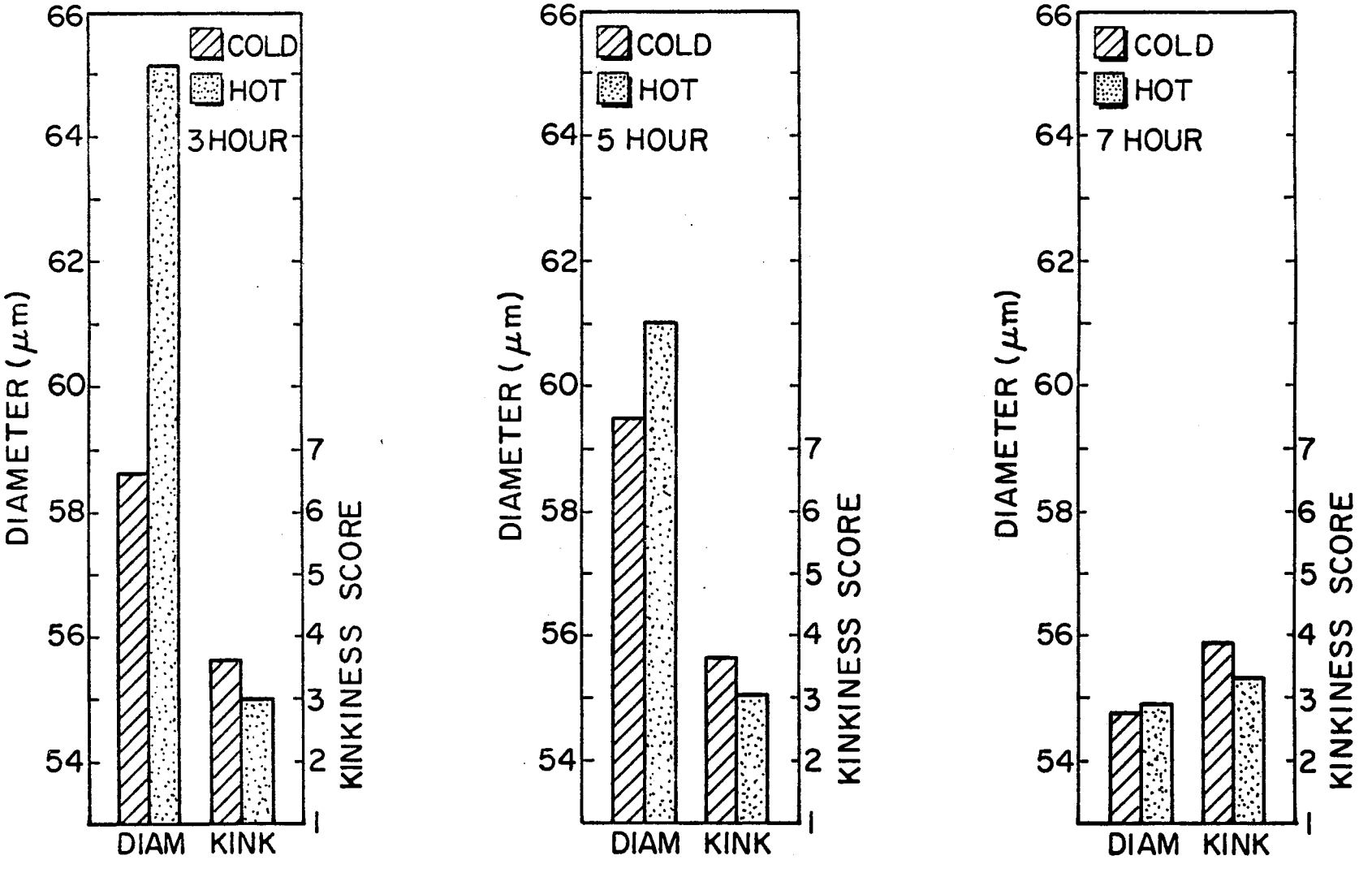

Figure 12. Fiber Characteristics of Bovine Semitendinosus Excised "Hot" and "Cold"

TABLE XI

PAIRED COMPARISON ANALYSIS FOR THE LONGISSIMUS DORSI

[a]Holding Period (Hr)	Total Number of Paired Comparisons	Total Number Identifying Pair
3	120	63 NS
5	120	62 NS
7	120	73*

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

TABLE XII

PREFERENCE RANK ANALYSIS FOR THE LONGISSIMUS DORSI

[a]Holding Period (Hr)	[b]Mean Rank of "Cold" Boned Steaks	[b]Mean Rank of "Hot" Boned Steaks
3	1.60	1.40 NS
5	1.62	1.38*
7	1.48	1.52 NS

[a]Post-mortem holding period for "hot" boned side.

[b]Larger value denotes increased preference.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

ences in frequency of preference between the two processes was not statistically different ($P > .05$). As shown in Figure 13, the steaks from the anterior and posterior portion of the LD performed similarly regardless of processing method as evidenced by the nonsignificant ($P > .05$) process x steak interaction.

At the five hour holding period, the judges preferred the "cold" boned LD to its "hot" boned counterpart a significantly ($P < .05$) greater number of times (Table XII). As evidenced in Figure 13, the difference in preference frequency between the two processes in steak one versus steak two was almost identical. In addition, the process x steak interaction was nonsignificant ($P > .05$) at the five hour holding period.

Evaluation of the seven hour holding period (Table XII) showed that the judges preferred the "hot" processed LD to the 48 hour control a slightly greater number of times, however, the difference was again nonsignificant at the five percent level of probability. Figure 13 illustrates the similarity in preference between the two processes, in fact, panelists preferred "hot" and "cold" boned steak two with equal frequency. As with the previous holding periods, the process x steak interaction was nonsignificant ($P > .05$).

Results of the hedonic score assignments (Table XIII) for the three hour holding period indicated that the judges scored the 48 hour control a higher level of acceptability a greater number of times ($P < .05$) than the LD counterpart which had been "hot" boned. However, as indicated in Table XIII, the mean tenderness score was in the range of slightly acceptable, therefore, the practical difference in score assignment was small. The process x steak interaction for the three hour holding period was nonsignificant ($P > .05$) as illustrated in Figure 14.

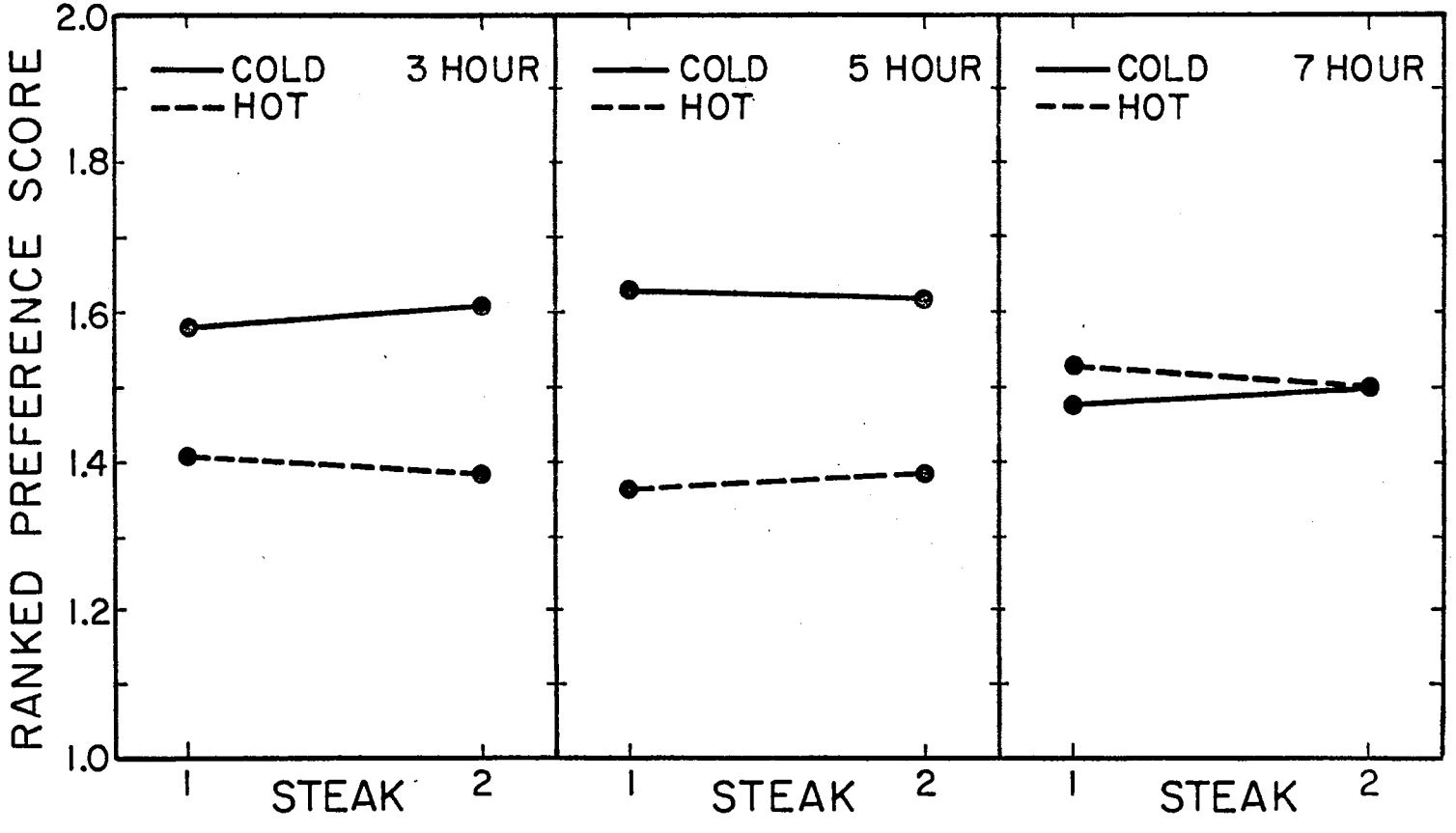

Figure 13. Frequency of Preference for "Hot" Versus "Cold" Boned Longissimus Dorsi

TABLE XIII

HEDONIC SCALE SCORE RANK ANALYSIS FOR THE LONGISSIMUS DORSI

[a]Holding Period (Hr)	[b]Mean "Cold" Hedonic Score	[b]Mean "Hot" Hedonic Score	[b]Mean "Cold" Ranked Score	[b]Mean "Hot" Ranked Score
3	4.42	4.14	1.59	1.41*
5	4.68	4.42	1.59	1.41 NS
7	4.41	4.47	1.48	1.52 NS

[a]Post-mortem holding period for "hot" boned side.

[b]Larger value denotes higher acceptability.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

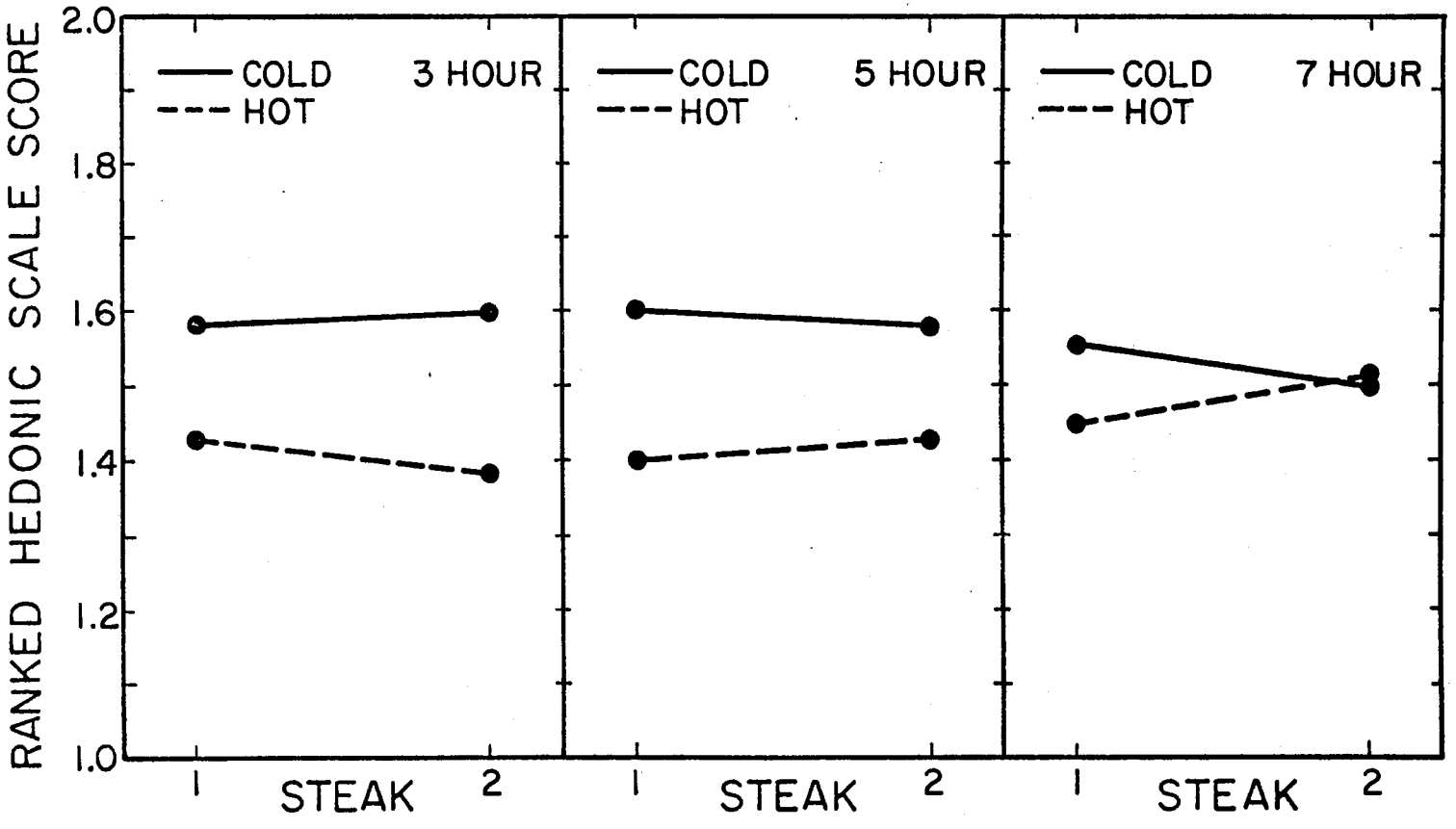

Figure 14. Rank Frequency of the Hedonic Scale Score for "Hot" Versus "Cold" Boned Longissimus Dorsi

The level of acceptability assignments followed a similar trend at the five hour holding period as the judges scored the "cold" processed LD with a higher value more frequently than the "hot" boned muscle, however, as shown in Table XIII, the difference was nonsignificant ($P > .05$). The absence of significance was reflected in the actual hedonic score, as both processes were assigned values in the range of slightly acceptable. From Figure 14, it may be observed that steaks one and two followed similar trends regardless of the processing method, as evidenced by the nonsignificant ($P > .05$) process x steak interaction.

The difference in the frequency of higher acceptability assignment for "hot" versus "cold" processed LD at the seven hour holding period was not statistically different ($P > .05$). However, as shown in Table XIII and Figure 14, the panelists tended to assign the "hot" processed LD a higher level of acceptability more frequently than the 48 hour control. Examination of Figure 14 reveals that this statement is true for steak one, however, panelists found "hot" and "cold" boned steak two to be almost equally acceptable. As before, the process x steak interaction was nonsignificant ($P > .05$) at the seven hour holding period.

Comparison of Figures 13 and 14 with Figure 6 illustrated that the tenderness evaluation of the LD reflected the shear force analysis quite well. As the difference in shear force increased between the two processes, the magnitude of the difference in preference and level of acceptability increased. Thus the "hot" process showed slight decreases in preference and acceptability if one compares the three and seven hour holding periods to the five hour holding period, as well as, the seven to the three hour holding period. As may also be noted in the above figures, minimization in the difference between the two processes oc-

curred at the seven hour holding period. The author questions the significance of the duo-trio test at the seven hour holding period in view of the fact that almost no difference in preference or level of acceptability occurred between the "hot" and "cold" boned LD. Based on these data, it is felt that the results of the duo-trio test were due more to chance than to treatment effect. Significant differences in acceptability and preference scores indicated in the three and five hour holding periods, respectively, were greatly diminished by the fact that judges could not differentiate between processes in the duo-trio analysis, and in addition, by the similarity in the actual acceptability scores. Therefore, the lack of agreement of the duo-trio test with the preference and acceptability analyses was good indication that differences in tenderness within steaks of a given process were no greater than differences between processes.

Other investigators have reported relationships between objective and subjective evaluations of tenderness. Pearson (1963) reviewed numerous experiments and observed that the correlation between various sensory methods and the Warner-Bratzler shear was generally in the range of -0.60 to -0.85 with an average value of about -0.75. Sharrah et al. (1965) observed a significant correlation of -0.73 between objective and subjective measures of tenderness. Recently, Gacula et al. (1971) reported a correlation of -0.86.

Semimembranosus (SM) Muscle

Analysis of the duo-trio test indicated that panelists were correctly able to pair the reference sample with its corresponding unknown 60, 51, and 59 times out of 120 trials each for the three, five,

and seven hour holding periods. As indicated in Table XIV, analysis of these data by using Table 85 as shown in Kramer and Twigg (1966) revealed that the judges could not significantly distinguish ($P > .05$) differences between "hot" versus "cold" boned SM at any of the three holding periods.

Analysis of the preference ranking indicated that the judges preferred the "cold" processed SM a greater number of times ($P < .05$) than SM excised at three hours post-mortem (Table XV). Figure 15 illustrates that although the difference in frequency of preference of the 48 hour control versus "hot" processed SM was greater in steak two than in steak one, the process x steak interaction was nonsignificant ($P > .05$) at the three hour holding period.

As shown in Table XV, the "cold" processed SM was again preferred to the five hour "hot" boned muscle with a slightly greater frequency, although the difference in preference was not statistically different at the 0.05 probability level. Judges tended to prefer the 48 hour control to the "hot" boned SM with a slightly greater frequency in steak one as compared to steak two where, as shown in Figure 15, the two processes were preferred equally. The process x steak interaction was again nonsignificant ($P > .05$).

At the seven hour holding period, the panelists preferred the conventional process to the "hot" boned SM a slightly greater number of times, however, the difference in preference was again nonsignificant ($P > .05$). Judges preferred the "hot" process to the 48 hour control with a slightly higher frequency in steak one (Figure 15). Steak two however, showed a greater magnitude of difference in preference frequency, but in this case, the "cold" processed SM was preferred.

TABLE XIV

PAIRED COMPARISON ANALYSIS FOR THE SEMIMEMBRANOSUS

[a]Holding Period (Hr)	Total Number of Paired Comparisons	Total Number Identifying Pair
3	120	60 NS
5	120	51 NS
7	120	59 NS

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

TABLE XV

PREFERENCE RANK ANALYSIS FOR THE SEMIMEMBRANOSUS

[a]Holding Period (Hr)	[b]Mean Rank of "Cold" Boned Steaks	[b]Mean Rank of "Hot" Boned Steaks
3	1.59	1.40*
5	1.54	1.46 NS
7	1.53	1.47 NS

[a]Post-mortem holding period for "hot" boned side.

[b]Larger value denotes increased preference.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

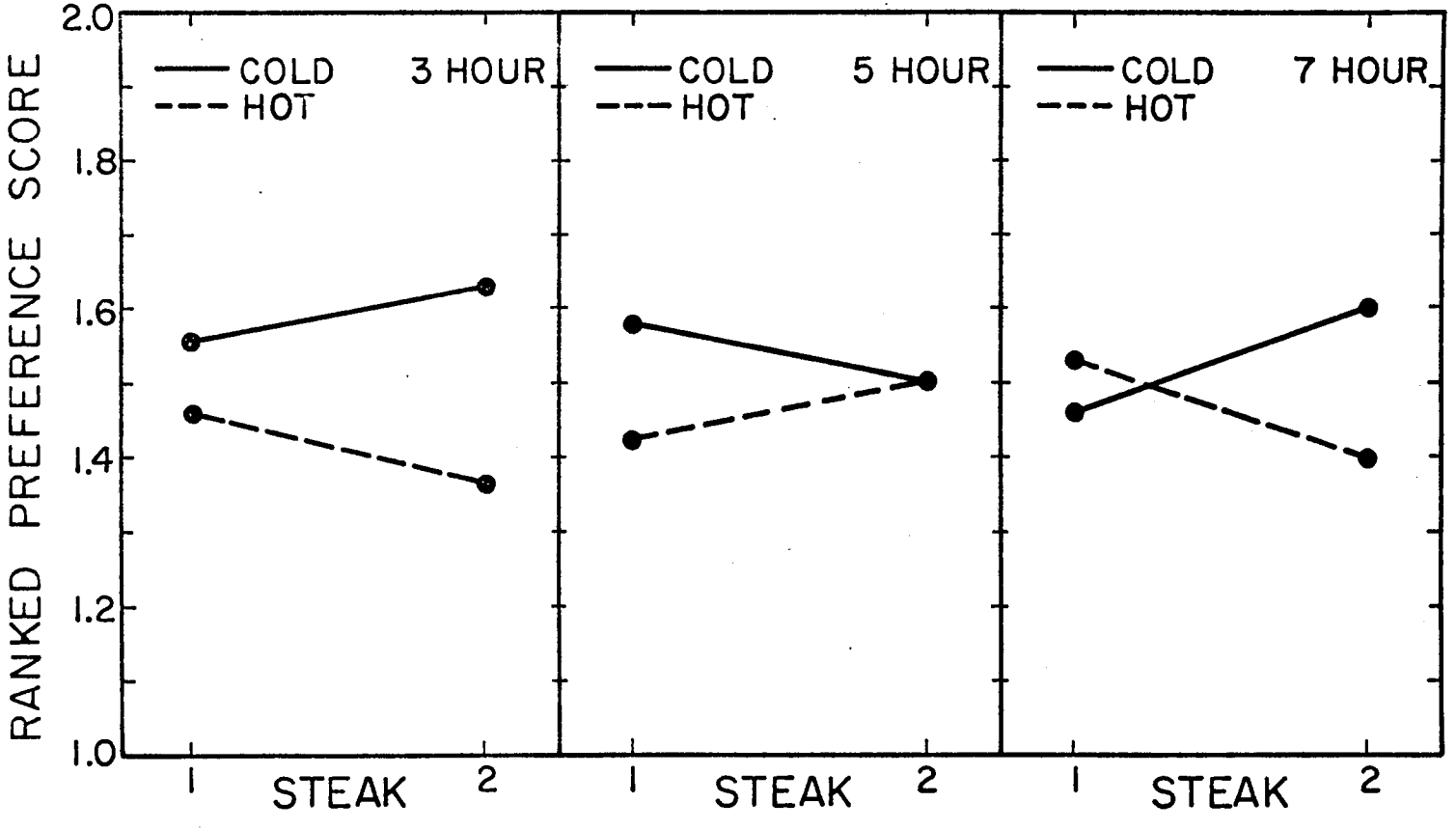

Figure 15. Frequency of Preference for "Hot" Versus "Cold" Boned Semimembranosus

Statistical analysis revealed that the discrepancey was small and therefore, the process x steak interaction was nonsignificant ($P > .05$).

Rank analysis of the ranked hedonic scale scores revealed that the judges assigned the tenderness of the 48 hour control a higher level of acceptability (Table XVI) than the three hour "hot" boned SM, however, the difference in frequency was nonsignificant ($P > .05$). As may be observed in Figure 16, the magnitude of the difference in the level of acceptability between the two processes was higher for steak two than for steak one where the judges scored the two processes equally. The steak x process interaction for the three hour holding period, however, was found to be nonsignificant ($P > .05$).

The difference in ranking the "cold" process over the "hot" boned SM was nonsignificant ($P > .05$) for both the five and seven hour holding periods (Table XVI). As shown in Figure 16 differences did occur in the magnitude of the frequency of assigning one process a higher level of acceptability over the other in steak one versus steak two at both the five and seven hour holding periods. However, the process x steak interaction was nonsignificant ($P > .05$). As may be noted in Table XVI, the judges assigned both processes a hedonic score in the range of slightly acceptable at all three holding periods. The somewhat low acceptability level was probably a result of the method of cookery and the fact that the muscles were not aged.

As with the LD, the inability of the panelists to detect large differences in tenderness reflected the small differences in shear force which existed at all of the holding periods evaluated (Figure 7). Even though small differences in tenderness unquestionably existed between the two processes, one must consider that they would be minimized further

TABLE XVI

HEDONIC SCALE SCORE RANK ANALYSIS FOR THE SEMIMEMBRANOSUS

[a]Holding Period (Hr)	[b]Mean "Cold" Hedonic Score	[b]Mean "Hot" Hedonic Score	[b]Mean "Cold" Ranked Score	[b]Mean "Hot" Ranked Score
3	4.08	3.96	1.54	1.46 NS
5	4.19	3.91	1.58	1.42 NS
7	4.07	3.76	1.57	1.43 NS

[a]Post-mortem holding period for "hot" boned side.

[b]Larger value denotes higher acceptability.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

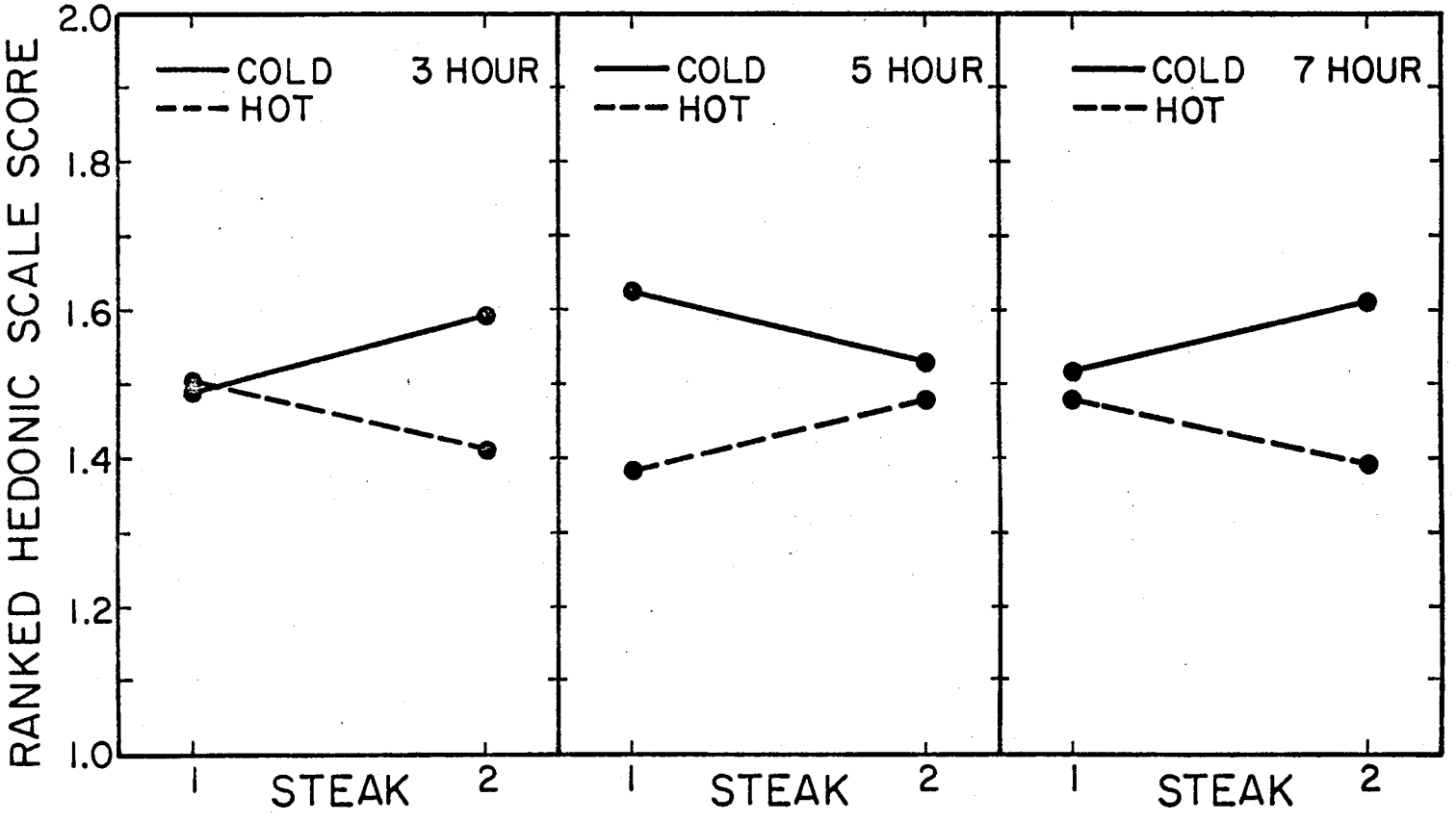

Figure 16. Rank Frequency of the Hedonic Scale Score for "Hot" Versus "Cold" Boned Semimembranosus

by methods of tenderization which are utilized extensively in the industry. Thus, evaluating the tenderness data, it is feasible to initiate excision of muscles from the bovine carcass, in a similar manner to that described in this study, as early as three hours post-mortem.

Effect of "Hot" Processing on Color Acceptability

The importance of color to consumer acceptability was demonstrated by Danner (1959) and Dunsing (1959a,b) who showed that the physical appearance of a retail cut in the display case was the most important factor utilized in the retail selection of meat products. The consumer selects a meat cut primarily for leaness, and then for appearance and freshness, with the latter judgements based primarily on brightness of color (ASPC, 1964; Rhodes et al., 1955; Seltzer, 1955). Shaw, as cited by Nelson (1964), further emphasized the importance of an attractive lean color by reporting that 36.7 percent of the meat purchases from self-service counters were unplanned and that these impulse purchases were made primarily because of attractive appearance. Allen (1968) described the ideal beef color as "cherry red". In view of the important role that color has in consumer acceptability, a second sensory panel was utilized to determine if significantly large differences existed between "hot" and "cold" processed LD and SM muscles.

Longissimus Dorsi (LD) Muscle

Analysis of the duo-trio sensory panel indicated that the judges were able to correctly pair the color of the reference sample with its corresponding unknown 44, 36, and 32 times out of 60 trials each for the

TABLE XVII

PAIRED COMPARISON ANALYSIS OF THE COLOR OF "HOT" AND "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	Total Number of Paired Comparisons	Total Number Identifying Pair
3	60	44*
5	60	36 NS
7	60	32 NS

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

TABLE XVIII

PREFERENCE RANK ANALYSIS OF THE COLOR OF "HOT" AND "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	[b]Mean Rank of "Cold" Boned Steaks	[b]Mean Rank of "Hot" Boned Steaks
3	1.63	1.37*
5	1.58	1.42 NS
7	1.45	1.55 NS

[a]Post-mortem holding period for "hot" boned side.

[b]Larger value denotes increased preference.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

TABLE XIX

HEDONIC SCALE SCORE RANK ANALYSIS OF THE COLOR OF "HOT" AND "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	[b]Mean "Cold" Hedonic Score	[b]Mean "Hot" Hedonic Score	[b]Mean "Cold" Ranked Score	[b]Mean "Hot" Ranked Score
3	4.30	4.30	1.56	1.44 NS
5	4.63	4.53	1.54	1.46 NS
7	4.45	4.51	1.50	1.50 NS

[a]Post-mortem holding period for "hot" boned side.

[b]Larger value denotes higher acceptability.

NS = Nonsignificant.

three, five, and seven hour holding periods. As shown in Table XVII, analysis of these data by Table 85 of Kramer and Twigg (1966) revealed that the judges could only distinguish ($P < .05$) a difference between the color of the "hot" and "cold" processed LD at the three hour holding period.

The preference rank analysis indicated that the panelists preferred the color of the "cold" LD with a higher frequency than the LD excised at three and five hours post-mortem. However, as indicated in Table XVIII, the difference in the frequency of preference was only significant ($P < .05$) at the three hour holding period. These results agree with Kastner (1972) who found that the two hour "hot" boned product was somewhat darker than the control and was thought to have a more compact or closed structure. Thus, the "hot" boned product may not have allowed surface oxygenation of myoglobin to the same extent as the relatively open structure of the "cold" boned product. At the seven hour holding period, the judges preferred the "hot" processed LD to the "cold" product with a slightly greater frequency ($P > .05$).

Rank analysis of the hedonic scale assignment of acceptability showed that the judges found the color from both processes to be equally acceptable (Table XIX) at three hours post-mortem. However, rank analysis of the scale assignments found that the judges rated the "cold" process higher a slightly greater number of times than the "hot" process ($P > .05$). Essentially the same trend in hedonic scale assignment was followed at the five hour holding period as the "cold" process was given a higher level of acceptability than the "hot" process with slightly greater frequency ($P > .05$). In agreement with the previous sensory data assessing the color of "hot" versus "cold" LD at the seven hour holding period, the "hot" process was assigned a somewhat higher level of acceptability than the "cold" process ($P > .05$).

Semimembranosus (SM) Muscle

The duo-trio color panel analysis of "hot" versus "cold" boned semimembranosus muscle showed that the judges were correctly able to pair the reference sample with its corresponding unknown 47, 34, and 45 times out of 60 trials each for the three, five, and seven hour holding periods. Analysis of these data showed that the judges were able to significantly ($P < .05$) distinguish between the color of "hot" and "cold" boned semimembranosus at both the three and seven hour holding periods, however, as shown in Table XX, no significant difference ($P > .05$) was noted at the five hour treatment.

Preference rank analysis revealed that even though the panelists could discern a difference between "hot" and "cold" boned SM at the three hour holding period, they did not significantly ($P > .05$) discriminate between the color of the two processes. However, as may be noted in Table XXI, the panelists did prefer the "cold" process to the "hot" boned SM with a slightly greater frequency. The five hour holding period preference rank analysis revealed that, as before, the panelists did not discriminate ($P > .05$) between the two processes, although there was a slightly higher frequency of preference for the "hot" processed SM. At the seven hour holding period, the judges preferred ($P < .05$) the "hot" to the "cold" process as shown in Table XXI.

Hedonic scale score rank analysis agreed well with the previous data as shown in Table XXII. Ranked score analysis showed that the panelists did not rate the acceptability of one process over the other a significant ($P > .05$) number of times at either the three or five hour

TABLE XX

PAIRED COMPARISON ANALYSIS OF THE COLOR OF "HOT" AND "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	Total Number of Paired Comparisons	Total Number Identifying Pair
3	60	47*
5	60	34 NS
7	60	45*

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

TABLE XXI

PREFERENCE RANK ANALYSIS OF THE COLOR OF "HOT" AND "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	[b]Mean Rank of "Cold" Boned Steaks	[b]Mean Rank of "Hot" Boned Steaks
3	1.57	1.43 NS
5	1.47	1.53 NS
7	1.27	1.73*

[a]Post-mortem holding period for "hot" boned side.

[b]Larger value denotes increased preference.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

holding periods. Comparison of the five hour holding period in Tables XXI and XXII reveals that although the judges preferred the "hot" to the "cold" process, they tended to assign the "hot" process a slightly lower value more frequently than the "cold" process. This discrepancy may be attributed to the small difference in color which existed between the five hour "hot" boned SM and the 48 hour control. On the other hand, the seven hour "hot" boned SM was assigned a higher level of acceptability with greater frequency ($P < .05$) than the conventionally processed muscle (Table XXII).

As shown in Table XXII, the judges assigned hedonic scale scores in the slightly acceptable range for both the three and five hour boning periods. Thus, the difference in color between the two processes was small and difficult to interpret at the earlier holding periods. However, at the seven hour conditioning period, judges tended to rate the "hot" boned SM in the acceptable range, whereas the "cold" boned product was rated only slightly acceptable. These results agree well with Kastner (1972) who observed that the "hot" boned product, conditioned for five and eight hours, exhibited a significantly brighter, fresher color.

It appears from these data that "hot" boning is feasible as early as three hours post-mortem without diminution of the attractive, cherry-red color that makes the product desirable to the consumer. Additionally, the samples were taken from steaks which had been quickly frozen ($-10^{\circ}C$) and then thawed slowly at $1.1^{\circ}C$. Although caution was exercised in preserving the steaks until sampling was initiated, some localized discoloration of both "hot" and "cold" processed steaks was noted and, in some instances, may have confounded treatment differences. The majority

TABLE XXII

HEDONIC SCALE SCORE ANALYSIS OF THE COLOR OF "HOT" AND "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	[b]Mean "Cold" Hedonic Score	[b]Mean "Hot" Hedonic Score	[b]Mean "Cold" Ranked Score	[b]Mean "Hot" Ranked Score
3	4.33	4.23	1.56	1.44 NS
5	3.95	3.85	1.52	1.48 NS
7	3.70	4.55	1.28	1.78*

[a]Post-mortem holding period for "hot" boned side.

[b]Larger value denotes higher acceptability.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" and "cold" boned steaks.

of steaks utilized for color sampling did not undergo this darkening effect.

Effect of "Hot" Processing on pH and Temperature

As shown in Figures 17 and 18, the pH of "hot" boned psoas major (PM) was always lower from two through the 24 hour measurement period as compared with the 48 hour control. The rate of pH decline also appeared to be slightly greater at the two through five hour post-mortem measurement. The somewhat more rapid rate of pH decline probably was a result of conditioning the "hot" side in a 16°C cooler. Thus the muscles would maintain their temperature (≃ 37°C) for a longer period of time since the temperature differential between the muscle and environment was less than the 48 hour "cold" boned side. As may be noted in Figures 17 and 18, the "hot" processed PM appeared to be near the ultimate pH value (5.5) at 3.5 to four hours post-mortem indicating that the muscle had apparently completed the majority of post-mortem glycolysis and was proceeding into rigor. Similar results were discussed by Busch et al., (1972). These findings support the tenderness data, as well as, the hypothesis of "hot" boning the muscles at three hours post-mortem. Furthermore, differences between the ultimate pH of "hot" versus "cold" boned psoas major were small, thus large differences in water-holding capacity and percent cooking loss were not anticipated.

Variations in muscle size, location, and fiber type have an important role in the rate of temperature decline which subsequently, has a dramatic effect on the rate of post-mortem glycolysis. Therefore, one would not expect all muscles to reach their ultimate pH at the same time. The LD, SM, and ST muscles of the seven hour "hot" boned side were used

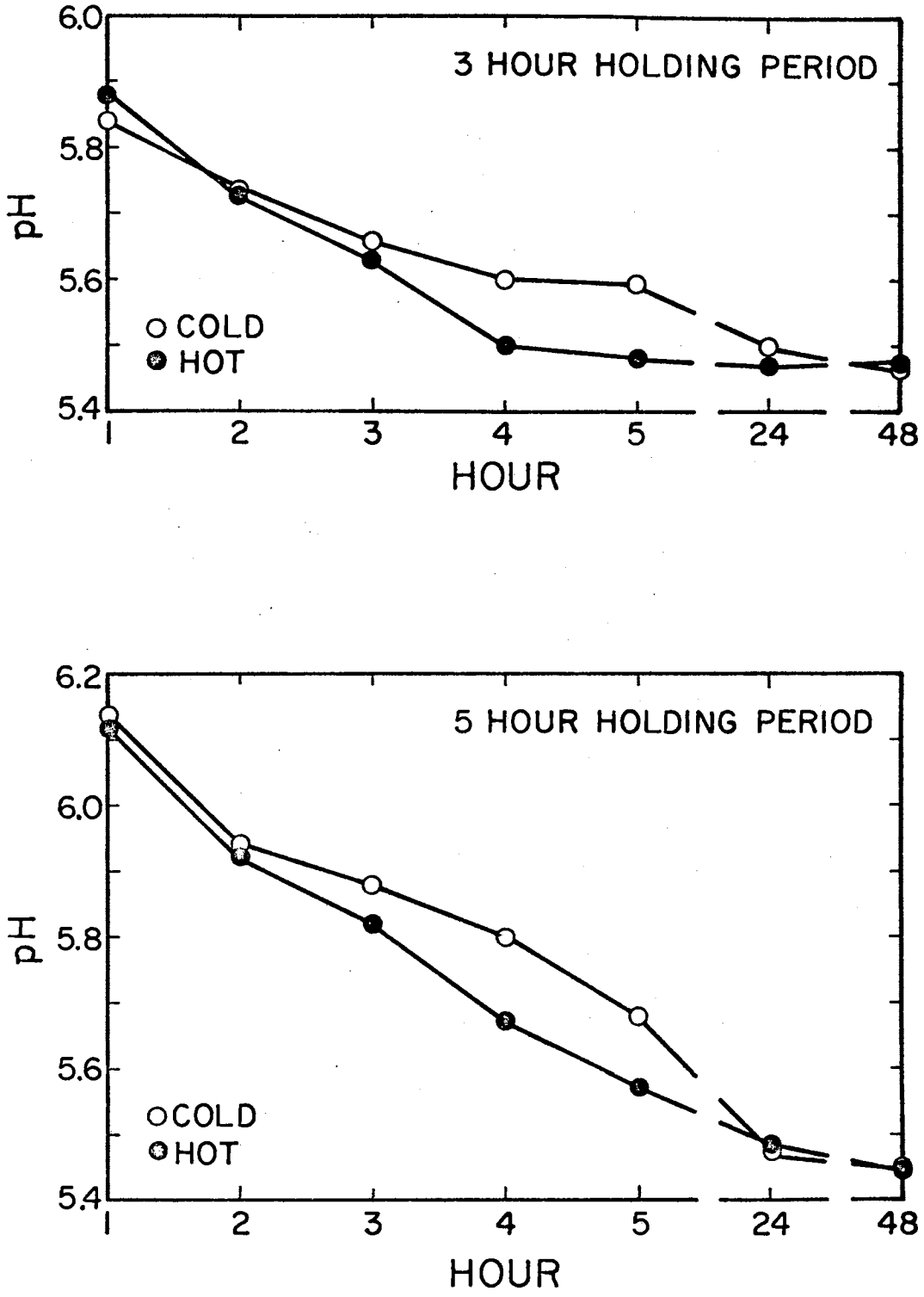

Figure 17. pH Decline in "Hot" Versus "Cold" Boned Psoas Major at the Three and Five Hour Holding Periods

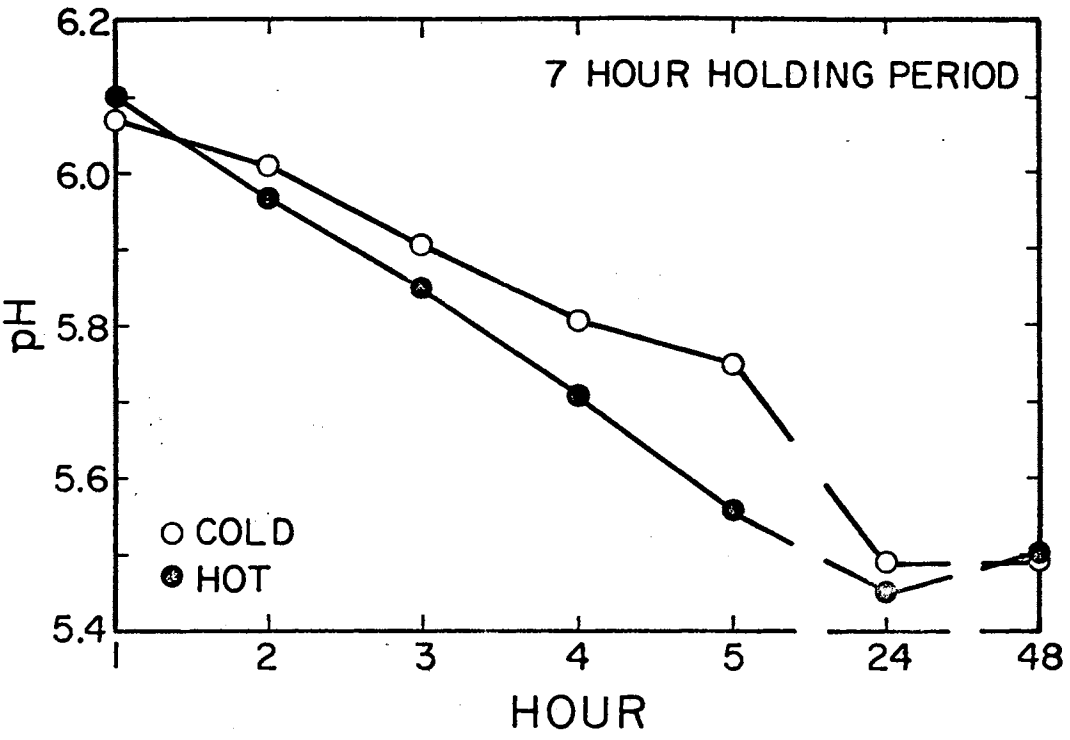

Figure 18. pH Decline in "Hot" Versus "Cold" Boned Psoas Major at the Seven Hour Holding Period

to illustrate the time course of temperature decline. Figure 19 reveals that both the LD and ST muscles had attained their maximum rates of temperature decline from one to three hours post-mortem, whereas, the SM muscle showed almost no temperature decrease during this time interval. As may be noted, the maximum rate of temperature decline in the SM occurred between the five and seven hour time interval. Considering the mass and location of the three muscles studied, one would expect the greatest temperature decline in the LD, followed by the ST, and lastly the SM. Even though there was variation in the degree and rate of temperature decline, it appeared that the muscles studied had either completed or just begun their maximum rate of temperature decline at three hours post-mortem. Realizing that post-mortem glycolysis results in a large amount of heat production, maximal temperature decline would not begin until the glycolytic rate decreased. Thus, estimating the time-course of glycolysis by pH decline, it was shown that a gradual decrease in glycolytic activity was indicated between the interval of one and five hours post-mortem.

Effect of "Hot" Processing on Psychrophilic Bacterial Populations

Psychrophilic bacteria are able to grow at $0^{\circ}C$ or lower, although they show optimum growth at 10 to $20^{\circ}C$ (Pelczar and Reid, 1972). Since meat products are generally stored from 2.0 - $4.4^{\circ}C$ both in the display case and in the home refrigerator, prime consideration was given to the effect of "hot" processing upon bacteria which show optimum growth in this temperature range. As mentioned earlier, plates from serial dilutions were incubated for seven days at $10^{\circ}C$ to facilitate counting.

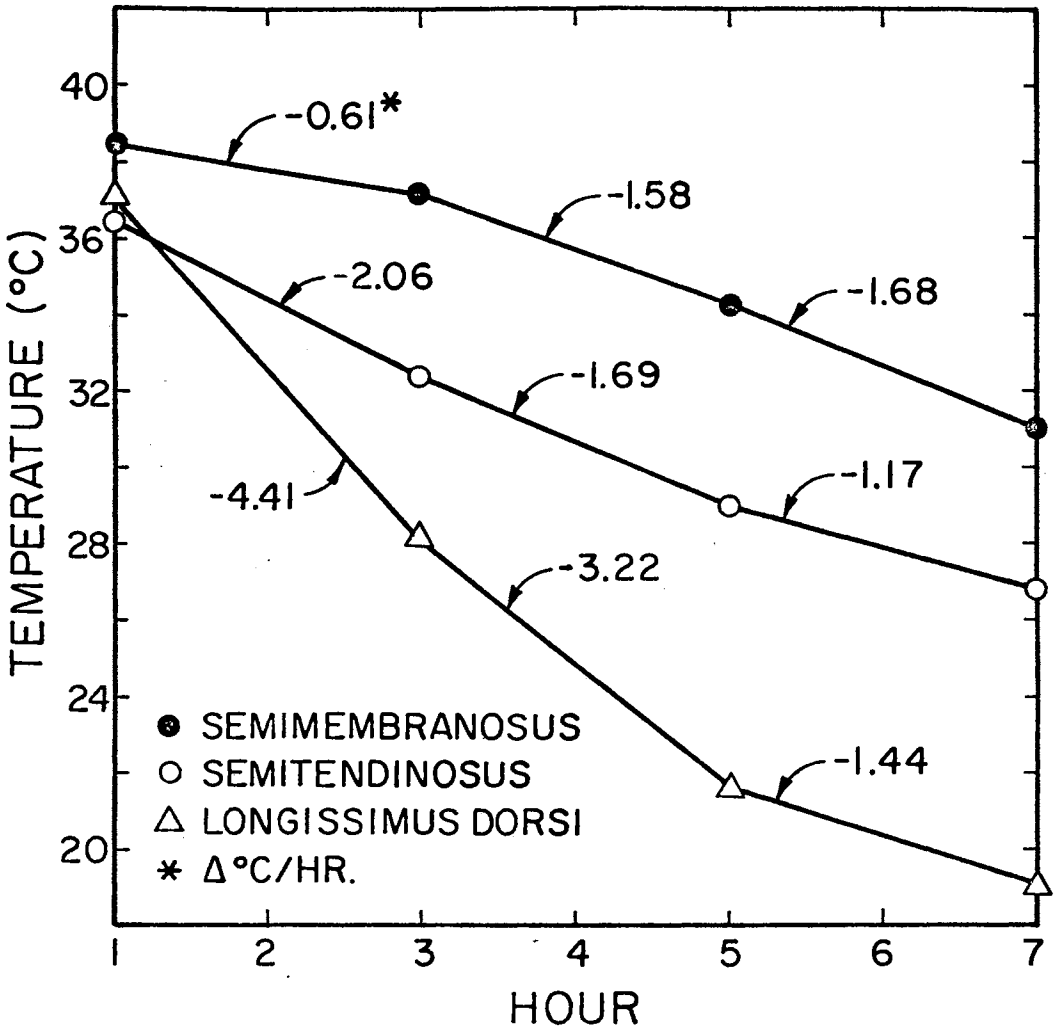

Figure 19. Temperature Decline of Test Muscles in the Seven Hour "Hot" Boned Side

Attempts to count plates from three to five days incubation proved to be unsatisfactory because the slow growth rate of the colonies made counting of the colonies difficult. Logarithms of the actual plate counts were used for analysis in view of the fact that Empey et al. (1939), Hansen (1962), and Rey et al. (1970) observed that the numbers of bacteria on contaminated surfaces showed a wide variation, whereas, the distribution of the logarithms of the bacterial counts was approximately normal. As shown in Table XXIII the evaluation of psychrophilic populations revealed that there was no significant difference ($P < .05$) in mean log number of bacteria per gram in "hot" versus "cold" boned lean trim at any of the three holding periods. Mean bacterial counts for both "hot" and "cold" processed lean trim were less than 10^3 bacteria/gram. As may be further noted in Table XXIII, bacterial counts were slightly higher for "hot" processed lean trim as compared to that which was "cold" boned. It was hoped that the psychrophilic counts would be lower for the "hot" processed muscle in view of the fact that the muscles were stored in Cry-O-Vac bags during the time interval of storage in the $1.1^{\circ}C$ chill cooler. However, it is felt that the number of psychrophiles may be reduced by more rapid processing because of less exposure to possible contamination.

Another point to be considered is that a bacterial count in the range of 10^2 to 10^3/gram was quite low in view of the fact that Kraft and Ayres (1952) reported that the first off odor of freshly sliced beef was detectable when the surface count was 2×10^6 organisms per cm^2. Furthermore, they considered that incipient spoilage was indicated by the onset of off-odor at this level, but definite off-odors were more readily recognized when surface counts on meat samples approximated

TABLE XXIII

MEAN LOGARITHMIC NUMBERS OF PSYCHROPHILIC BACTERIA PER GRAM ON CULTURE PLATES INCUBATED SEVEN DAYS AT 10°C FOR "HOT" VERSUS "COLD" BONED LEAN TRIM

[a]Holding Period (Hr)	"Cold" 10°C Plate Count (Log No./Gram)	"Hot" 10°C Plate Count (Log No./Gram)	Std. Error of Treatment Mean (Log No./Gram)
3	2.32	2.53 NS	0.23
5	1.98	2.54 NS	0.22
7	2.63	2.72 NS	0.22

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

TABLE XXIV

MEAN LOGARITHMIC NUMBERS OF MESOPHILIC BACTERIA PER GRAM ON CULTURE PLATES INCUBATED THREE DAYS AT 34°C FOR "HOT" VERSUS "COLD" BONED LEAN TRIM

[a]Holding Period (Hr)	"Cold" 34°C Plate Count (Log No./Gram)	"Hot" 34°C Plate Count (Log No./Gram)	Std. Error of Treatment Mean (Log No./Gram)
3	3.76	3.98 NS	0.12
5	3.32	3.64*	0.08
7	3.89	4.27 NS	0.15

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

* = Significant difference ($P < .05$) between "hot" versus "cold" boned lean trim.

10^7 organisms per gram. Haines (1937), Empey and Vickery (1933), and Schmid (1931) observed a slime point at populations of 32 million, 50 million, and 50 to 100 million per cm^2 respectively. Kraft and Ayres (1952) observed slime on sliced beef when the load of organisms exceeded 100 million. More recently, Ayres (1960) found the critical value of slime production to be a log value of 7.8. In view of these facts, it appeared that "hot" on-the-rail boning had no adverse effect upon bacterial populations which have growth optima at temperatures in the range of fresh meat refrigerated storage. Additionally, more rapid and efficient processing could reduce the bacterial load still further.

Effect of "Hot" Processing on Mesophilic Bacterial Populations

Pelczar and Reid (1972) defined mesophilic bacteria as those which show optimum growth within a temperature range of 25 to 40°C.

Since carcass sides which were to be "hot" boned were suspended in a 16°C holding area for three to seven hours, an increase in mesophilic load was anticipated as compared to the "cold" sides which were immediately transferred to a 1.1°C chill cooler post-slaughter. Thus, the 16°C conditioning area would allow the muscle surface to remain at optimum mesophilic growth temperatures for a longer duration.

As may be seen in Table XXIV, analysis of log bacterial numbers per gram indicated that there was no significant difference ($P > .05$) in mesophiles at either the three or seven hour holding period. However, a significant difference ($P < .05$) did occur in log bacterial numbers in lean trim "hot" boned at five hours post-mortem, as compared to the 48 hour control. As may be noted in Table XXIV, mean log mesophilic

numbers are always greater for "hot" as compared to "cold" boned sides. Since it appears that three hours is the minimum holding time required before "hot" boning can be initiated, the mesophilic count could be minimized by transferring the product to the 1.1°C cooler as soon as possible. In addition, an increased efficiency in processing would further decrease the time lag between boning and final chill. The mesophilic count was in the range of 10^3 to 10^4 bacteria per gram in "hot" lean trim boned as late as seven hours and was comparable to the "cold", 48 hour boned side.

In view of the fact that the number of bacteria required to produce off-odors and slime appears to be in the range of 10^6 to 10^7, the low counts in this study indicate that "hot" boning will not be detrimental to shelf life. Furthermore, this study agreed well with the conclusions of Brasington and Hammons (1971) that on-the-rail boning (whether "hot" or "cold") is more sanitary than previously used methods.

Effect of "Hot" Processing on Percent Cooler Shrinkage

The data presented in Table XXV strongly support the hypothesis that "hot" processing, followed immediately by packaging in moisture impermeable bags, will reduce cooler shrinkage. Sides which were "hot" processed exhibited significantly less cooler shrinkage at the three ($P = .06$), five and seven ($P < .001$) hour holding periods as compared to the corresponding 48 hour controls.

No visual increase in purge was noted in comparing the three holding periods upon removal of the "hot" boned components from their Cry-O-Vac bags at 48 hours post-mortem. The author encourages rapid boning

TABLE XXV

PERCENT COOLER SHRINKAGE OF "HOT" VERSUS "COLD" BONED SIDES

[a]Holding Period (Hr)	"Cold" Boned Side (%)	"Hot" Boned Side (%)	Std. Error of Treatment Mean (%)
3	2.20	1.38**	0.28
5	2.39	0.98*	0.16
7	2.40	0.67*	0.06

[a]Post-mortem holding period for "hot" boned side.

*Significant difference ($P < .001$) between "hot" versus "cold" boned sides.

**Significant difference ($P = .06$) between "hot" versus "cold" boned sides.

and packaging to reduce the amount of exposure to the environment in order to minimize surface desiccation. In addition Kastner (1972) postulated that shrinkage might further be minimized by not allowing the surface of the musculature to be cut, that is, to leave the epimysium intact whenever possible during muscle dissection. Thus, it is evident that substantial increases in yield could be obtained by processing carcasses in a manner similar to that described in this study.

Effect of "Hot" Processing on Water Holding Capacity

Longissimus Dorsi (LD) Muscle

As illustrated in Table XXVI, the difference in water holding capacity (WHC) between "hot" and "cold" processed LD was not statistically different ($P > .05$) for all three holding periods. "Hot" processed LD tended to have a slightly lower WHC as indicated by higher pressed fluid ratios. Differences between steaks of a given process from the anterior versus the posterior portion of the LD were statistically nonsignificant ($P > .05$) at the three hour holding period, whereas, differences between steaks at both the five and seven hour holding periods were highly significant ($P < .001$). The process x steak interaction was nonsignificant ($P > .05$) indicating that the steaks followed similar trends regardless of processing method. Steak one had a slightly greater pressed fluid ratio than did steak two.

Semimembranosus (SM) Muscle

Differences in WHC between "hot" versus "cold" boned SM were also nonsignificant ($P > .05$), however, as before, the "hot" processed muscle

TABLE XXVI

PRESSED FLUID RATIO OF "HOT" VERSUS "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	"Cold" Pressed Fluid Ratio	"Hot" Pressed Fluid Ratio	Std. Error of Treatment Mean
3	2.22	2.26 NS	0.08
5	2.22	2.34 NS	0.08
7	2.16	2.26 NS	0.05

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

TABLE XXVII

PRESSED FLUID RATIO OF "HOT" VERSUS "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	"Cold" Pressed Fluid Ratio	"Hot" Pressed Fluid Ratio	Std. Error of Treatment Mean
3	2.57	2.62 NS	0.06
5	2.58	2.66 NS	0.06
7	2.64	2.76 NS	0.06

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

had a slightly higher pressed fluid ratio as compared to the 48 hour control (Table XXVII). "Hot" and "cold" processed steaks excised nearer the insertion of the SM had significantly ($P < .001$) lower WHC than did steaks from nearer the origin at all three holding periods. The process x steak interaction was statistically nonsignificant ($P > .05$) indicating that the steaks did follow similar trends regardless of processing method.

Semitendinosus (ST) Muscle

As shown in Table XXVIII, differences between "hot" versus "cold" boned ST when evaluated for WHC were not statistically different ($P > .05$) at all three holding periods. Once again, the "hot" processed muscle appeared to have a slightly lower WHC as compared to the "cold" processed ST. Steaks sampled nearer the origin of the ST had a significantly ($P > .05$) higher pressed fluid ratio than steaks from nearer the insertion of the muscle. Again, the process x steak interaction was statistically nonsignificant ($P > .05$) indicating that the steaks followed similar trends regardless of the method of processing.

The water holding capacity of a product is closely related to taste, tenderness, color, and other features of meat quality. Its importance in tenderness has been demonstrated by Wierbicki et al. (1956), Wierbicki et al. (1957) and Hamm (1955). These reports suggested that meat having a high WHC tended to be more tender. Hamm (1960) showed that WHC was related to pH in view of the fact that the water was bound to certain hydrophilic groups forming between the peptide chains of muscle proteins. Thus, WHC will vary as the charges on the proteins change due to variation in pH. Additionally, Hamm (1960) found that WHC reached a minimum

TABLE XXVIII

PRESSED FLUID RATIO OF "HOT" VERSUS "COLD" BONED SEMITENDINOSUS

[a]Holding Period (Hr)	"Cold" Pressed Fluid Ratio	"Hot" Pressed Fluid Ratio	Std. Error of Treatment Mean
3	2.58	2.67 NS	0.06
5	2.52	2.65 NS	0.08
7	2.71	2.75 NS	0.05

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

in meat at pH 5.0. Howard and Judge (1968) found that as sarcomere length decreased so did the WHC. Bouton et al. (1971; 1973a; 1973b) showed a highly significant relationship between WHC and pH. Reviewing the pH data from the psoas major in this study, as presented in Figures 17 and 18, it may be observed that the "hot" processed muscle tended to have a slightly greater rate of pH decline, although the ultimate pH for both processes was very close to pH 5.50. The slightly greater rate of pH decline in the "hot" muscle may account for the small decrease in water holding capacity that was exhibited. However, the lack of a large difference in ultimate pH between "hot" and "cold" processed muscle resulted in the close similarity in WHC between the two processes. Realizing that myosin, with an isoelectric point of 5.40, binds 34-38 percent of the water in meat, an ultimate pH of 5.50 or greater would not be expected to produce a large difference in pressed fluid ratio. Thus, if pressed fluid ratios are an indice of the juiciness of a cooked product, there should not be large differences in percent cooking loss. These results do not agree with Kastner (1972) who found that the pressed fluid ratios were statistically different for "hot" versus "cold" boning for all holding periods. It was found that the ratio for "hot" boning was less than the control at the two hour conditioning period, but was greater than the control at the five and eight hour periods.

Effect of "Hot" Processing on Percent Cooking Loss

Longissimus Dorsi (LD) Muscle

As shown in Table XXIX the percent cooking loss data agreed well

with the pressed fluid evaluation. No significant difference ($P > .05$) was found to exist between "hot" versus "cold" boned LD at either the three, five, or seven hour holding periods. A significant ($P < .05$) difference did occur between steak one and steak two at the five hour holding period, whereas, differences between steaks were nonsignificant ($P > .05$) at both the three and seven hour holding periods. The steaks from the anterior and posterior portion of the muscle performed similarly, regardless of the processing method, as evidenced by a nonsignificant ($P > .05$) process x steak interaction.

Semimembranosus (SM) Muscle

As observed in the LD, the percent cooking loss data was in good agreement with the estimate of WHC. Results shown in Table XXX illustrate that the percent cooking loss of "hot" versus "cold" boned SM was not statistically different ($P > .05$) at any of the holding periods. No significant difference ($P > .05$) was also observed between steak one as compared to steak two. In addition, the process x steak interaction was also found to be nonsignificant ($P > .05$). Thus, as illustrated by both pressed fluid and by actual cooking loss data, one would not expect "hot" processed muscle to be less juicy than conventionally processed muscle. These results are in agreement with Kastner (1972).

Effect of "Hot" Processing on Percent Moisture

Longissimus Dorsi (LD) Muscle

Evaluation of the percent moisture data presented in Table XXXI shows that differences in moisture content of "hot" versus "cold" boned LD were statistically nonsignificant ($P > .05$) for all three holding

TABLE XXIX

PERCENT COOKING LOSS OF "HOT" VERSUS "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	"Cold" Cooking Loss (%)	"Hot" Cooking Loss (%)	Std. Error of Treatment Mean (%)
3	29.67	29.94 NS	0.27
5	29.15	28.52 NS	0.36
7	29.75	29.08 NS	0.56

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

TABLE XXX

PERCENT COOKING LOSS OF "HOT" VERSUS "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	"Cold" Cooking Loss (%)	"Hot" Cooking Loss (%)	Std. Error of Treatment Mean (%)
3	34.68	33.84 NS	0.36
5	32.32	32.49 NS	0.35
7	34.55	33.93 NS	0.38

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

periods. Comparison of the moisture contents of steaks one and two showed that steak one had a significantly ($P < .05$) greater moisture content than steak two in the three hour LD. Although a similar trend was followed for both the three and seven hour LD, the difference in moisture content between steaks was not statistically different at the five percent level of probability. The process x steak interaction was also found to be nonsignificant ($P > .05$) for all three holding periods. Differences in moisture content between steaks within a given LD were attributed to the amount of connective tissue content which allowed for a varying amount of fat deposition.

Semimembranosus (SM) Muscle

Moisture contents of "hot" versus "cold" boned SM as shown in Table XXXII were not statistically different ($P > .05$). However, differences between steaks from the anterior as compared with steaks from the posterior portions of the muscle were highly significant ($P < .001$). Generally, steak one had a lower moisture content than did steak two. The process x steak interaction, however, was nonsignificant ($P > .05$) for all three holding periods. Differences in percent moisture between steaks within the SM were again attributed to varying connective tissue content.

Semitendinosus (ST) Muscle

Following a similar trend as shown in both the LD and SM muscles, the moisture content of "hot" versus "cold" boned ST was statistically nonsignificant ($P > .05$) in each of the three holding periods (Table XXXIII). Within a given ST muscle, steak two had a significantly greater

TABLE XXXI

PERCENT MOISTURE OF "HOT" VERSUS "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	"Cold" Moisture (%)	"Hot" Moisture (%)	Std. Error of Treatment Mean (%)
3	72.68	72.72 NS	0.10
5	72.42	72.30 NS	0.13
7	72.83	72.59 NS	0.13

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

TABLE XXXII

PERCENT MOISTURE OF "HOT" VERSUS "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	"Cold" Moisture (%)	"Hot" Moisture (%)	Std. Error of Treatment Mean (%)
3	73.46	73.64 NS	0.23
5	73.46	73.37 NS	0.12
7	73.95	73.94 NS	0.16

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

TABLE XXXIII

PERCENT MOISTURE OF "HOT" VERSUS "COLD" BONED SEMITENDINOSUS

[a]Holding Period (Hr)	"Cold" Moisture (%)	"Hot" Moisture (%)	Std. Error of Treatment Mean (%)
3	73.26	73.48 NS	0.18
5	73.50	73.32 NS	0.14
7	73.80	73.70 NS	0.12

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

($P < .001$) moisture content than did steak one. As before, the process x steak interaction was nonsignificant ($P > .05$) for all three holding periods. Variations in percent moisture between steaks from a given ST were attributed to differences which existed in the fat deposition within the muscle.

The lack of a significant difference in the moisture content of "hot" boned muscles when compared to those that were "cold" boned implied that the difference in yield as discussed previously was due to surface desiccation rather than an intramuscular loss of moisture. This conclusion appears to be even more reasonable in view of the fact that the pressed fluid ratios were nonsignificant when one compares "hot" and "cold" processed muscle. Similar findings with respect to moisture content were found by Kastner (1972).

Effect of "Hot" Processing on Percent Fat

Because one would not expect "hot" processing to have an effect upon lipid content as estimated by ether extract, only a limited study was accomplished utilizing the first four carcasses of a given holding period, as may be seen from Tables XXXIV, XXXV, and XXXVI, no significant ($P > .05$) differences existed in either the LD, SM, or ST muscles for any of the holding periods. Variation did occur between steaks in a given muscle, however, this difference was primarily due to connective tissue content. Similar results were shown by Kastner (1972) utilizing two, five, and eight hour holding periods.

TABLE XXXIV

ETHER EXTRACTION DATA FOR "HOT" VERSUS "COLD" BONED LONGISSIMUS DORSI

[a]Holding Period (Hr)	"Cold" Fat Extract (%)	"Hot" Fat Extract (%)	Std. Error of Treatment Mean (%)
3	3.61	3.64 NS	0.27
5	4.19	5.00 NS	0.42
7	3.69	4.03 NS	0.26

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

TABLE XXXV

ETHER EXTRACTION DATA FOR "HOT" VERSUS "COLD" BONED SEMIMEMBRANOSUS

[a]Holding Period (Hr)	"Cold" Fat Extract (%)	"Hot" Fat Extract (%)	Std. Error of Treatment Mean (%)
3	2.64	2.28 NS	0.13
5	3.14	2.49 NS	0.21
7	2.33	2.30 NS	0.12

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

TABLE XXXVI

ETHER EXTRACTION DATA FOR "HOT" VERSUS "COLD" BONED SEMITENDINOSUS

[a]Holding Period (Hr)	"Cold" Fat Extract (%)	"Hot" Fat Extract (%)	Std. Error of Treatment Mean (%)
3	2.82	3.05 NS	0.10
5	3.60	4.03 NS	0.38
7	3.15	3.54 NS	0.19

[a]Post-mortem holding period for "hot" boned side.

NS = Nonsignificant.

CHAPTER V

SUMMARY AND CONCLUSIONS

Three holding periods (three, five, and seven hours post-mortem), each utilizing ten Angus steer carcasses, were investigated to evaluate "hot" boning as compared to conventional "cold" boning of bovine carcasses. One side of each of the 30 carcasses was assigned at random to be "hot" boned and the remaining side was conventionally processed ("cold" boned). The "cold" boned side was held at 1.1^{o}C for 48 hours post-mortem before fabrication was initiated at all holding periods. Several yield and quality parameters were used to compare two methods of processing the longissimus dorsi (LD), semimembranosus (SM) and semitendinosus (ST).

Differences in shear force values between "hot" versus "cold" boned muscle were small, averaging less than two pounds. Although not practically important, shear force values were statistically different ($P > .05$) only at the five hour holding period for the LD and at the seven hour holding period for the SM.

Sarcomere length was evaluated only in the LD muscle. "Hot" boned LD was found to have a slightly smaller ($P > .05$) sarcomere length than the 48 hour control. Differences in fiber diameter were found to be significant ($P < .05$) in the LD, SM, and ST at the three hour holding period. Fiber diameter was greater for "hot" processed LD and ST as compared to the control at the three holding periods evaluated. However,

the reverse was true in the SM at the three, five, and seven hour holding periods. The largest difference in fiber diameter between the two processes was 7.0 μm which occurred in the three hour ST. The "hot" boned LD had a significantly ($P < .05$) greater kinkiness score than did the 48 hour control at all three holding periods. Differences in kinkiness score for "hot" versus "cold" boned SM and ST were nonsignificant ($P > .05$) for all holding periods. Kinkiness scores were in the range of wavy to twisted.

The duo-trio test revealed that panelists were able to distinguish differences ($P < .05$) in tenderness between "hot" and "cold" processed LD at the seven hour holding period. Preference frequency between the two processes was not statistically different ($P > .05$) at the three and seven hour holding periods. A significant difference ($P < .05$) was indicated for the LD at the five hour holding period. "Hot" processed LD was slightly preferred to the 48 hour control at the seven hour holding period. Differences in the frequency of assigning one process a higher level of acceptability over the other were nonsignificant ($P > .05$) at the five and seven hour holding periods, but a significant ($P < .05$) difference did occur at three hours. Panelists at the seven hour holding period, found the "hot" process to be more acceptable than the "cold" with greater frequency. Practical differences in tenderness were small as the judges assigned both processes values of slightly acceptable at all three holding periods.

The duo-trio test for the SM revealed that the panelists could not significantly ($P > .05$) distinguish differences in tenderness between processes at any of the holding periods. Preference responses showed a greater ($P < .05$) selection frequency for the "cold" process as compared

to the "hot" processed meat at three hours, however, the difference was nonsignificant ($P > .05$) at the five and seven hour holding periods. Panelists assigned a higher level of acceptability to the "cold" process more frequently than "hot" boned SM at all three holding periods, however, the difference was nonsignificant at the five percent level of probability. Mean hedonic scale scores for both processes at all three holding periods averaged slightly acceptable. These results suggested that subjective differences between "hot" as compared to muscle which was "cold" boned were small and not practically important.

Evaluation of the color of "hot" versus "cold" boned LD by the duo-trio test indicated that the panelists could distinguish differences ($P < .05$) between the two processes only at the three hour holding period. Judges preferred ($P < .05$) the "cold" boned product to "hot" LD excised at three hours post-mortem. Differences in preference between the two processes at five and seven hours were not statistically different ($P > .05$) when compared to their corresponding controls. In addition, differences in acceptability of "hot" LD versus the 48 hour control were found to be nonsignificant at all holding periods ($P > .05$). Both processes were scored as slightly acceptable at each of the three holding periods.

Color evaluation by the duo-trio test for "hot" versus "cold" boned SM revealed that the judges could significantly ($P < .05$) distinguish differences in color between the two processes at the three and seven hour holding periods. Differences in preference were nonsignificant ($P > .05$) at both the three and five hour holding periods, however, a significant difference in preference between the two processes occurred at the seven hour treatment. "Hot" versus "cold" boned SM showed no

differences in acceptability at the three or five hour holding period. Panelists found the seven hour "hot" boned SM to be more acceptable with greater ($P < .05$) frequency than conventionally processed SM. Thus, subjective evaluation indicated that the LD and SM, excised at three, five, or seven hours post-mortem would be as acceptable to the consumer as conventionally processed muscle.

Little difference in the rate of pH decline or in the ultimate pH of the psoas major muscle occurred between "hot" versus "cold" boning. "Hot" boned psoas major tended to have a slightly greater rate of pH decline than did the "cold" boned counterpart.

No significant ($P > .05$) difference in psychrophilic bacterial populations occurred between "hot" versus "cold" boning at any of the holding periods. Differences in mesophilic count were nonsignificant ($P > .05$) for both the three and seven hour boning periods, however, a significant difference ($P < .05$) did occur at the five hour holding period. Mean log numbers of psychrophilic bacteria were in the range of 10^2 to 10^3/gram, whereas mesophilic bacteria ranged from 10^3 to 10^4 per gram for both processes. These low bacterial counts illustrate that on-the-rail boning is more sanitary than conventional methods of fabrication.

Yield data indicated that "hot" processing would substantially reduce cooler shrinkage. Differences in yield between "hot" and "cold" processed sides were significant at the three ($P = .06$), five and seven ($P < .001$) hour holding periods.

Pressed fluid ratio, percent cooking loss, percent moisture and percent fat between "hot" versus "cold" processed muscle were not statis-

tically different ($P > .05$) at each of the holding periods evaluated. Data from the quality and yield parameters estimated indicate that "hot" processing is feasible as early as three hours post-mortem. Due to the fact that the muscles, as well as, the outside fat cover on the "hot" side, are still warm and pliable, fabrication time is decreased, further enhancing the advantages of on-the-rail boning procedures. The enhancement should be particularly noted in yield, as well as, a further reduction in microbial population as a result of more rapid entry into the chill cooler, in addition to a more rapid rate of chilling.

Further research is needed to accurately estimate the economics of "hot" boning as compared to conventional processing. Additional microbial, color, and shelf-life studies should be initiated. A pilot plant study is encouraged to develop a conveyorized system for maximum efficiency of the process, as well as, studies to evaluate possible problems with consumer acceptance of boneless products.

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APPENDIX

TABLE XXXVII

ANALYSIS OF VARIANCE OF WARNER-BRATZLER SHEAR DATA AT THE THREE HOUR HOLDING PERIOD FOR "HOT" VERSUS "COLD" BONED LONGISSIMUS DORSI

Source	DF	Sum of Squares	Mean Square
Total Corrected	39	292.09	
Main Unit Analysis	19	255.65	
Animal	9	197.78	22.09
Process	1	16.77	16.77
Animal x Process	9	40.11	4.46
Subunit Analysis	20	36.43	
Steak	1	4.69	4.69
Process x Steak	1	0.55	0.55
Animal x Steak + Animal x Process x Steak	18	31.19	1.73

VITA

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