THE INFLUENCE OF DELAYED CHILLING ON BEEF TENDERNESS

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CHAPTER I

INTRODUCTION

Many revolutionary changes in slaughtering of the bovine animal, and processing of the carcass to retail cuts have taken place in the past century. With the advent of direct-expansion ammonia refrigeration and mechanized fabrication procedures, the conventional processing of the chilled carcass was pioneered. Today, a new processing method involving the separation of lean meat prior to chilling is being investigated for its potential contributions to the future of the meat industry.

It is well accepted that meat cooked before the onset of rigor mortis is relatively tender, whereas that meat cooked immediately after rigor mortis is relatively tough (Moran and Smith, 1929; Ramsbottom and Straudine, 1948; Paul et al., 1952; deFremery and Pool, 1960; Marsh, 1964; Weideman et al., 1967). Aging of the bovine carcass by conventional chilling methods at temperatures of 0 - 2°C for 10 - 14 days is regarded as a necessary procedure to obtain retail beef of satisfactory tenderness. An increase in aging temperature has been shown to be associated with more rapid tenderization of the bovine carcass (Deatherage and Reiman, 1946; Bate-Smith, 1948; Doty, 1950; Sleeth et al., 1957). Processing of the pork carcass to a finished product prior to initial chilling has been shown to have many applications to the meat industry. Meaningful research conducted by this rapid process using the bovine has only recently been investigated (Schmidt and Gilbert, 1970; Brasing-

ton and Hammons, 1971; Kastner, et al. 1972; Brasington and Hammons, 1972; Parrish et al., 1973; Falk and Henrickson, 1974; Schmidt and Keman, 1974).

Several potential advantages for the fabrication of the bovine prior to chilling have been suggested (Henrickson, 1974). First, the separation of muscles from the unchilled bovine carcass with placement of the lean tissue in Cry - O - Vac bags would eliminate cooling waste fat and bone and allow for a more rapid chill of the edible tissue. Second, on-the-line muscle separation could reduce meat spoilage as properly handled meat would have a lower potential for microbial contamination. Third, yield of edible boneless meat would be enhanced as weight loss due to evaporation could be kept to a minimum. Also expensive refrigeration facilities could be reduced since wasted space above and below the carcass would be eliminated. In addition, elimination of overhead rail transportation of sides or quarters of beef would greatly reduce transportation and processing costs for the packer, retailer, and consumer. Finally, delay of chill boning would produce a boneless, closely trimmed product that lends itself well to marketability.

When investigating new meat processing methods, tenderness of the final product must be considered since the consumer rates meat tenderness as the major attribute of eating quality (Lawrie, 1968b). Tenderness is greatly influenced by the conditions prevailing during the period between slaughter and the full development of rigor mortis. By allowing the onset of rigor mortis at a temperature at which post-mortem shortening is at a minimum (16^{o}C), the potential for producing the desired tenderness in the final product is enhanced.

The objective of this study was to examine the effect of three de-

layed chilling periods on meat tenderness (3 versus 48 hour, 5 versus 48 hour, and 7 versus 48 hour) as measured by several independent techniques. The instruments used were the Warner-Bratzler shear, Nip Tenderometer and Rotating Dull Knife Tenderometer. Subjective evaluation was by a trained taste panel.

CHAPTER II

LITERATURE REVIEW

> Muscle is unique among potential food products in that it undergoes a series of complex post-mortem changes over a relatively short period of time during its conversion from muscle to meat. The rate and extent to which these post-mortem changes proceed exert a strong influence on many important physical properties of meat and meat products (Forrest, et al. 1969, p. 2).

The above excerpt explains the basis for much of the research that has been conducted relative to physical and chemical changes occurring in the conversion of muscle to meat.

Chemical Changes

Upon death, the environment of muscle tissue quickly becomes anaerobic which in turn initiates the transformation of muscle to meat. Under this anaerobic condition glucose can no longer be transported to the cells of the body to provide energy for metabolism, leaving only two energy sources available for continuation of glycolysis: namely, creatine phosphate and glycogen.

Creatine phosphate is not present in appreciable quantities, therefore, leaving glycogen as the major source of energy to carry on the production of adenosinetriphosphate (ATP) in the muscle tissue. Glycogen, the basic carbohydrate reserve in muscle, is converted to lactic acid by the glycolytic pathway. Consequently, since the lactic acid can no longer be transported out of the cell via the blood, a resulting decline

of pH occurs in the muscle. The lowering of pH and the depletion of ATP are two events which are closely interrelated in the transformation of muscle before the onset of rigor mortis.

The rate and extent of post-mortem decline in pH at the onset of rigor mortis greatly influence the use of muscle for food and are reflected in major variations in the tenderness of the resulting meat. It was demonstrated by deFremery and Pool (1960) that the more rapid the onset of rigor mortis (whether measured by breakdown of ATP, glycogen, or drop in pH) the less tender will be the subsequently cooked Pectoralis major muscle in poultry. Further work on poultry meat has confirmed these results showing that extensive glycolysis immediately before or during slaughter and bleeding caused low post-slaughter pH, rapid cessa- of post-mortem glycolysis, rapid onset of rigor mortis, and toughness (Khan and Nakamura, 1970). Recent work on beef indicated that glycolysis and dephosphorylation of high energy phosphates occurring just before or during slaughter and a rapid rate of post-mortem pH change play major roles in determining the progress of post-mortem tenderization and ultimate tenderness (Khan and Lentz, 1973). Bouton et al. (1957) found that as the ultimate pH increased from 5.5 to 6.0, tenderness appeared to decrease in the bovine carcass. However, at ultimate pH levels above 6.0 tenderness in the bovine carcass increased once again. The trend of decreased tenderness with increased ultimate pH does not hold true for other species such as rabbit (Miles and Lawrie, 1970), sheep (Bouton et al., 1971), and fish (Kelly et al., 1966). Tenderness has been shown to increase with higher ultimate pH in rabbit, sheep and fish. Research has indicated that the rate of pH decline depends on temperature (Bate-Smith and Bendall, 1949; Bendall, 1951; Marsh, 1954; Marsh and Thompson,

1957; Bendall, 1960; deFremery and Pool, 1960; Cook and Langsworth, 1966; Cassens and Newbold, 1967). Lawrie (1968a) stated that the rate of decline in pH can also vary among different muscles from the same animal and among corresponding muscles from individuals of the same or different species. In rabbit Psoas muscle, lowering the temperature from 37 to 0°C the more slowly the decline in pH (Bendall, 1960). This is also true with lamb Semitendinosus muscle in the temperature range from 40 to 0°C (Cook and Langsworth, 1966). Work by Marsh (1954) on beef Longissimus dorsi muscle showed that the lower the temperature is from 43 to 7°C the slower the decline pH. On the other hand, by examining the temperature range from 37 to 0°C on ox Sternomandibularis muscle, it was observed that over the range 37 to 5°C, the lower the temperature, the slower the rate of pH decline, however, the rate of pH fall was shown in this same study to be more rapidly at 1°C than at 5°C (Cassens and Newbold, 1967; Newbold and Scopes, 1967).

Factors affecting the pH decline are primarily the results of the production of lactic acid from glycogen. It is clear that the extend of the pH fall depends upon the nature and condition of the muscle at the precise moment circulation ceases. The amount of glycogen present in the muscle at this time is of great importance. It has been well shown that glycogen content can be reduced by starvation (Bernard, 1877; Callow, 1936; Bate-Smith and Bendall, 1949), exhausting exercise (Mitchell and Hamilton, 1933), the imposition of pre-slaughter stress of various kinds (Callow, 1938), or by struggling at the time of death (deFremery and Pool, 1960; Khan and Lentz, 1973).

The final pH attained, whether through lack of glycogen, inactivation of the glycolytic enzymes, or because the glycogen is insensitive

(or inaccessible) to attack, is referred to as the ultimate pH (Callow, 1936). Even when there is an adequate supply of glycogen in the muscle at the time of slaughter, the ultimate pH is rarely less than 5.4 - 5.5. Assuming that at all temperatures the drop in pH is a measure of the extent of glycolysis (Bate-Smith and Bendall, 1956; Bendall, 1960), Cassens and Newbold (1967) concluded that temperature affects not only the rate but also the extent of glycolysis.

Physical Changes

At slaughter, muscle is plastic and highly extensible. Usually several hours elapse before muscles become firm and inextensible. This stiffening of post-mortem muscles has been associated with a decrease in ATP content in rabbit (Erdös, 1943; Bate-Smith and Bendall, 1947), whale (Lawrie, 1968c), horse (Lawrie, 1953), beef (Marsh, 1954; Howard and Lawrie, 1956, 1957), chicken (deFremery and Pool, 1960), and pig muscles (Lawrie, 1968a). Factors which influence the rate of disappearance of ATP could be expected to influence the time course of post-mortem stiffening. In addition to stiffening, unrestrained muscle shortens during the development of rigor mortis. Shortening can occur only while ATP is present; therefore, muscle is fixed in whatever state of contraction it is in when all available ATP is utilized.

Locker (1960) concluded that there is a relationship between post-mortem shortening and tenderness in beef. He found that Psoas muscle excised at death and allowed to shorten produced less tender meat. In addition, Locker (1960) suggested that a relationship exists between the post-rigor sarcomere length of the muscle and its ultimate tenderness. Since then many investigations dealing with the relationship between

tenderness and shortening have been conducted. In 1967 Herring et al. studied sarcomere length on excised Semitendinosus muscle of A and E maturity beef carcasses. In this study, fiber diameter was shown to be inversely related with sarcomere length (R = 0.95 and 0.87) for A- and E- maturity groups, respectively. Tenderness was shown to be directly related to fiber diameter (R = 0.82 and 0.87) for A- and E- maturity groups, respectively; however, sarcomere length was inversely related (R = 0.90 and 0.75) for A- and E- maturity groups. Gillis and Henrickson (1969) stated that with an increase in degree of rigor (percent kinkiness) there was a corresponding increase in shear force in pre-rigor excised beef semimembranosus muscle. Cagle and Henrickson (1970a) showed from porcine Longissimus dorsi muscles which were removed and held at 25°C for 30 to 480 minutes that fiber diameter and percent kinkiness followed essentially the same pattern; however, no definite relationship was apparent for shear force and percent kinkiness. Henrickson et al. (1974) indicated a significant ($P > 0.01$) difference in percent kinkiness between "hot" and "cold" excised beef Sartorious muscle for the 2 versus 48-hour holding periods, while differences for the 5 and 8- versus 48-hour holding periods were not significant. Marsh and Leet (1966), and Davey et al. (1967) showed that ox Stemomendibularis muscle shortened during early post-mortem periods affect the meat tenderness to a measurable degree. The researchers stated that muscle shortening length of up to 20% caused little or no toughening; however, from 20 to 40% muscle shortening, the toughness increased several fold. Beyond 40%, the meat becomes rapidly more tender, and at 60% shortening it is sheared as easily as meat in which almost no shortening had occurred. McCrae et al. (1971) has recently shown the relationship between post-

mortem shortening and tenderness for lamb Supraspinatus, Longissimus dorsi, Semimembranosus, Gluteus medius, Infraspinatus, Triceps brachii, Biceps femoris, and Semitendinosus muscles on carcasses held at 18°C for varying delayed freezing periods (0, 5, 10, 16, and 24 hour). The relationship of shortening to tenderness closely resembled that observed by Marsh and Leet (1966) in ox neck muscle. The authors felt that no intrinsic difference among the muscles of the lamb carcass affected their potential to shorten. The authors also stated that the difference in shortening of the muscles lies in the degree of stretch or slack imposed on them.

Post-mortem shortening has been shown to be dependent on temperature; however, not all muscles show the same degree of temperature dependence. For example, Locker and Hagyard (1963) showed that rabbit psoas muscle excised soon after slaughter and held at 37°C shortened by more than 30% of its excised length, and the amount of shortening decreased steadily to approximately 9% at 2°C. On the other hand, with ox Sternomandibularis muscle, the amount of shortening decreases from about 30% at 37°C to 10 - 15% at 15°C, but increased with further reduction in storage temperature of 2°C. This phenomenon of myofibrillar contraction is known as cold-shortening. At 0°C the psoas muscle shortens up to 50% of its excised length. This condition was also found to occur for beef Longissimus dorsi muscle and to a lesser extent for beef psoas major muscle (Locker and Hagyard, 1963; McCrae et al., 1971; Marsh et al., 1968). Ovine (Cook and Langsworth, 1966), porcine (Galloway and Goll, 1967; Hendricks et al., 1971) and avian (Smith et al., 1969) muscles have also been shown to cold shorten. In addition, Busch et al. (1967) while working with beef psoas and Semitendinosus muscle indicated

shortening at 37°C begins at pH values below 6.0; shortening at 2°C begins at pH values above 6.0.

The time and temperature history of a carcass during the pre-rigor period can also have marked effects on the tenderness of the resulting meat. The longissimus dorsi muscle from lamb carcasses held for various time periods at 20°C before being exposed to freezing conditions have been shown by Marsh et al. (1968) to be more tender when the holding period exceeds 16 hours than when held for shorter periods. McCrae et al. (1971) have shown that lamb muscles vary widely in their response to pre-rigor freezing of the carcass and that increasing the holding period at 18°C from 10 to 16 hours before freezer entry greatly improves the tenderness of some muscles. However, other muscles are very tender despite early freezing.

Schmidt and Gilbert (1970) have compared the tenderness of beef muscle removed pre-rigor and stored at 15°C for 24 and 48 hours with the corresponding muscles (controls) left on the carcass and chilled at 9°C for 24 hours. The Biceps femoris and Longissimus dorsi muscles stored at 15°C for 24 hours were of equivalent tenderness to their controls while those stored at 15°C for 48 hours were significantly more tender. The Semimembranosus showed no treatment effect while the excised Semitendinosus muscles were significantly tougher than their controls. Kastner et al. (1973) compared the tenderness of the control beef carcass chilled at 2°C for 48 hours before fabrication with that of corresponding sides which were held at 16°C for one of three holding periods, (2, 5, or 8-hour, post-mortem). It was shown that conditioning time at the 8-hour holding period alleviated shear force difference between the control 2°C and delayed chilling treatments. In addition, flavor, color

value notation, cooking loss, water-binding capacity, and percent moisture for the "hot" boned steaks were equal or superior to those steaks which were "cold" boned at the 8-hour treatment level. Parrish et al. (1973), compared the tenderness of beef Longissimus dorsi and Semitendinosus muscle aged on the carcass at 2° and 16°C. Four holding periods were studied: immediately after slaughter, 1, 3 and 7 days post-mortem. Rib steaks from the Longissimus dorsi, aged for 1 day post-mortem at 16°C, were about as tender as rib steaks from the control side aged for 7 days at 2°C. Tenderness of Semitendinosus muscle was improved by aging at 16°C, but the effect of temperature treatment on tenderness differences was not as pronounced for the Semitendinosus muscle as it was for the Longissimus dorsi. It was further stated that the Warner-Bratzler shear values decreased significantly for both post-mortem aging treatments at 1 day, but thereafter little difference was noted between the two treatments. Schmidt and Keman (1974) investigated the tenderness of beef muscle from control treatments chilled for 8 days at 1°C and experimental treatments fabricated into boneless wholesale cuts at 7°C for 4 hours before being transferred to 1°C chilling for 7 days. Shear force readings for the conventional and experimental treatments were found to be of equal magnitude. The authors indicated that holding meat at 7°C for 4 hours before being placed in the cooler at 1°C apparently decreased cold shortening.

In view of these studies dealing with the shortening and tenderness in the chilling of beef muscle, it has been shown that cold shortening is of practical significance in contributing to meat toughness. It is clearly desirable to minimize or prevent this increase in toughness associated with post-mortem shortening. This can possibly be accomplish-

ed in beef by new chilling methods which allow rigor mortis to develop at a temperature at which post-mortem shortening is at a minimum. In the bovine this would seem to be at 16°C.

Tenderness

Tenderness in meat is an attribute that has been shown to be influenced by many factors. Meat is not a homogenous material and shows variation not only among anatomically different muscles but also among corresponding muscles from animals of the same or different species. The influence of pre-slaughter factors such as breed, sex. maturity, nutrition, amount of exercise, and post-slaughter treatments of aging, freezing, and cooking methods have been shown to be influencial factors.

In general terms, striated muscle can be regarded as being made up of a fibrillar component which is responsible for the contraction and relaxation of the muscle and a connective tissue component which holds the fibers together, as well as, attaching the muscle to the skeletal framework. Work dating back to the beginning of the century put forth the belief that the quantity and strength of the connective tissue determined the tenderness of meat (Lehman, 1907; Mitchell et al., 1926; Mackintosh et al., 1936). However, there is now a great deal of evidence showing that changes in the myofibrillar component during the period between slaughter and the full development of rigor mortis can markedly influence the tenderness of the resulting meat. One of the earliest observations indicating that tenderness was influenced by pre-rigor changes was that meat excised soon after slaughter was tougher when rigor-mortis had developed than uncut muscle which had fone into rigor mortis on the bone (Lowe and Stewart, 1947; Ramsbottom and Strandine, 1948; Koonz et

al., 1954; Paul and Bratzler, 1955b; deFremery and Pool, 1960; Locker, 1960; Herring et al., 1967; Cagle and Henrickson, 1970b; McCrae et al., 1971). Additional citings have been made in the previous sections on changes which are known to influence tenderness and factors which influence these changes. In summary, Marsh et al. (1966) has suggested the term "background-toughness" to refer to meat toughness due to connective tissue. In addition, the reference "actomyosin toughness" refers to toughening due to configurational changes of actin and myosin in the muscle.

Objective Measures

An individual's concept of meat tenderness is a complex subject which stems from the physical process of chewing involving not only cutting and grinding but also squeezing, shearing, and tearing (Schultz, 1957). Since the brain must translate all of these sensations, it is easy to understand the possible variability among different individuals. Even though tenderness can be measured by sensory evaluation, problems stemming from consistency and difficulty in comparing results among laboratories have led to the development of mechanical methods for estimating tenderness.

Active work in the development of objective measures to evaluate meat tenderness dates back to 1907 when K. B. Lehman first developed two devices to measure meat toughness. One device measured the shear force required to bite through a meat sample; the other measured the breaking strength of a muscle. Since then many different objective measures have been developed in an attempt to objectively measure meat tenderness. To simplify the discussion, the instruments mentioned will be classified

according to their principal action whether it be shearing, penetrating, biting, mincing, or compressing.

Shearing Devices

The Warner-Bratzler shear, which enjoys great popularity, was developed to estimate meat tenderness by measuring the maximum shear force obtained from a given meat core (Figure 1). The device consists of a one mm-thick blade with a triangular hole large enough to hold a cylindrical sample of meat. The core is taken from the meat with an instrument similar to a cork borer and is placed in the opening of the blade. The blade is then drawn through a slit between two bars, and the amount of force (pounds) required to shear the sample is measured with a dynamometer. The greater the shear force reading, the less tender the meat.

The Warner-Bratzler shear was first described by Warner (1927), along with other experimental devices for measuring meat tenderness. In 1928, Warner reported on shearing studies done on 200 pairs of raw beef samples taken from right and left sides of the carcass. Correlations of -0.87 and -0.79 were obtained for the first and second hundred samples, respectively. Helser et al. (1930) used this device (calling it a dynamometer tenderness testing apparatus) to study the tenderness in cooked and uncooked beef. In 1932, L. J. Bratzler modified and improved the Warner shear by replacing the circular hole, where the muscle core sample is placed, with a triangular space. Eventually, the instrument came to be known as the Warner-Bratzler shear. The Warner-Bratzler shear has been motorized to ensure a constant rate of pressure with a shearing speed of 9 inches per minute. The dynamometer dial is calibrated to allow for readings of force to be made directly in pounds.

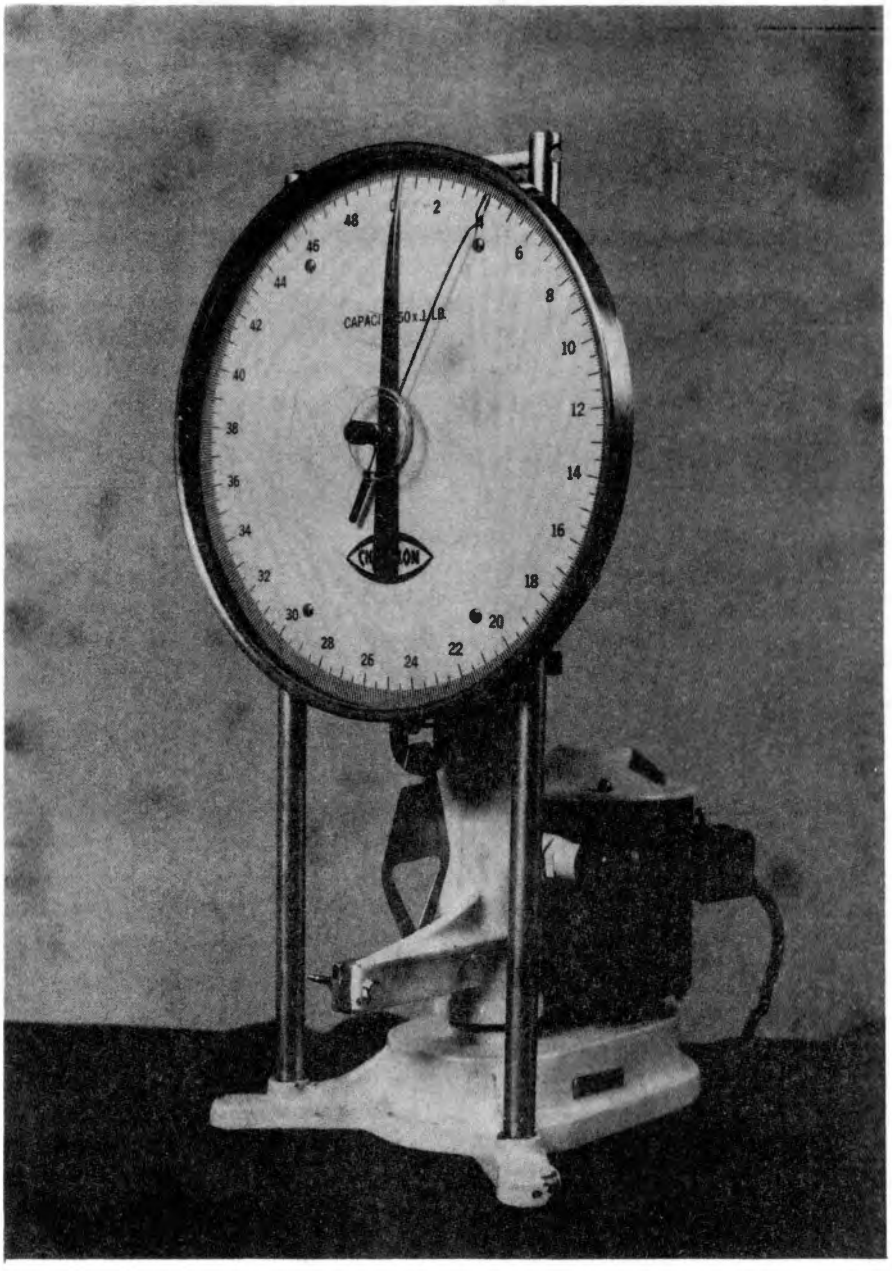

Figure 1. Warner-Bratzler Shear

Similar shear-type instruments such as the Minnesota Shear Stress apparatus which was later called the Child-Satorius Shear was based on the same principle as the Warner-Bratzler shear but differed only in mechanics and precision (Paul and Child, 1937; Satorius and Child, 1938). The instrument recorded the number of pounds force on a gage as shearing bars were pulled across a dull blade with a triangular opening through which the sample of meat was placed (Schultz, 1957). Improvements in the Warner-Bratzler shear design were stated as the probable reason for no further work on the Child-Satorius device (Pearson, 1963).

Spencer et al. (1962) modified the Warner-Bratzler shear by substituting a more sensitive strain gauge and recording system for the dynamometer. An aluminum tie bar connected the knife blade to the strain-gauge beam. Output of the bridge passed through a stabilized high-gain amplifier to a Varian recorder. Tests made with plastic modeling clay and beeswax to obtain measurements in two widely separate ranges on the tenderness scale indicated that the modified shear reduced variance at the 1% level with the clay and at the 5% level with the beeswax. No data has been published on the correlation of the modified instrument with sensory evaluation of meat tenderness.

Mackey and Oliver (1954) referred to the use of "a shearing apparatus similar to the Warner-Bratzler machine" (p. 298); however, no further mention of its mechanical make-up was mentioned nor further data was published using this device.

Bray (1951); Deatherage (1951) both determined the Warner-Bratzler shear to be the most widely used device to estimate tenderness. However, some workers have expressed disappointment in the low correlation of shear force values to panel estimates of tenderness. Deatherage and

Garnatz (1952) showed a low correlation coefficient of 0.17 for increases in tenderness determined by a panel. Hurwicz and Tischer (1954) conducted an investigation of variation in shear force measurements with the Warner-Bratzler shear using parawax and beeswax as homogeneous standards. The study evaluated three criteria of tenderness: (a) maximum shear force, (b) total time for failure in shear, and (c) slope of the curve of shear force vs. time. The authors concluded that the shear force vs. time curve had a pooled coefficient of variation of 4.79% compared to 7.41% for maximum shear force. Other researchers found coefficients of variation of 6.6% (plastic clay) and 13.5% (beeswax) (Spencer et al., 1962) and 9.0% (broiled beef) (Szczesniak, 1963).

In spite of its supposed shortcomings, the Warner-Bratzler shear is often used for comparison with newer devices being developed as well as with sensory evaluation. Lowe (1934) compared the Warner-Bratzler shear with the Penetrometer (New York Testing Laboratory) and found no significant correlation. Sperring (1959) used the Tenderness Press and showed significant correlations between press and organoleptic scores and between press and Warner-Bratzler shear readings. Webb et al. (1959) and Burrill et al. (1962) found a significant correlation between the Warner-Bratzler shear and the Kramer Shear Press.

Sensory evaluation data and its correlation with the Warner-Bratzler shear has been numerous. Ramsbottom and Strandine (1948) reported coefficients of correlation for beef as -0.9 for 50 muscles cooked in lard at (121.1^{o}C). Cover et al. (1962) studied the relationship of shear force in the Warner-Bratzler shear to the six components of sensory tenderness (softness to tooth pressure, ease of fragmentation, adhesion, juiciness, mealiness, and tenderness of connective tissue) using the

Longissimus dorsi and Biceps femoris muscles cooked to three internal temperatures (61°, 80°, and 100°). The results indicated the highest coefficients between shear-force values and panel scores were in the LD muscles cooked to 80° and 100°C. High correlation was found in the following sensory components: softness to tooth pressure (-0.81 and -0.83), ease of fragmentation (-0.84 and -0.82), and adhesion (-0.79 and -0.83). Sharrah et al. (1965) presented additional results pertaining to the comparisons of sensory methods with the Warner-Bratzler shear and the L. E. E. Kramer Shear Press. A detailed discussion of these data will be mentioned later in this section.

Whatever the reliability of the Warner-Bratzler shear may be, continuous efforts are being made to design instruments which would be more sensitive and reproducible in reflecting meat tenderness as judged by sensory evaluation. Bratzler (1949) pointed out several important variables which influence tenderness measurements. They are, degree of cooked meat doneness, uniformity of sample size, direction of muscle fibers, presence of connective tissue, fat deposit, sample temperature when measured, and speed of shearing. Blade dullness has also been mentioned as a factor in the precision of the Warner-Bratzler shear (Sale, 1960). Uniformity of meat cores for mechanical shear force measurements exerted on influence on reading as shown by Kastner and Henrickson (1969) from mechanically and hand-bored cores. As to core diameter to be used, investigators suggested that 1/2-, 3/4-, or 1-inch diameter cores may be used to measure shear tenderness (Paul and Bratzler, 1955a; Kastner and Henrickson, 1969).

The L. E. E.-Kramer Shear Press is a device primarily designed for use on fruits and vegetables, however, it has been applied to meat ten-

derness studies (Schultz, 1957). The shear press measures the maximum pressure required to force the plunger through a meat sample. The instrument consists of a test cell, a hydraulic drive system, and a proving-ring dynamometer. The shearing cell uses a combination of shearing and compression forces. It consists of 10 bars, 0.124 inches thick and spaced 0.126 inches apart. These bars pass through a sample-holding box having a corresponding number of slots on the bottom. The sample is laid across slots in the box, through which the shear bars are driven. The bars are moved by a piston driven at a predetermined rate (15 to 100 seconds). Force required to shear the sample is measured by the compression of the proving-ring dynamometer (Kramer et al., 1951).

The L. E. E. Kramer shear press was first applied to poultry meat studies. Correlation coefficients obtained by various workers between sensory evaluation showed high relationships. Shannon et al. (1957) reported correlation of -0.86 between the Kramer shear press and organoleptic panel scores for poultry meat. Wise (1959) reported a correlation of -0.89 between the number of chews by panelists and the Kramer shear value. Cameron and Ryan (1955) indicated that sample size had a great influence on tenderness measurements. Dodge and Stadelman (1959) found that dehydration of cooked samples had considerable influence on the Kramer shear-press values. Wells et al. (1962) substantiated this finding by indicating the L. E. E.-Kramer shear press has limited use as an objective method of measuring tenderness of freeze dried poultry meat. Bailey et al. (1962) indicated correlations between shear and sensory tenderness for beef Longissimus dorsi, Semimembranosus, Semitendinosus, and Biceps femoris muscle without regard to grade or cut ($r = -0.74$). The correlation of mean shear and mean sensory tenderness values for all

steaks studied within grades and cuts was -0.89. Burrill et al., (1962) reported a correlation coefficient for beef Longissimus dorsi and Semimembranosus, Semitendenosus, and Biceps femoris muscles between taste panel scores and Warner-Bratzler shear and between panel scores and maximum Kramer force were -0.83 and -0.72, respectively. No significant differences were obtained between maximum force and total work determination on the Kramer shear press, leading the authors to conclude that total load does not offer any advantage. A similar conclusion was reached by Tuomy and Young (1962) involving pre-cooked, sliced, freeze-dehydrated beef Semimembranosus muscle. Their correlation coefficients for the two instruments ranged from -0.87 to -0.90.

A different view was expressed by Sharrah et al. (1965) based on a 2-year study of Semimembranosus and Longissimus dorsi muscle from 176 animals of various breeds. Correlation coefficients between chew count and Warner-Bratzler shear or Kramer shear press were -0.84 and -0.45, respectively. The results indicated that the Warner-Bratzler shear correlated somewhat closer with sensory tenderness than did the Kramer shear press.

Sharrah et al. (1965) also tested a modified L. E. E. Kramer shear press containing a Warner-Bratzler shear-plate attachment. This instrument provided the advantage of a smaller sample size than the Warner-Bratzler shear and greater sensitivity than the L. E. E. Kramer Shear Press with respect to sensory evaluation for tenderness scores, texture scores, and number of chews. However, this estimate of tenderness was still less sensitive than the Warner-Bratzler shear.

The Nip Tenderometer was developed by the Food Technology Corporation of Dallas, Texas and was recently made available to several Univer-

sities for additional evaluation (Figure 2). The gross dimensions of the instrument are as follows: overall length, 19 cm; overall height, 22 cm; and overall width, 5 cm. The Tenderometer has a pistol-grip handle and an associated trigger. Upper and lower jaws extend 4 cm to the forward edge of the metal case. A spring-and-dial indicator arrangement measures the amount of force (0 - 50 lbs) required to mechanically shear a sample. The upper jaw (knife) is pointed at its extreme anterior end and rounded on the lower surface. The lower jaw (anvil), which is approximately four times as wide as the upper jaw, is flat on the entire upper surface. The upper jaw is equipped with a depth stop which can be set to obtain the desired uniform penetration. Individual estimates are made by the dial indicator being set at zero with the cooked steak being held in the left-hand and the jaws of the Nip Tenderometer are inserted so that the flat surface of the anvil is parallel to the longitudinal orientation of the muscle fibers. The trigger is engaged and the dial reading at the trip point is recorded as the measure of force required to shear the muscle fibers. The incision produced in the muscle sample is tee-shaped and is approximately 0.6 by 0.6 cm in dimension.

Smith and Carpenter (1973) carried on a series of evaluations to compare the sensory panel ratings to tenderness with the Warner-Bratzler shear and the Nip Tenderometer values as indicated by 150 Longissimus dorsi pork chops, 239 lamb chops, and 674 beef steaks. The Warner-Bratzler shear force values were more highly correlated with panel tenderness ratings than were the Nip Tenderometer (cold) readings for the pork ($r = -0.81$ and $r = -0.53$), lamb ($r = -0.72$ and $r = -0.52$), and beef ($r = -0.63$ and $r = -0.58$) tested after cooling of samples to room temperature. Nip Tenderometer determinations on hot samples of beef ($75^{o}C$)

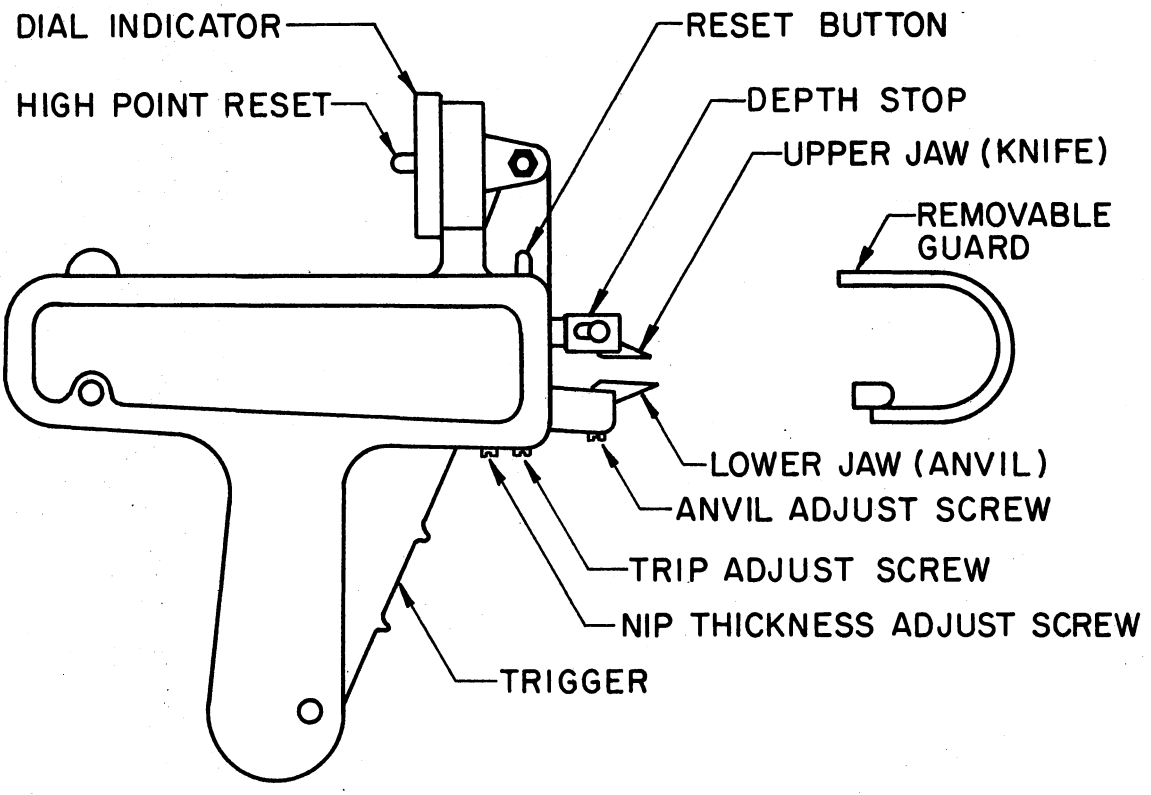

Figure 2. Nip Tenderometer Parts Identification

were more closely related to panel tenderness ratings (r = -0.80) than were cold Nip Tenderometer readings (r = -0.58) or Warner-Bratzler shear values (r = -0.63) obtained on cold samples (23°C). The hot readings of the lamb chops also showed a closer relationship with panel responses for the hot Nip Tenderometer (r = -0.75) than cold Nip Tenderometer readings (r = -0.52) or Warner-Bratzler shear (r = -0.72) values. No investigation of hot (75°C) Nip Tenderometer readings was made with pork loins. The authors concluded that the combined advantages of ease and speed of application, correlation with sensory panel ratings, and the demonstrated accuracy in identifying tough versus tender steaks, suggested that the Nip Tenderometer had potential as an objective means for evaluating meat tenderness.

A shear-jaw device reported by Shockey et al. (1944) measured changes in the texture of dehydrated fish. The instrument consisted of a set of shearing plates (jaws) supported on a stand, a spring scale of 120-pound capacity, and a gear-down winch. Measurements were taken by placing the sample in the bottom compartment with the jaws open and lowering the shield into position. The upper jaw is lowered until it rests on the meat sample, a spring scale is hooked to it, and a pulling force is applied to the scale by means of a cable fastened to the winch. The force necessary to shear the sample is read directly in pounds from the spring scale. No correlations with other mechanical instruments have been reported. However, Shockey et al. (1944) stated that organoleptic tests ranked the samples in the same order as the instrument.

Dassow et al. (1962) modified this device by replacing the winch with a hydraulic system and by eliminating the sample compartment. The device was tested with cardboard clips and with skinless frankfurters.

The franks gave an average shear value of 1.55 pounds and a standard deviation of 0.09. No further literature mention was made of this device.

Voisey and Hansen (1967) developed a shear instrument for evaluating meat tenderness. The apparatus produced the same test conditions and used the shearing blade design for the Warner-Bratzler shear. A 0.02-horsepower, 1725-revolutions-per-minute sychronous motor drives two threaded shafts by the gears. A study was conducted with the device testing two brands of frankfurters. The authors concluded the new apparatus was sensitive to changes in meat texture and showed that differences can be measured in a product, such as franks, which are normally considered homogeneous. However, the authors stated that brand A weiners were approximately 15% larger in diameter than brand B. Also, the diameter of the weiners was not recorded, "since a precise measurement was difficult to obtain" (p. 355). In addition, no proximate analysis for percent fat, protein, and moisture was undertaken on the weiners, which leaves many questions unanswered as to the true precision of this instrument. Voisey and Hansen (1967) also stated that a comparison of the performance of the Warner-Bratzler shear and the new device would be published at a latter date; however, no report has been made to the present.

Purchas (1973) devised a biting instrument which in fact is a shear device built from a pair of bone forceps. As the 27 mm-long biting edges meet with increased resistance in a meat sample, the bending element bends to an increasing extent and the resulting movement of one arm away from the other is recorded on a dial gauge attached to the biting instrument. The author examined raw versus cooked tenderness and concluded the instrument was not beneficial in measuring the tenderness of

raw meat. Purchas suggested that additional work should be done to correct flaws in the instrument itself and "to ascertain the relationship between biting instrument values and taste panel assessment of cooked meat tenderness" (p. 556).

Penetration Devices

Anderson et al. (1972) described a third generation Rotating Dull Knife Tenderometer which he believes is much easier to operate and has greater reproducibility and sensitivity than the second generation tenderometer described by Bjorksten et al. (1967).

The third generation Tenderometer uses a rotary circular cutter with three equally spaced cutting knives which have relatively dull blades (Figure 3). This blade makes a rotary cut in the meat; the penetration depth and shearing of the meat is an estimate of the tenderness. The knife is attached to a vertical, constant force-biased, electrically-driven shaft which moves substantially free of friction. Negator springs, used in the second generation instrument, were eliminated. With the removal of the negator springs, the Tenderometer can measure only unidirectionally; but the problem of spring fatigue is avoided.

The recording mechanism includes a drum with positioning knobs for attaching the tenderness score sheet and a scribe which can be moved against or away from the drum. The drum and weight, or biasing force, are fixed to the rotary shaft, whereas the knife, by means of a bayonet joint, can be removed for cleaning. The motor is programmed by microswitches to make one revolution when the push-button power switch is pressed. The scribe is then set to engage the chart at the base line. When the power switch is pressed the second time, the motor rotates the

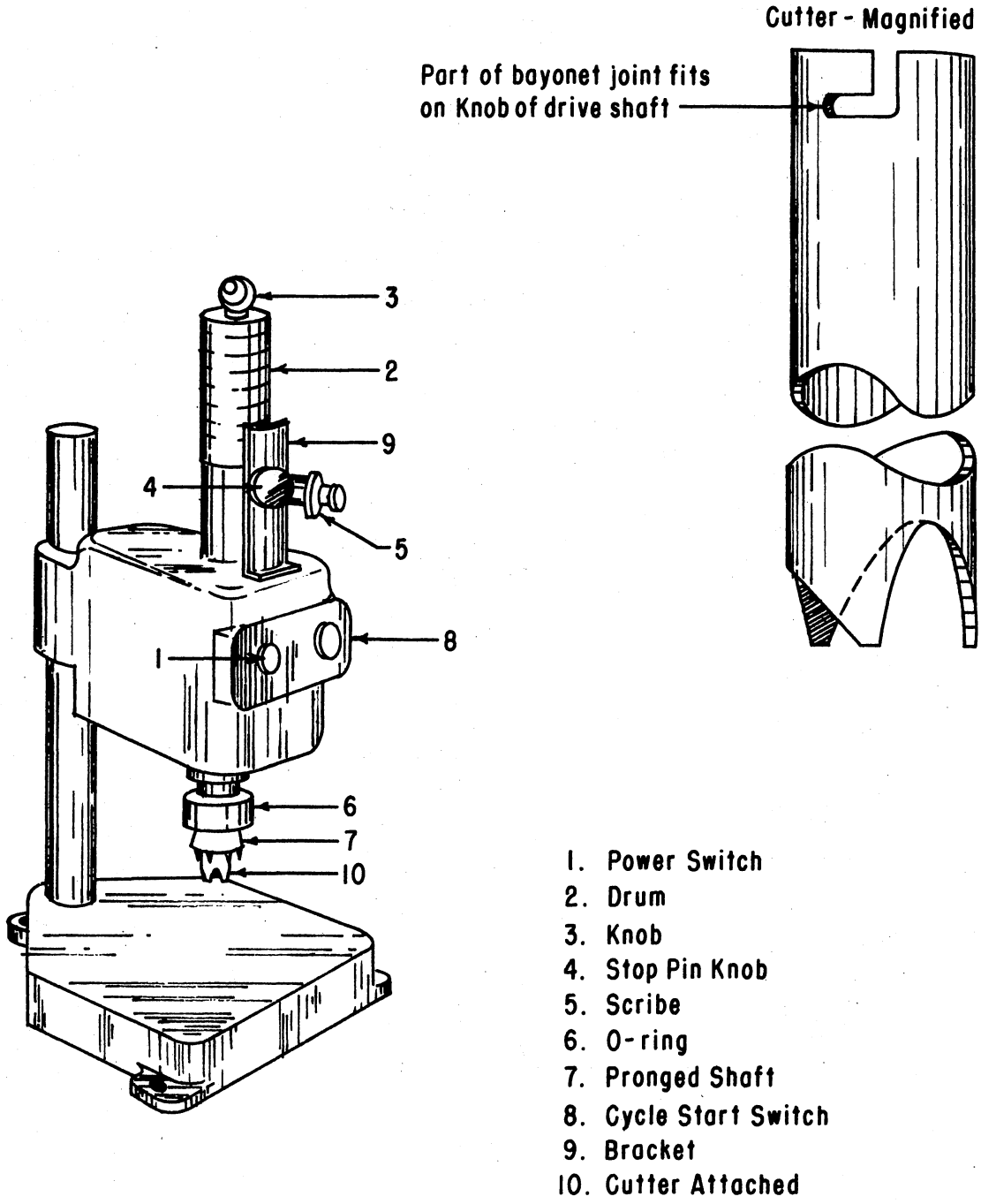

Figure 3. Rotating Dull Knife Tenderometer Parts Identification

drive shaft 7 times, thereby cutting the sample and forming a continuous line on the chart. The deeper the cut, the greater is the recording height, and the more tender is the sample.

Work carried on by Bjorksten et al. (1967) in comparing tenderness with the second generation Tenderometer on low U.S. Choice (A maturity) and U.S. Standard (C maturity) Longissimus dorsi muscles from 24 beef carcass indicated a correlation coefficient relating to sensory evaluation for the Tenderometer of ($r = +0.57$) and ($r = -0.66$) with the Warner-Bratzler shear.

Anderson et al. (1972) working with the third generation Rotating Dull Knife Tenderometer indicated the potential of predicting the tenderness of a carcass from measurements made on one portion of that carcass: namely, the heart. In their study seven hearts and matching hind quarters were divided into identical muscle pieces or groups of muscles. Evaluation of 15 muscle or muscle groups per hind quarter were carried on with samples cooked at $155^{o}F$ for 8 hours in a hot water bath and then ground through a meat grinder with 1/8-inch orifice before being pressed at 100 pounds per square inch for 1 minute. By an animal ranking procedure determined by the muscles in the study, and comparing the ranking of the heart muscle alone the authors indicated a relationship between the two estimates of meat tenderness. The animal ranking 6,7,5,4,3,2,1 (from tender to tough) compared with the ranking of the heart muscle alone which was 7,5,4,6,3,2,1. To verify that hear muscle correlated well with animal ranking is questionable and will require considerably more research.

The Christel Texturemeter was originally developed for measuring hardness of raw peas. This instrument consists of 25 rods, 3/16 inch-

diameter, which may be pushed into a sample held in a box. The resistance of the peas to the prongs, measured by a pressure gauge, is taken as an indication of hardness. Miyada and Tappel (1956) applied the Texturemeter to meat by attaching an electric motor and reducing the shear rate to 0.32 mm per second. The nonfluctuating rate of shear of the Christel Texturemeter was tested on total work required to shear the sample and maximum shear force. The data indicated total work required to be slightly more precise than maximum shear force. The pooled coefficient of variation was 1.99% for total work and 1.37% for maximum shear force. On the basis, of these coefficients, the authors concluded that this instrument seemed to be more precise than the Warner-Bratzler shear as reported by Hurwicz and Tisher (1954). Their pooled coefficient of variation for the Warner-Bratzler shear was 4.79%, 7.41%, and 9.00% for slope of the shear force versus time curve, maximum shear force, and total time for failure, respectively.

The Slice Tenderness Evaluator (STE) operates using a thin slice of cooked meat mounted on a sample holder and is held in position by a cover plate. The meat is punctured and then sheared by a stainless steel penetrator which presses vertically downward on the sample. The penetrator is a circular rod having a diameter of 0.372 inches at the base and 0.125 inches at the tip. The change in the diameter is sudden, creating a shearing edge. A small clearance of 0.003 inches exists between this shearing edge and the corresponding opening in the base plate of the sample holder. The STE is mounted on the Instrom materials-testing instrument, which makes a continuous recording of the force-penetration curve. Values for force to puncture and force to shear are read off the recorded curves. Alsmeyer et al. (1962) carried out a compari-

son with STE and Warner-Bratzler shear on 61 swine Longissimus dorsi muscles. Measurements were performed perpendicular and parallel to the orientation of muscle fibers. Numerical values of the Slice Tenderness Evaluator for coefficients of simple correlation with the panel and the Warner-Bratzler shear were as follows: perpendicular shear, -0.61 and +0.61; parallel shear, -0.72 and -0.71; perpendicular puncture, -0.55 and -0.41; and parallel puncture, -0.65 and -0.51, respectively. Kulwich et al. (1963) further stated that multiple-correlation coefficients for the relationship between STE-shear and puncture-force reading, parallel to muscles fiber orientation, and taste-panel tenderness scores for the cooked pork Longissimus dorsi muscle samples was -0.79. This finding was very close to the -0.80 simple correlation coefficient obtained for the relationship of Warner-Bratzler shear and taste-panel scores.

Alsmeyer et al. (1965) studied the cross section variations in 97 pork loin-roasts by sensory panel, Warner-Bratzler shear, and Slice Tenderness Evaluator. The Warner-Bratzler shear and STE shear had correlations of -0.77 with the panel scores. Since the average STE value displayed a closer relationship with the panel score, the authors indicated that no single location can be effectively evaluated for tenderness, but rather the entire muscle cross-section should be measured to obtain the most reliable tenderness estimate.

The Carbide Penetrometer reported by Simon et al. (1965) was developed to perform frankfurter puncture tests. It features a constant (5.0 in/min) driving mechanism, a force transducer, a compression transducer and an incisor-type probe. Frankfurters were manufactured to specific percentages of lean beef, pork, and fat with proximate analyses being carried out on the finished product. The correlation coefficient

between the Carbide Penetrometer and the Instrom was 0.95 for the average of three replications. The correlation coefficient between Instrom puncture moduli and whole frankfurter taste panel scores was -0.73. The correlation coefficient was -0.79 between the Carbide apparatus puncture moduli and whole frankfurter taste panel scores.

The Lynn-Mitchell Maturometer which initially was designed for measuring the maturity of peas has been modified and is being used on meat by the Commonwealth Meat Laboratory in Australia. Mitchell et al. (1961) describes the device as using a set of pins to puncture the peas held in the countersink of 3/16-inch-diameter holes. The pins are 1/8-inch in diameter and 3/4-inch long and arranged in 13 rows of 11 pins each. A variable speed permits control of variations in the rate of penetration. The use of an automatic recorder enables graphic presentation of the force-distance relationship during penetration. Lynch et al. (1959) working with the chemistry of preservation of green peas mentioned the use of the instrument on 1/8-inch thick meat slices which were cut at right angles to the fibers. The author stated that the instrument has application to meat since a long line of shear estimates can be obtained with a relatively small sample.

The Armour Tenderometer is a battery-operated instrument consisting of a probe assembly and strain gauge. The probe assembly includes 10 stainless steel needles, each 3-inches long. The needles are mounted on a manifold which is attached to a strain gauge. The gauge is connected by cable to a peak force indicator. The depth of needle penetration is determined by a guard bar that regulates the penetration to exactly 2 inches. The instrument is nondestructive to the lean meat and is designed to be used on the raw Longissimus dorsi muscle at the area of the

12th and 13th thoracic vertebrae. The measurement is made while the carcass hangs from a cooler rail. Readings from the muscles recorded at a minimum temperature of 32°F (0°C) but not more than 39°F (4°C) Hansen (1971). Hansen (1972) indicated correlation coefficients between tenderness evaluated by a taste panel and the tenderometer as 0.77 and 0.69 for U.S.D.A. Choice and Good carcasses, respectively. Simple correlations were found between the Warner-Bratzler shear and the taste panel; however, when the tenderometer was compared to the Warner-Bratzler shear, the correlation coefficients were lower (0.42 and 0.30 for Choice and Good, respectively). Henrickson et al. (1972) likewise indicated correlation coefficients for the Warner-Bratzler shear and the Armour Tenderometer were not highly related. The author concluded the instruments likely measure different elements of tenderness. While the tenderometer is believed to measure the force necessary to separate the individual raw muscle fibers, the Warner-Bratzler measures the force required to cut the cooked fibers at right angles to their long axis. Other studies (Dikeman et al., 1972; Carpenter et al., 1972; Luckett et al., 1972; Huffman, 1974) also have reported relatively low correlation coefficients between tenderometer and Warner-Bratzler shear or taste panel tenderness.

Hinnergardt and Tuomy (1970) modified an Allo-Kramer Shear Press to function as a penetrometer by replacing the standard shear compression cell and shearing blades with a plate containing 5 needles. The needles measured 1/8-inch in diameter and were semi-blunt, having a 0.007-inch diameter land and 0.472/1.000-inch taper. Working with 30 bone-in pork chops, correlation coefficients for the penetrometer and taste panel were 0.86 for chops steam cooked to 160°, 180°, and 200°F. Raw penetrometer

and taste panel correlation coefficients were 0.72. The results showed promise for predicting cooked meat tenderness from raw product. However, these results do not agree with investigations carried on with other instruments dealing with the same problem of cooked meat versus raw meat tenderness. Additional studies with this penetrometer would be warranted by other research groups to determine the validity of these findings.

A review of Miscellaneous Penetrometers studies are as follows: Tressler et al. (1932) and Tressler and Murray (1932) fitted the New York Testing Laboratory penetrometer with a different needle and used it to detemrine the tenderness of meat. Although Tressler et al. (1932) concluded that this penetrometer gave more uniform results than the Warner-Bratzler shear, its correlation with sensory tenderness scores has not been good, Lowe (1934) suggested that the density of the tested material might be a possible secondary factor affecting the reading. Lack of correlation with tenderness scores may be a result of the fact that penetrometers measure resistance to penetration rather than resistance to mastication. Hiner and Hankins (1941) used the penetrometer to determine the firmness of fatty tissue in hogs and found a correlation coefficient of -0.9 between depth of penetration and a committee grade for firmness.

In 1961 Pilkington et al. experimented with a precision penetrometer, modified by using a single ball and a multiple-spike pressure head. This instrument was used to measure firmness, while the Warner-Bratzler shear and a trained panel were used to measure the tenderness of beef rib steaks. The results indicated a low but significant positive correlation between firmness and tenderness. Firmness was highly correlated with fat content ($r = 0.90$). The data also suggested that at

the equivalent fat level, softer meat tends to be more tender than firmer meat. A similar positive correlation between sensory tenderness and firmness was reported by Kropf and Graf (1959). In this case, firmness was determined subjectively.

A multineedle penetrometer was devised by Charnley and Bolton (1933) and also described and used by Craven (1952). It was designed for measuring the textural characteristics of salmon. It employed ten needles to decrease error due to nonuniformity of texture.

The test time required was 60 seconds. Of interest is the cutting gauge constructed by Tressler et al. (1932). It consisted of a tire pressure gauge fitted with a metal rod 2 1/2-inches long, 5/16-inch in diameter and tapered to a 1/8-inch cone with the point made blunt by rounding it to a radius of 0.08 inches. Measurements were made by determining the pressure required to pass the cutting gauge through a sample of meat 1 inch thick and 3 inches square. In subsequent work, Tressler and Marray (1932) modified the gauge by attaching it to a motor. The device showed little promise; consequently, no further work was conducted.

Biting Devices

In one of the earliest studies on meat texture, Lehman (1907) described the Lehmann Dexometer, a mechanical device which measured the force necessary to bite through a meat sample. This instrument was fitted with two steel toothlike edges which bite through the sample by the addition of weights attached to the side of a lever. Although this instrument is primarily of historical interest today, many researchers in the field still acknowledge the high quality of Lehmann's work which

led to the development of the Dextometer and the subsequent study of factors affecting meat texture.

The Volodkevich Bite Tenderometer was designed and described by Volodkevich (1938). The original device consisted of two wedges with rounded points. The lower wedge, and its resistance to the squeezing force was recorded on a revolving drum as a function of the distance between the wedges. The measured forces were of the order of 10 to 120 kg. and could be determined with an accuracy of about 150 grams. Distance was measured with an accuracy of 0.1 mm. Steiner (1939) reported using this device in studies of post-mortem changes in beef muscle. The Volodkevich Bite Tenderometer has undergone several modifications since its original design. Sale (1960) rounded the wedges to a radius of curvature which was durable and easy to reproduce. He also provided plates on each of the wedges to prevent the meat from being smashed sideways. Sale studied the relationship of the force-generation curve with textural properties of meat and reported that the shape of this curve distinguishes rubbery meat from that which breaks apart easily.

The Winkler Device is an attempt to construct an apparatus which would combine simplicity of design with the advantages of a recording device (Winkler, 1939). The instrument consisted of a fixed and a movable jaw, the latter attached to a lever counter balanced by a weight. The jaws are somewhat blunt and similar to those used by Volodkevich--the meat sample is placed on the fixed jaw, and the movable jaw is made to approach it by applying a constantly increasing force in the form of a stream of lead shot. The meat is crushed, and the force is recorded on graph paper fastened around a drum which is attached to a motor. The motor is started simultaneously with the flow of the lead shot. The

area under the recorded curve is taken as a measure of the work done in cutting unit thickness of a given meat. Winkler used the device to study the effect of pH on tenderness of pork and beef. Only one other study with this apparatus was found: work by Nottingham (1956) concerned with connective tissue versus toughness in lamb. Nottingham studied 17 muscles from 7 sheep and found a correlation coefficient of 0.78 between connective tissue as determined by sodium hydroxide extraction and shear-force parallel to the fibers. There was no study initiated with shear force reading made across the fibers.

Macfarlane and Marer (1966) modified the Winkler apparatus by substituting a four-wheeled load carriage for the falling lead shot. The steadily increasing load was moved along the beam at a constant speed by a motor-operated screw. Tenderness was judged from either the shearing load, which was proportional to the elapsed time or from the work done on the sample prior to shearing as measured by the area under the load compression curve. Only a description of this instrument has been published.

The Strain Gage Denture Tenderometer is an instrument designed by Proctor and his students (1955, 1956a,b) at the Massachusetts Institute of Technology. It stimulated the chewing motion and the chewing surfaces of the mouth in a relatively refined manner. The apparatus consisted of a complete set of human dentures, the upper one being attached to the Hanau articulator moved by a drive motor. A pair of sensitive strain gauges in the driving arm of the upper jaw transmit the response of the chewing action through a amplifier unit into a cathode ray oscilloscope. The force-penetration relationship traced on the face of the cathode-ray tube is then photographed with a Polaroid camera. In addition to

dentures, the apparatus is also equipped with simulated cheeks, lips and tongue built from a resilient plastic material to aid in maintaining the food sample between the teeth during the measurement. The obtained force penetration oscillograms are related to the textural properties of a food and were used to describe a variety of foodstuffs, including raw and broiled steaks (Proctor et al., 1956).

The KT Biting Device was developed by R. F. Kelly and J. C. Taylor and is similar in purpose to the Strain-Gage Denture Tenderometer in that it similates the action of teeth during mastication. Kelly et al. (1960) indicated the teeth were made from two steel plates 2 inches square and machined to points 1/2 inches apart and 1/4 inch high. The lower plate is connected to a hydraulic gauge while the upper plate moves down until the points of the top and bottom plate nearly meet, after which it moves sideways to complete the "bite". The KT device was tested on 223 cattle and compared with the Warner-Bratzler shear. Coefficients of linear correlation with organoleptic measurements for the Warner-Bratzler shear and KT Biting device were as follows: tenderness, 0.93 and 0.41; number of chews, 0.60 and 0.29; and juiciness, 0.33 and 0.28. The coefficient of correlation between the two instruments was 0.38. Kelly et al. (1960) concluded that at that stage of development, the KT device was not as valuable as the Warner-Bratzler shear for estimating tenderness.

The KT instrument was subsequently refined and substitution of the hydraulic gauge with strain gauges to allow for more accurate measurement of the resistance of meat to chewing by the steel plates. The remodeled device was called KTG after Kelly, Taylor, and P. P. Graham. The modified KTG device was evaluated on 139 cuts of Longissimus dorsi

muscle from beef, pork, veal and lamb carcasses. As previously studied with the KT device, the KTG instrument was compared with the taste panel and the Warner-Bratzler shear. The coefficients of linear correlation were found for the Warner-Bratzler shear and the KTG, taking into account all meat types: tenderness, 0.60 and 0.49; number of chews, 0.61 and 0.33; juiciness, -0.18 and 0.48; and marbling, -0.43 and -0.21. This improved model indicated no advantages of the modified KT device over the Warner-Bratzler shear.

The General Foods Texturometer was developed in the research labs of the General Foods Corporation. It is a modification of the Strain Gauge Denture Tenderometer and utilized the classification system of textural characteristics described by Szczesniak et al. (1963). The instrument is comprised of a mechanical motor, a variable-voltage power supply, a Wheatstone-bridge circuit with balancing potentiometer, and a fast-speed recorder (Friedman et al., 1963). It differs from the original Strain-Gauge Denture Tenderometer in that a strip-chart, fast-speed recorder was substituted for the oscilloscope, dentures were replaced by a plunger and a sample-holding plate, the strain-gauge sensing unit was removed from the articulator arm and repositioned on the plate support arm, and several chewing speeds were provided. The sideways motion in the Strain-Gauge Denture Tenderometer and KT Biting device was also eliminated. The recorded curves give a force-distance relationship which is characteristic of the mechanical properties of the tested food. Szczesniak et al. (1963) indicated the instrument gave good correlations with sensory evaluations when tested on a large number of different foods. The instrument served in the development of standard rating scales for mechanical parameters of texture. Of the parameter developed

for texture: hardness, cohesiveness, elasticity and chewiness were stated as applicable to meat.

Mincing Devices

The household Hamilton-Beach food grinder was equipped by Miyada and Tappel (1956) with a power unit, a grinder plate containing 36 holes 5 mm in diameter. The motor was wired in series with an A.C. ammeter. The ampere readings were recorded at 5 second intervals. A plot was made of these ampere readings as a function of time, and the area under the curve was obtained and converted into energy per unit weight of sample. Miyada and Tappe (1956) expressed the opinion on the basis of the coefficient of variation being 2.11% that the grinder was a more precise instrument than the Warner-Bratzler shear.

Hanning et al. (1957) used a meat grinder in combination with the Warner-Bratzler shear, the Carver press and subjective evaluation in assessing the tenderness of Veal loin roasts and chops. By using different nutritional levels as treatments and comparing instrument readings it was indicated that the measurement of force required to grind the meat indicated no significant differences. While readings by the Warner-Bratzler shear, Carver press and subjective evaluation detected treatment differences. Simone et al. (1959) found insignificant correlation coefficients between panel scores for beef tenderness and the electric grinder method, except for the Semimembranosus muscle, where $r = -0.83$. It was concluded on the basis of this work that the food grinder was not as precise as believed by other workers. Peterson et al. (1959) used the instrument to study chicken muscle and found a definite increase in toughness with the age of the bird. However, the

authors did not publish any comments regarding the reliability of the food grinder method in estimating tenderness. Emerson and Palmer (1960) tested the food grinder against the Warner-Bratzler shear and a taste panel, and found this device the least repeatable on raw meat. Correlation coefficients on broiled steaks showed a higher relationship between the taste panel and the Warner-Bratzler shear ($r = -0.53$ to -0.73) than between the taste panel and the food grinder ($r = 0.27$ to -0.61). Emerson and Palmer concluded that the Warner-Bratzler shear gave a more precise measurement of tenderness than that of the food grinder. No recent work has been reported on this objective method of evaluating tenderness.

Compression Devices

W. E. Palmer obtained a patent for Swift and Co. on a device called the Swift Tenderness Testing Device. The instrument was reported to measure the elasticity or plasticity of meat samples. The instrument is composed of an indentor plug connected to a calibrated shaft and movable by a compression spring. The instrument is small and easily carried. This device is based on a nondestructive method of testing. In making the measurements, an established pressure is applied across a selected area of meat and the depth of indentation is measured. Next the pressure is released and the amount of elastic recovery is measured. The applied force is governed by the strength of the compression spring (Palmer, 1962). No published data with meat was found with this instrument.

An Orifice method for assessing meat tenderness based on measuring the pressure required to force a sample of meat (of definite size and shape) through a small hole in the bottom of a cylinder has been develop-

ed and is called a Tenderness Press. The device consists of a modified carver press with a 0.3 cm diameter hole drilled in the base. Meat slices 1/2 inch thick are placed inside the cylinder and pressure is applied. The reading on the pressure gauge at the time when meat begins to extrude through the opening in a base is taken as a measure of meat tenderness. Readings up to 200 pounds per square inch indicate a tender, 200 to 300 a moderately tender, and over 300 a tough cut of meat (Sperring et al., 1959). Sperring et al. (1959) tested three muscles from 57 beef cattle and on one muscle from 35 other steers. Her research showed significant differences due to muscles. Coefficients of correlation for the Longissimus dorsi muscle from the two groups I and II of animals were: -0.36 and -0.62, respectively for Tenderness Press and taste panel evaluation. Panel and Warner-Bratzler shear coefficients of correlation were -0.77 and -0.59 for Group I and II, respectively. Bratzler and Smith (1963) working with Longissimus dorsi muscles from beef and lamb compared the Tenderness Press, Warner-Bratzler shear and Taste-Panel. Correlations of Tenderness Press and Warner-Bratzler shear with taste panel for the beef Longissimus dorsi ribs were: r = -0.85 to -0.67; and Longissimus dorsi shortloins r = -0.95 to -0.75, respectively. Relatively equal values were obtained for the Tenderness Press and Warner-Bratzler shear in the Semitendenosus round of beef r = -0.34 to -0.38; and lamb loin r = -0.51 to -0.57.

CHAPTER III

MATERIALS AND METHODS

Twelve U.S.D.A. choice grade steers of similar age, breed, nutritional feeding, and management with a mean weight of 4.83 ± 11.3 kg. were utilized in the investigation. The designation of treatments were determined by animal number prior to the initiation of the investigation. Animals were slaughtered according to the procedures established at the meat laboratory and consistent with methods currently used in the industry (Deans, 1951). Each carcass was split and the sides randomly designated to either the chilled or delay-chill treatment. A streamlined hindquarter was fabricated for both process treatments (Figure 4). The study was divided into three separate experiments (Figure 5). In each experiment the designated sides utilized for the chilled treatment were held at 1.1°C for a 48-hour post-mortem conditioning period before individual muscles or muscle systems were excised (Figure 5). Upon removal, each muscle or muscle system was placed into Cry-O-Vac polythylene bags (S - 507) and held at 1.1°C to prevent surface moisture evaporation. The opposite pair sides receiving the delay-chill treatment were randomly designated to either the 3 (Experiment I), 5 (Experiment II), or 7 (Experiment III) hour post-mortem conditioning period, at 16°C (Figure 5), before the muscle or muscle systems were excised (Kastner, 1972; Falk, 1974). The delay-chilled muscles upon removal were then stored in Cry-O-Vac bags at 1.1°C identical to those muscles excised in the chilled

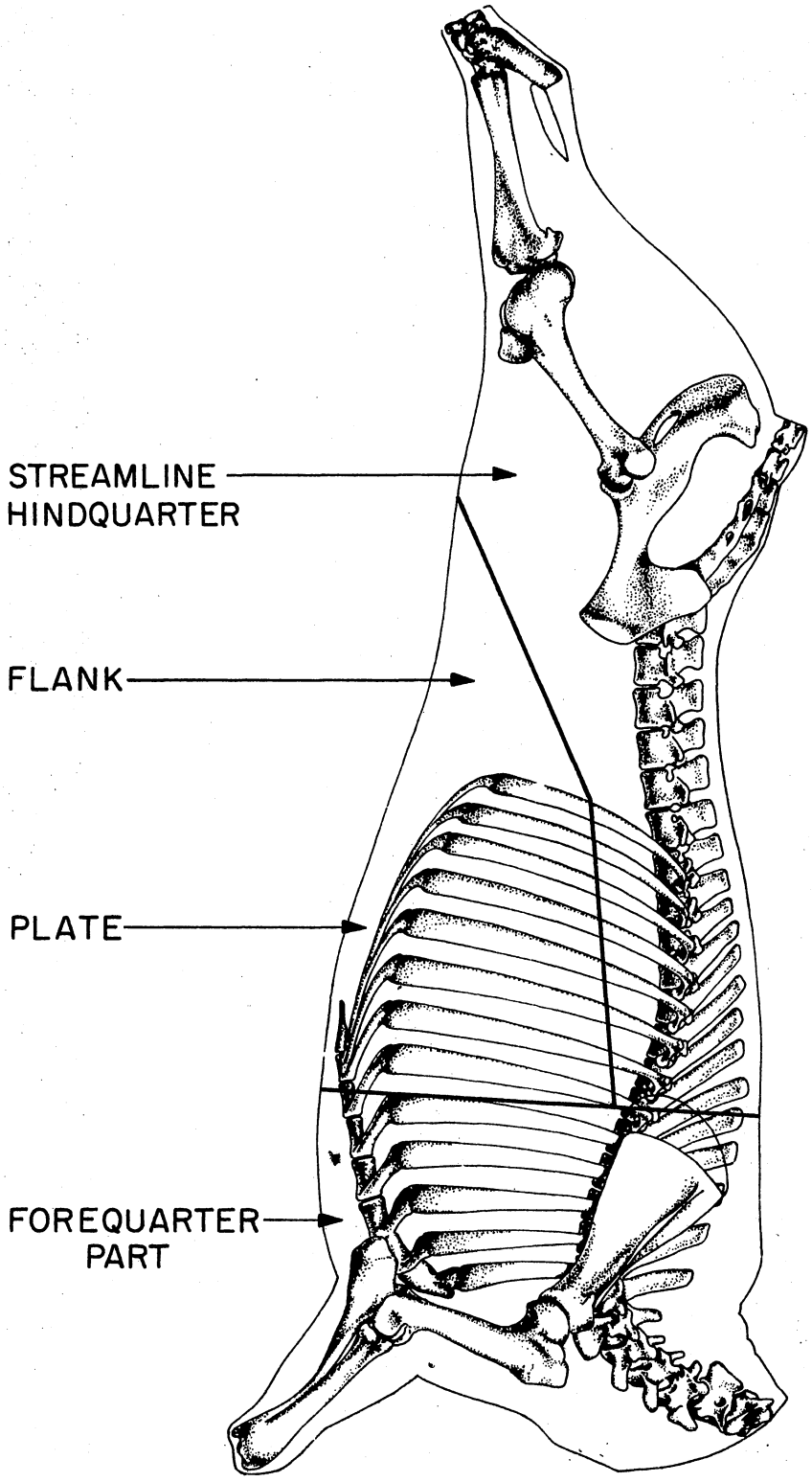

Figure 4. Diagram of Carcass Preparation for Delay Chill and Conventional Boning Treatments

MUSCLES ANALYZED

1. Biceps Femoris (BF)
2. Longissimus Dorsi (LD)
3. Semimembranosus (SM)

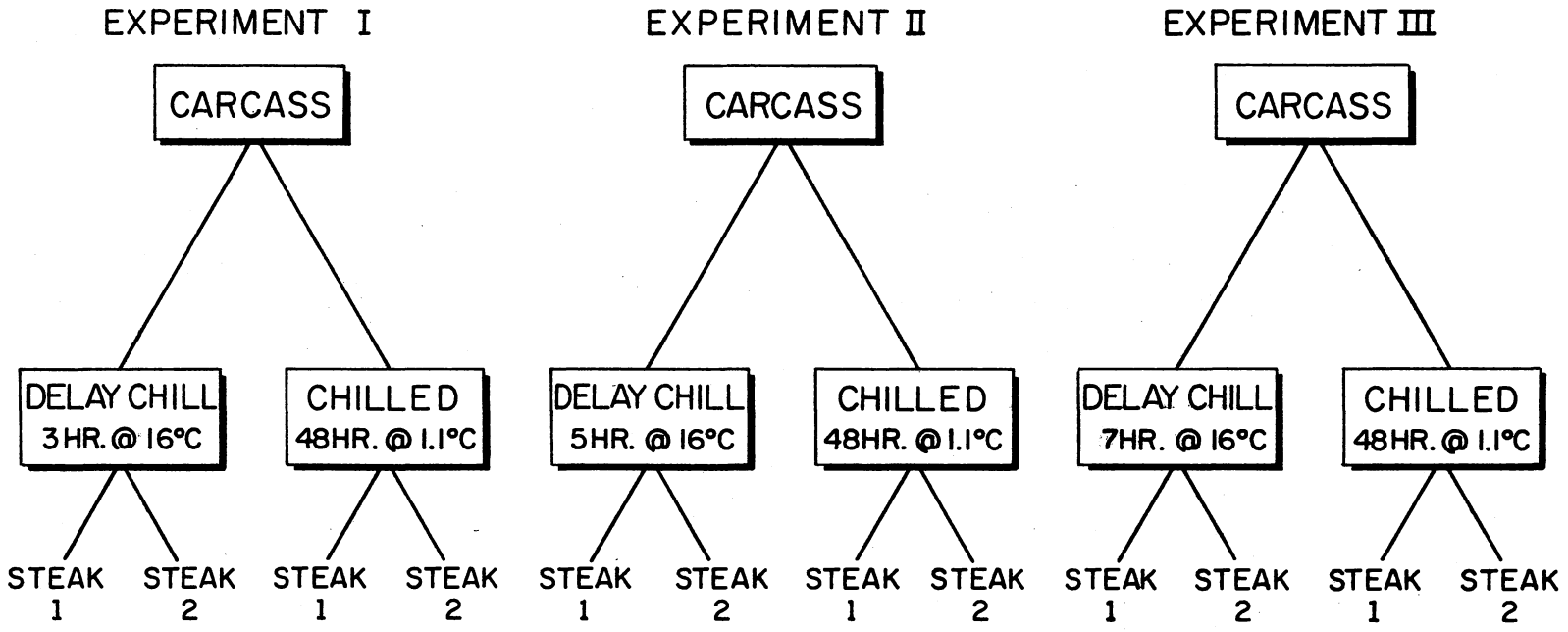

Figure 5. Schematic of Experimental Design

treatment. Muscles used for the tenderness evaluation were the Biceps femoris (BF), the Longissimus dorsi (LD), and the Semimembranosus (SM).

Two steaks from specific areas of these muscles were removed from each treatment side for both the objective and subjective evaluation (Figure 5). Steak 1 for mechanical and sensory evaluation, was removed from the anterior end (muscle origin) while steak 2 was removed from the posterior end (muscle insertion) as shown in the shaded area (Figure 6). Steaks for objective evaluation were cut 5.08 cm. thick and those for panel evaluation were 2.54 cm. (Figure 6) (Kastner, 1972; Falk, 1974). Individual steaks from the chill and delay-chill boning treatments were labeled, tightly wrapped, and stored at -30°C until utilized. Upon readying for evaluation the chill and delay-chill treatment steaks were removed from storage and allowed to thaw 24 hours at 4.5°C. Steaks were individually metal tagged for ease of identification throughout the study. The cooking of steaks was carried out by the deep fat fry method with Frymax cooking oil being preheated to 135°C. Weston model 2261 meat thermometers were inserted into the geothermal center of the uncooked steaks to insure uniformity of internal doneness. The individual steaks were completely immersed in the cooking oil and heated to an internal temperature of 65.5°C. When the desired internal temperature was reached, the steaks were removed from the oil, and blotted.

The objectively evaluated steaks were then covered with plastic food wrap (to prevent excess moisture loss) and placed in the cold storage at 4°C for 24 hours. The subjectively evaluated steaks were further processed as discussed in the sensory evaluation section of this chapter.

A flow chart indicating the steps taken thourhgout the study are shown in Figure 7.

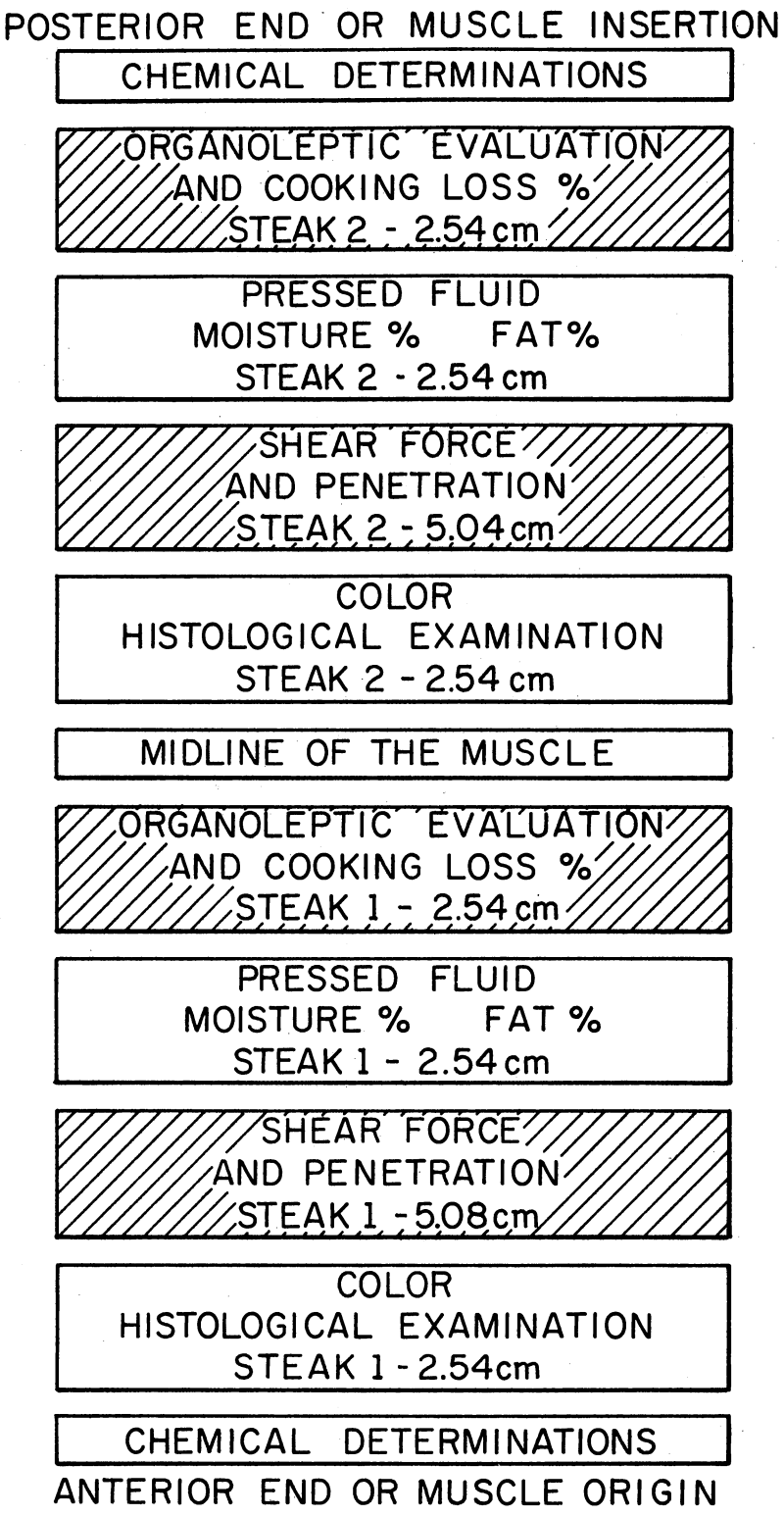

Figure 6. Schematic for Removing Steaks for Various Quality Determinations on Each Test Muscle

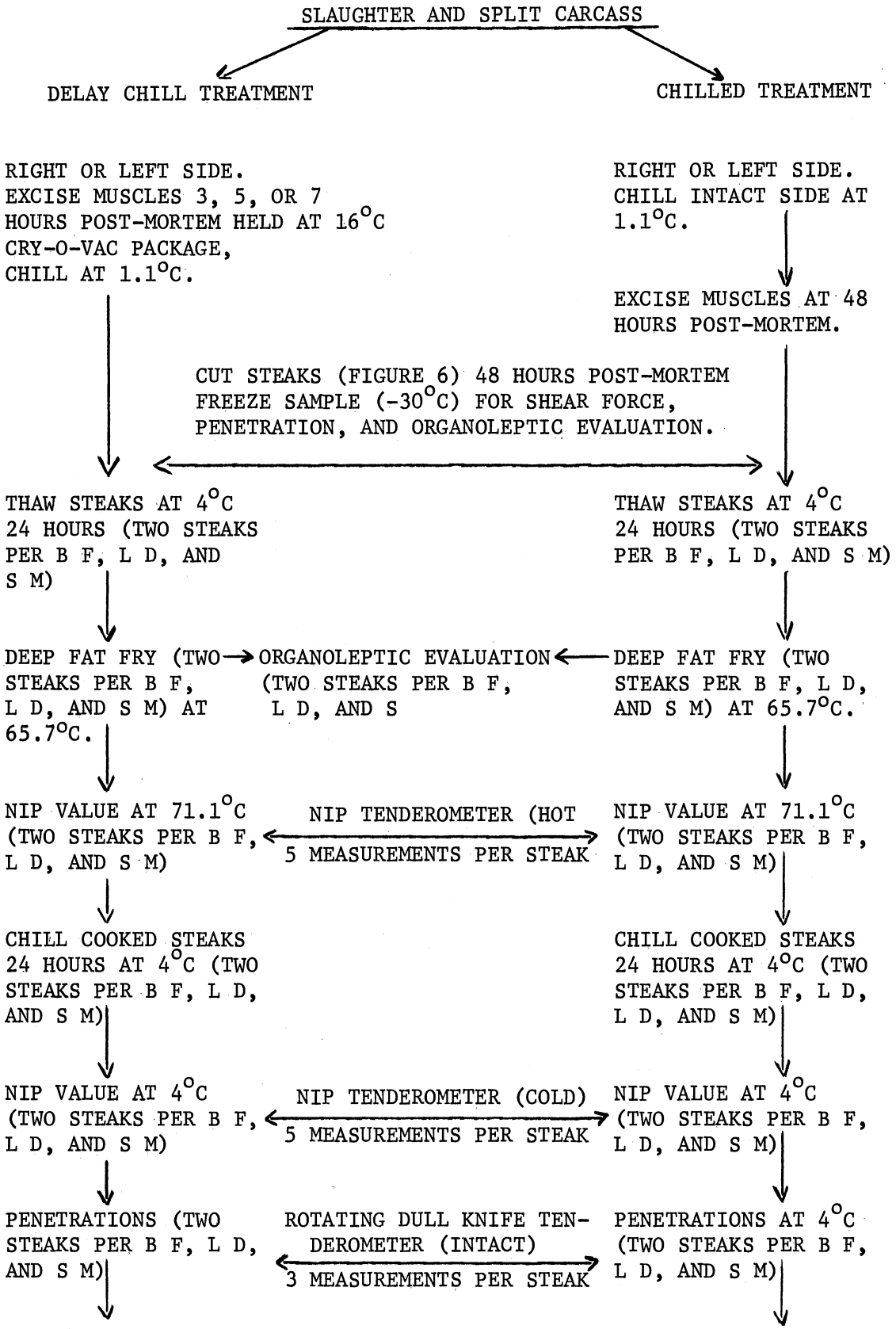

Figure 7. Treatment Sequence and Assignment for the Three, Five and Seven Hour Holding Periods

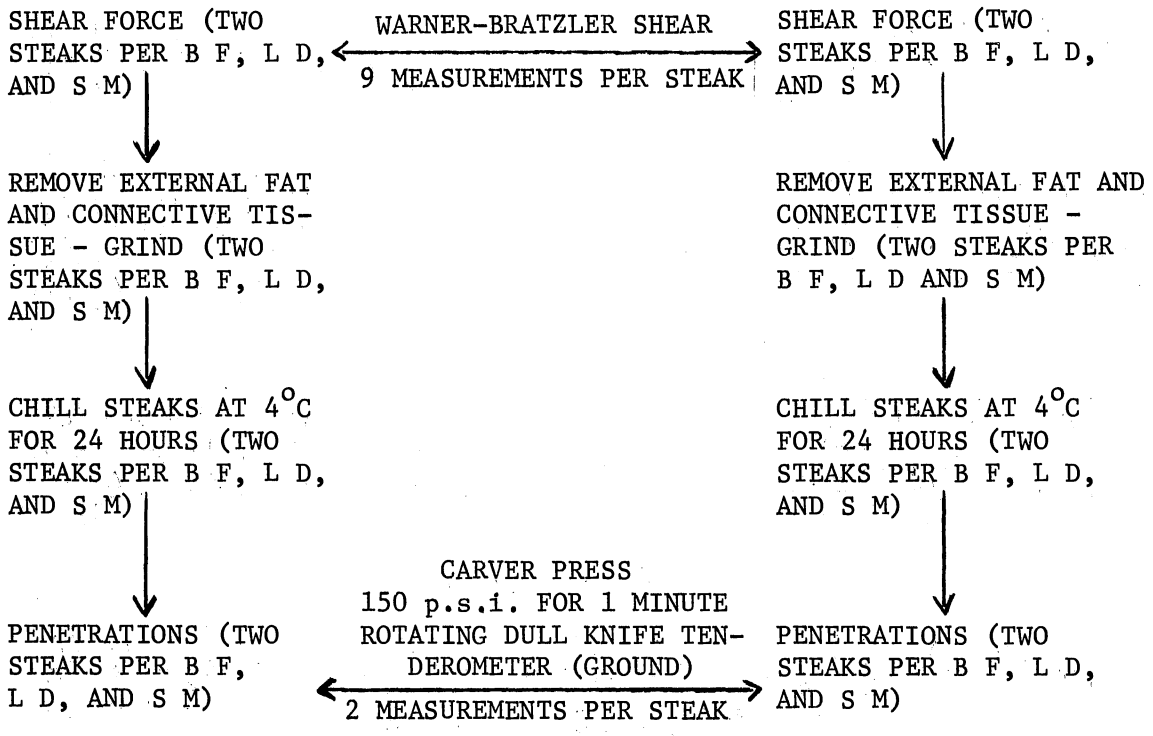

Figure 7. (Continued)

Objective Measures

Rotating Dull Knife Tenderometer

Two comparisons of the LD, SM, and BF muscles, from the chill and delay-chill process treatments were studied using the Rotating Dull Knife Tenderometer (RDKT). First, an evaluation was conducted with the cooked meat (muscle fibers, and connective tissue) in its natural cooked intact state. Each steak was subjected to three test borings (Figure 8) at a standardized temperature 4°C. Core penetrations were made parallel to the grain of the muscle fibers (Figure 8). The degree of penetration by the circular cutting knife into the intact cooked steaks was referred to as the RDKT (intact) measurement. Three penetration readings were used to determine the mean penetration value for the intact measurement.

The second investigation with the RDKT was made using the remaining steak sample in a ground form. This reading was made after the Nip Tenderometer, and Warner-Bratzler shear measurement had been taken on the BF, LD, and SM muscles (Figure 8). When the NT and W-B shear readings had been taken the meat samples were trimmed of subcutaneous fat and connective tissue. The closely trimmed steaks were then cut into 2-inch squares, and ground using a General model H meat grinder with 3/16 inch plate. The meat grinder was cleaned after each steak was ground to insure accurate measurements of meat tenderness for all steaks analyzed. The ground cooked steak samples were placed in plastic bags, to insure that evaporation did not occur, then the samples were placed in cold storage for 24 hours at 4°C. The ground steak samples upon reading for evaluation were shaken well in the plastic bags before being placed into two polyethylene cylinders (45 x 12.6 cm). Ground steak samples were

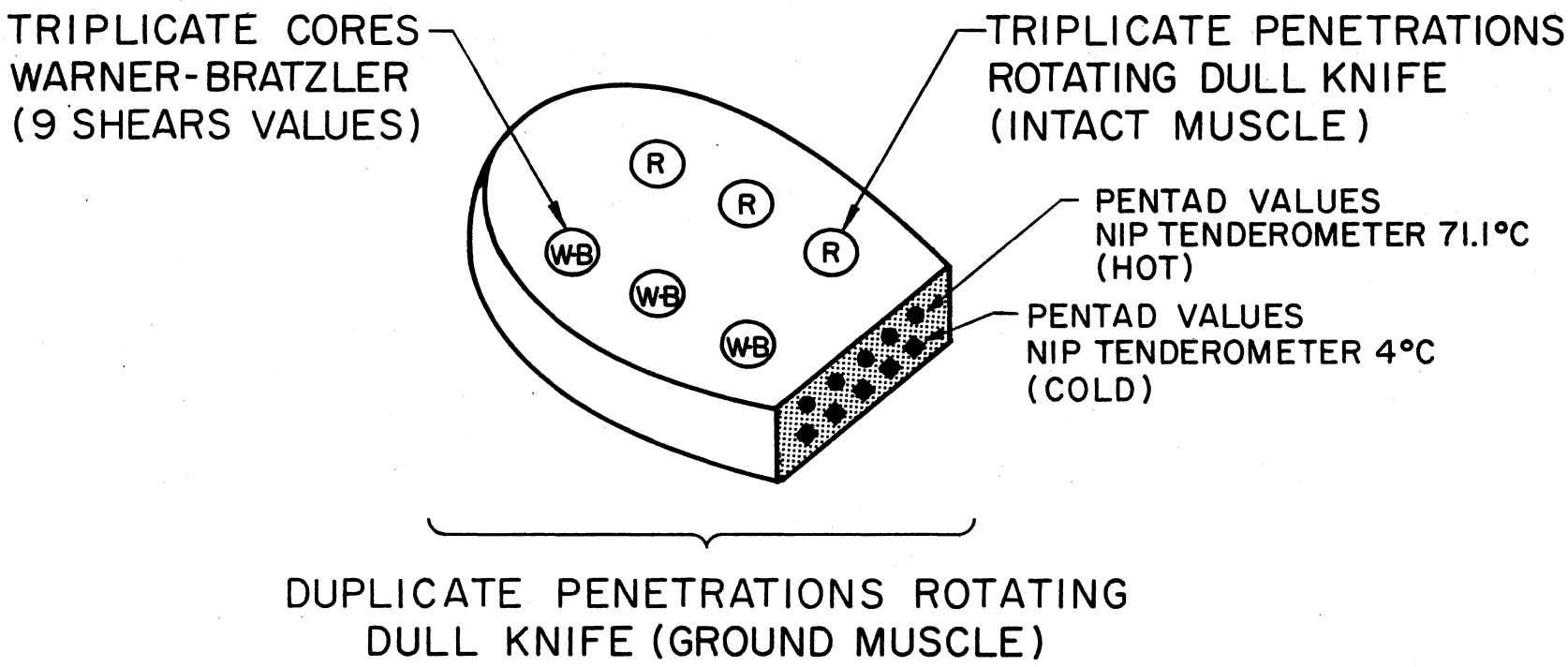

Figure 8. Schematic Drawing of a Steak Showing the Sample Location for Each Tenderness Evaluation

pressed to 150 pounds per square inch for one minute using a Carver Press. This compressing of the ground meat produced a compact meat sample that resembled sampling methods described by Anderson et al., 1972. Two test borings were taken per sample. The mean penetration value was determined from these measurements and designated RDKT (ground) readings.

Nip Tenderometer

Two investigations were carried out using the Nip Tenderometer on the BF, LD, and SM muscles for chill and delay-chill treatments. After the steaks were cooked by the deep fat fry method to 65.5°C additional increases in internal temperature occurred. This increase being primarily due to the thermal conductivity within the steak. Five Nip Tenderometer readings were taken at 71.1°C, and were designated Nip Tenderometer (hot) values (Figure 8). These five readings made up the mean shear force value for the first Nip Tenderometer study. Steaks were then covered with plastic food wrap and placed in cold storage for 24 hours at 4°C before five additional Nip Tenderometer readings were taken. The latter readings were designated Nip Tenderometer (cold) values and were the second study measurement (Figure 8). Both (hot) and (cold) Nip Tenderometer readings were taken perpendicular to the muscle fiber orientation. This was accomplished by cutting across a specified region of each steak. The BF muscle NT values were taken anterior to the ischiatic head of the BF muscle. The LD muscle NT readings were taken on the lateral surface away from the thoracic and lumbar vertebrae, while the SM muscle readings were from the medial surface adjacent to the Adductor muscle.

Warner-Bratzler Shear

Cooked steaks from the BF, LD, and SM muscles were also analyzed using the mechanically powered Warner-Bratzler shear. The steaks from the three muscles after cooking were allowed to cool at 4°C for 24 hours. Three, 1.90 cm diameter cores were taken per steak by a mechanical boring device (Kastner et al., 1969). Three shear force measurements were taken per each core, therefore, nine shear force readings were made per steak. These nine values made up the mean shear force reading obtained by the WB shear (Figure 8).

Subjective Measures

Organoleptic Evaluation

A tenderness panel made up of six trained members was assembled to determine if differences between treatments could be detected. Panelists consisted of both men and women of all ages which were employees at the Meat Science Building. Individuals were trained by the use of the triangle test of comparisons (Kramer and Twigg, 1970; Amerine et al., 1965). The panelists were given a wide variety of differing degrees of meat tenderness to test their ability to discriminate. Ten training sessions were held with the panelists in an attempt to achieve maximum efficiency.

The sensory panel investigation was conducted with the BF, LD and SM muscles. Two sample steaks (1 and 2) from each muscle was used for each treatment (Figure 6). Steak 1 from both treatments or steak 2 from the same two treatments were evaluated in a given trial. The order of presentation of steak 1 or steak 2 to the panel was determined by a toss of a coin. After the determination of the order of presentation of the

steaks, a second toss of the coin determined which process (chill or delay chill) would serve as the pair (reference plus corresponding unknown) and which would be designated as the single (odd) sample. The steaks were then cooked by deep fry method at 135°C to an internal temperature of 65.5°C. Upon attaining this internal temperature the cooked steaks were removed from the deep fat fryer and blotted of excess oil. Coded pair and single sample data sheets were prepared, in advance by the use of the random number table, for each treatment and individual panelists. A 1.27 cm diameter core, taken by hand boring, was removed from the cooked steaks and placed in the appropriate 30 ml. medical dispenser cups. Dispensers containing the core samples in a wooden serving tray (Figure 9) were placed in 14 x 19 inch Pervac polyester storage bags and held at 54.5°C in a Curtin Boekel oven until samples were presented to the panelists. Scoring by the panelists was accomplished within 15 minutes after the samples were prepared, insuring reliable evaluation. Tese cores from steak 1 and steak 2 were taken from the same position up and down the steak on both the pair and single steak (Figure 10). Each panel station received a steak sample from the same location for a given muscle at each sitting.

The panelists were given sufficient privacy so that independent results were obtained. Complementary lighting, to give all test cores the same appearance during evaluation, was provided with the use of two 25-watt red light bulbs. To eliminate odors from the preparation room a positive air pressure was placed on the sensory evaluation test room. Clear and precise instructions were given each member as how to score the evaluation sheets. Two evaluations per sitting were carried out making preparation and handling most efficient. The recording of re-

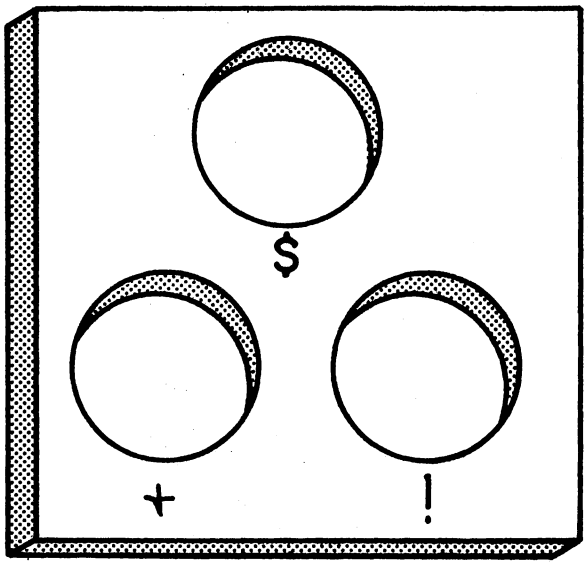

Figure 9. Sample Tray Used in the Duo-Trio Analysis

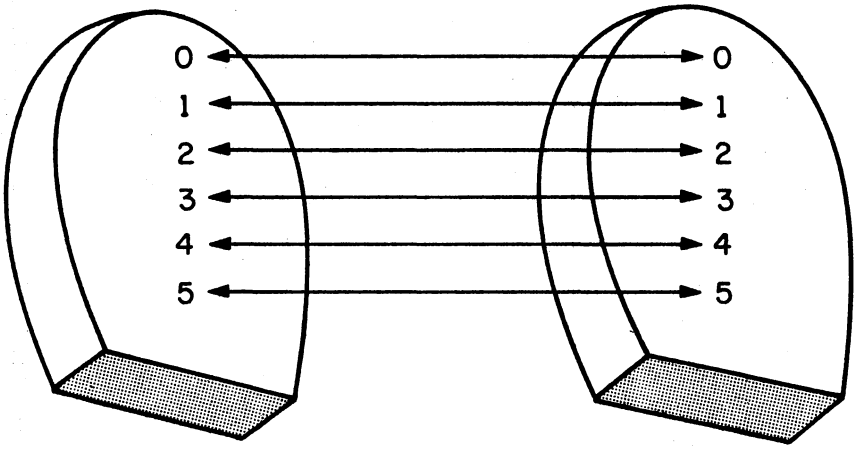

Figure 10. The Order and Location of Steak Sampling

sponses was accomplished by using tenderness evaluation sheets (Figure 11). Upon completion of data collection responses were directly transferred to computer cards for final analysis.

The method used by the panelist to determine if there was a difference between chilled and delay-chilled boning treatments was the Duo-Trio method of comparisons (Kramer and Twiggy, 1970; Amerine et al. 1965). Each panelist was presented with a wooden serving tray containing the three test samples. Each tray had imprinted on it a: $, &, and ! (Figure 9). The $ sign always represented the reference sample, whereas the & and ! always served as the two unknowns. By the code sheet which was produced by the random number table it was determined which unknown sample would serve as the second member of the pair, matching the reference $ sample for each individual panel member.

On receiving the tray with the three samples, each panelist was asked to evaluate the samples using the form shown in Figure 11. Each judge was required to indicate which of the two unknowns (&) or (!) was like the ($) reference sample (Figure 11). Panelists then indicated his or her preference between the two unknowns (&) or (!) (Figure 11). If there was no preference the panelist was asked to flip a coin so that the possibility of bias could be eliminated from their choice. Finally, the panelist was asked to separately rate the tenderness of the two unknown (&), (!) samples using a hedonic scale rating with a numerical value of 1 as highly unacceptable to 6 as being highly acceptable (Figure 11). In this manner, it was possible to test for differences between chilled and delay-chilled treatments, as well as, preference and overall acceptability in boning processes.

The duo-trio panel responses were evaluated by means of Kramer and

TENDERNESS EVALUATION

PRODUCT _____ NAME _____

PANEL NUMBER _____ DATE _____

The $ is the reference sample. One of the two remaining samples is identical to the reference sample. Please test the reference sample for tenderness and then the remaining two samples. 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 11. Sensory Panel Evaluation Sheet

Twigg (1970) Table 85 such that 32 correct responses out of a total of 48 were required for the attaining of significance at the 0.5 level. The preference between the two unknowns was analyzed by assigning the preferred treatment a value of two and the remaining treatment a value of one. Similar procedures in evaluating the hedonic scale rating was used such that the treatment receiving the higher level of acceptability was ranked with a two and the remaining treatment assigned a value of one. In case the resulting response was a tie each treatment received a value of 1.50.

Statistical Analysis

All data presented in this study was analyzed by the use of the SAS computer programming system (Service, 1972). The analysis for determining statistical significance for tenderness in the organoleptic evaluation was accomplished 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 evaluation. F-tests for main unit analysis utilized the carcass * process mean square with the error term having three degrees of freedom. The subunit analysis with the F-tests used the pooled carcass * steak plus carcass * process * steak mean square with 6 degrees of freedom as the error term. An example of the Analysis of Variance is presented in the Appendix (Tables VII, VIII, and IX). Each holding period was considered a separate experiment; therefore, no statistical comparisons were made among the three, five, and seven hour conditioning treatments.

CHAPTER IV

RESULTS AND DISCUSSION

Objective Measures

Experiment I (3 Versus 48 Hour)

Penetration and Shear Force. The data from five mechanical methods of measuring meat tenderness for three bovine muscles boned 48 or 3 hours post-mortem are shown in Table I. A statistically significant difference in shear force between the chilled and delay-chilled Biceps femoris (BF) muscle was noted ($P < 0.01$) by the Warner-Bratzler (W-B) shear. This shear force difference indicated that the chilled BF muscle was less tender than the corresponding BF muscle taken from the delay-chilled treatment. The W-B shear, in addition to showing differences between 3 versus 48 hour boning treatments for the BF muscle, had a significant process x steak interaction ($P < 0.05$). This interaction indicated that steak one and two from the two process treatments reacted differently. Finally, the W-B shear measurement was significant ($P < 0.01$) for muscle location difference. The anterior end of the BF muscle (steak 1) was noted to be more tender than the posterior end (steak 2) for the 48 hour versus 3 hour boning treatments (Figure 12c). Similar variations in W-B shear force measurements with respect to steak from the BF were observed by Ramsbottom et al. (1945); Cover et al. (1962); and Kastner (1972). The indication by the W-B shear of significance for boning

TABLE I

MEAN MECHANICAL MEASURES OF TENDERNESS AS INFLUENCED BY TREATMENT AND MUSCLE

Instrument	Process[4,5] Treatment	n	BF[6]	LD	SM[8]
RDKT[1] Intact	Chilled (48 Hr)	24	1.60	1.40	1.64
cm	Delay chilled (3 Hr)	24	1.35	1.26	1.53
Carcass * Process MS DF = 3			0.08	0.63	0.02
RDKT Ground	Chilled (48 Hr)	16	1.44	1.36	1.38
cm	Delay chilled (3 Hr)	16	1.52	1.27	1.20
Carcass * Process MS DF = 3			0.04	0.008	0.18
W-B[2]	Chilled (48 Hr)	72	7.87[a]	6.41	8.89
Kg	Delay chilled (3 Hr)	72	6.22[a]	6.89	8.74
Carcass * Process MS DF = 3			5.33	3.81	4.49
Hot Nip[3]	Chilled (48 Hr)	40	4.27	4.97	5.03
Kg	Delay chilled (3 Hr)	40	4.60	4.89	5.84
Carcass * Process MS DF = 3			2.44	8.76	1.09
Cold Nip	Chilled (48 Hr)	40	4.10	4.49	4.53
Kg	Delay chilled (3 Hr)	40	4.29	4.42	4.62
Carcass * Process MS DF = 3			6.46	1.58	1.77

[1]Rotating Dull Knife Tenderometer.

[2]Warner-Bratzler shear.

[3]Nip Tenderometer.

[4]Chilled.

[5]Delay chilled.

[6,7,8]Biceps femoris (BF), Longissimus dorsi (LD), Semimembranosus (SM).

Subscript a denotes significant difference at $P < 0.01$.

Nonsubscript denotes nonsignificant difference.

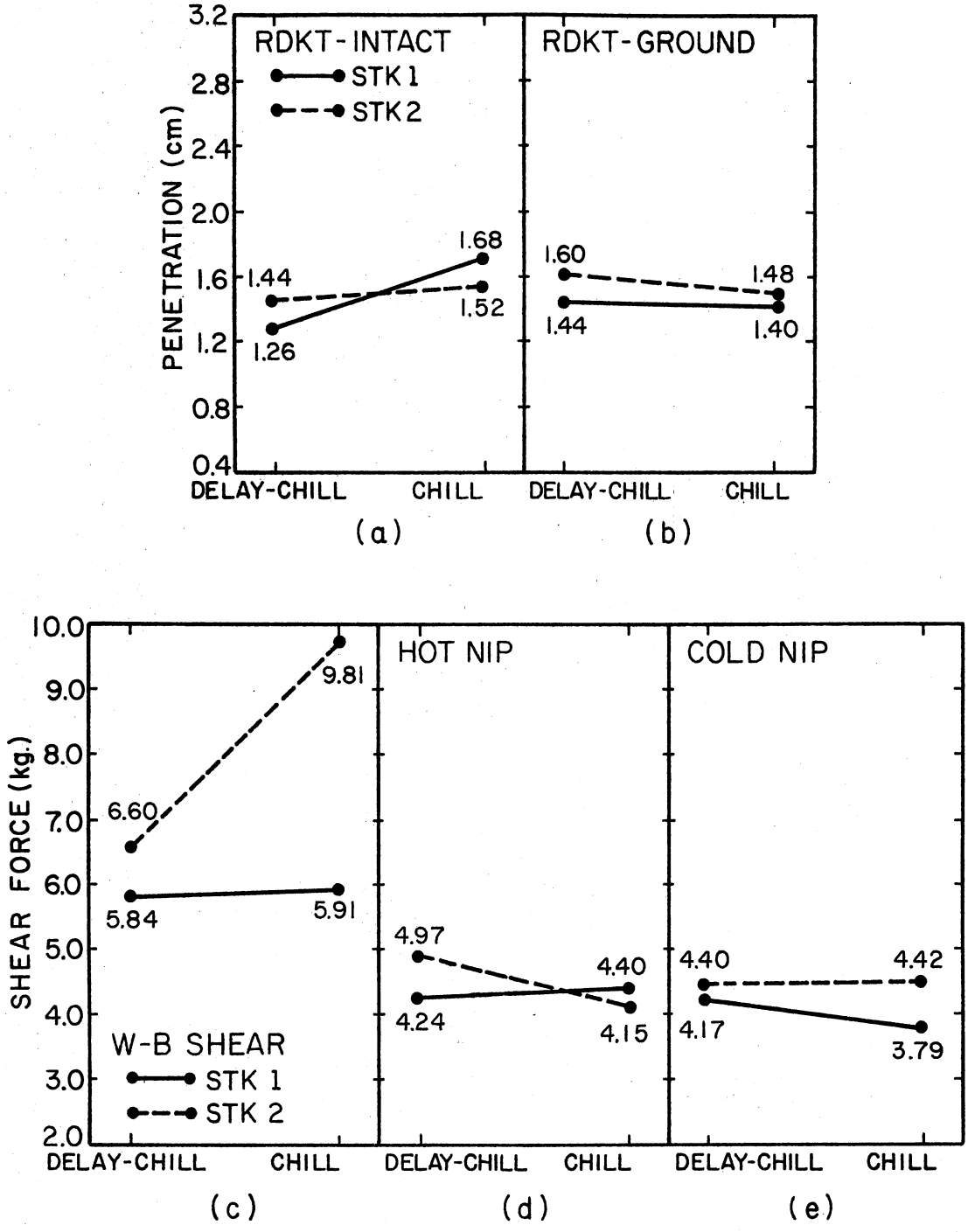

Figure 12. Penetration and Shear Force Measurements of the Biceps femoris for Chill and Delay Chill Treatments at 3 Versus 48 Hour Post-mortem

period, process x steak interaction, and muscle location differences may, in part be explained by the composition and arrangement of the muscle fibers in the BF muscle. This muscle, because of its locomotion function in the live animal, has a high connective tissue content (Cover and Smith, 1956; Cover et al., 1962; Ritchey and Hostetler, 1965; Bailey, 1972). According to Sisson and Grossman (1953) and Frandson (1969), the arrangement of the muscle fibers in the BF muscle are of the multipennate form. This combination of varying connective tissue content and muscle fiber orientation in the BF muscle understandably complicates the W-B shear measurement as the instrument was designed to principally evaluate the shear force when made perpendicular to the orientated muscle fibers Kastner and Henrickson (1969); Kastner (1972).

In direct contrast to W-B shear reading the remaining four mechanical methods of estimating tenderness for the BF muscle indicated tenderness of equal quality between 48 versus 3 hour boning treatment (Table I). Slight variations in the anterior (steak 1) and posterior portion of the muscle (steak 2) were observed within treatments by these four mechanical measures (Figure 12a,b,d,e), but no statistical significance was obtained. Process x steak interactions for RDKT (intact), (ground), NT (hot), and NT (cold) values were nonsignificant (NS). This indication of lack of interaction revealed that the two steaks from the anterior and posterior portions of the BF muscle responded similarly regardless of processing treatment.

Data obtained from the RDKT (intact), RDKT (ground), W-B shear, NT (hot) and NT (cold) for the Longissimus dorsi (LD) muscle indicated products of equal tenderness between 48 versus 3 hour boning treatments (Table I). Nonsignificant (NS) steak x process interaction were observed

for all objective measurements carried on with the LD muscle. Muscle variations within boning treatments for anterior and posterior steaks were nonsignificant (NS) for the five objective measures (Figure 13a,b, c,d,e). Similar results in shear force values with respect to steak location in the LD muscle were observed by Ramsbottom et al. (1945); Weir (1953); Mackey and Oliver (1954); Paul and Bratzler (1955a); Mjoseth (1962); Cover, et al. (1962); Kastner (1972); Hansen (1973); and Falk (1974).

Penetration depth for the RDKT (intact), and RDKT (ground), along with shear force values for the NT (hot), NT (cold), and W-B shear in the Semimembranosus (SM) muscle yielded steaks of equal tenderness for the chilled and delay-chilled meat (Table I). In addition, no significant process x steak interaction existed for the SM muscle as measured by the five mechanical instruments. Differences within the SM muscle for the chilled and delay-chilled treatments revealed that the anterior portion (steak 1) was more tender than the posterior portion (steak 2) (Figure 14). This within muscle variation was shown to be significant for the RDKT (intact) ($P < 0.05$), W-B shear ($P < 0.01$) and NT (cold) ($P < 0.05$) (Figure 14a,c,e), with a trend being indicated for the NT (hot) ($P < 0.10$) measurement (Figure 14d). No indication for within muscle variation was detected by the RDKT (ground) measurement (Figure 14b). This absence of variation by the RDKT (ground) reading would be expected as steaks were forced through a meat grinder with 3/16 inch plate as mentioned in Chapter III. The act of grinding removed any "unconformity" as to muscle location (Anderson, et al., 1972). Results by Paul and Bratzler (1955a); Taylor et al. (1961); Ginger and Weir (1958); Kastner (1972); and Falk (1974) agree with data presented in

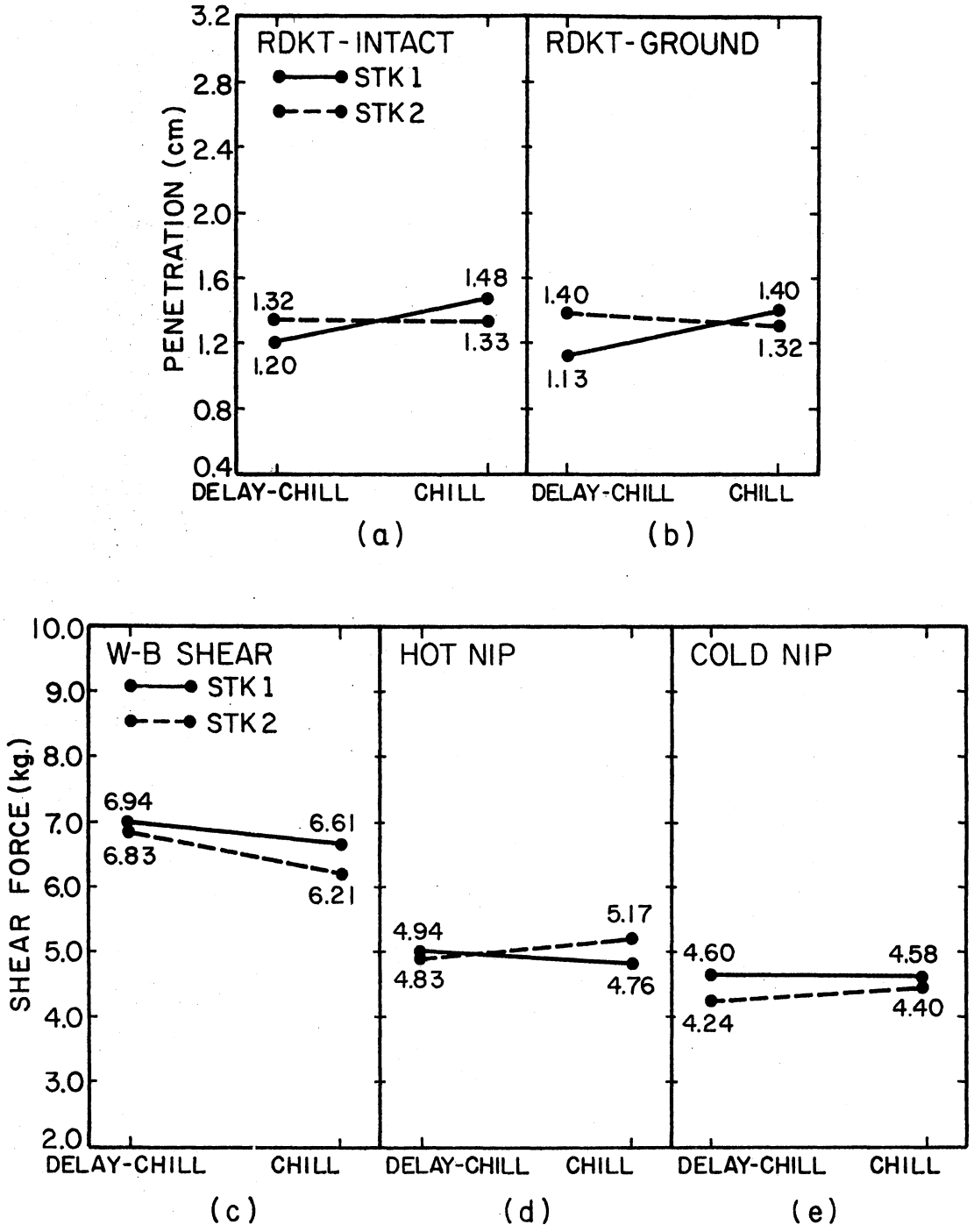

Figure 13. Penetration and Shear Force Measurements of the Longissimus dorsi for Chill and Delay Chill Treatments at 3 Versus 48 Hour Post-mortem

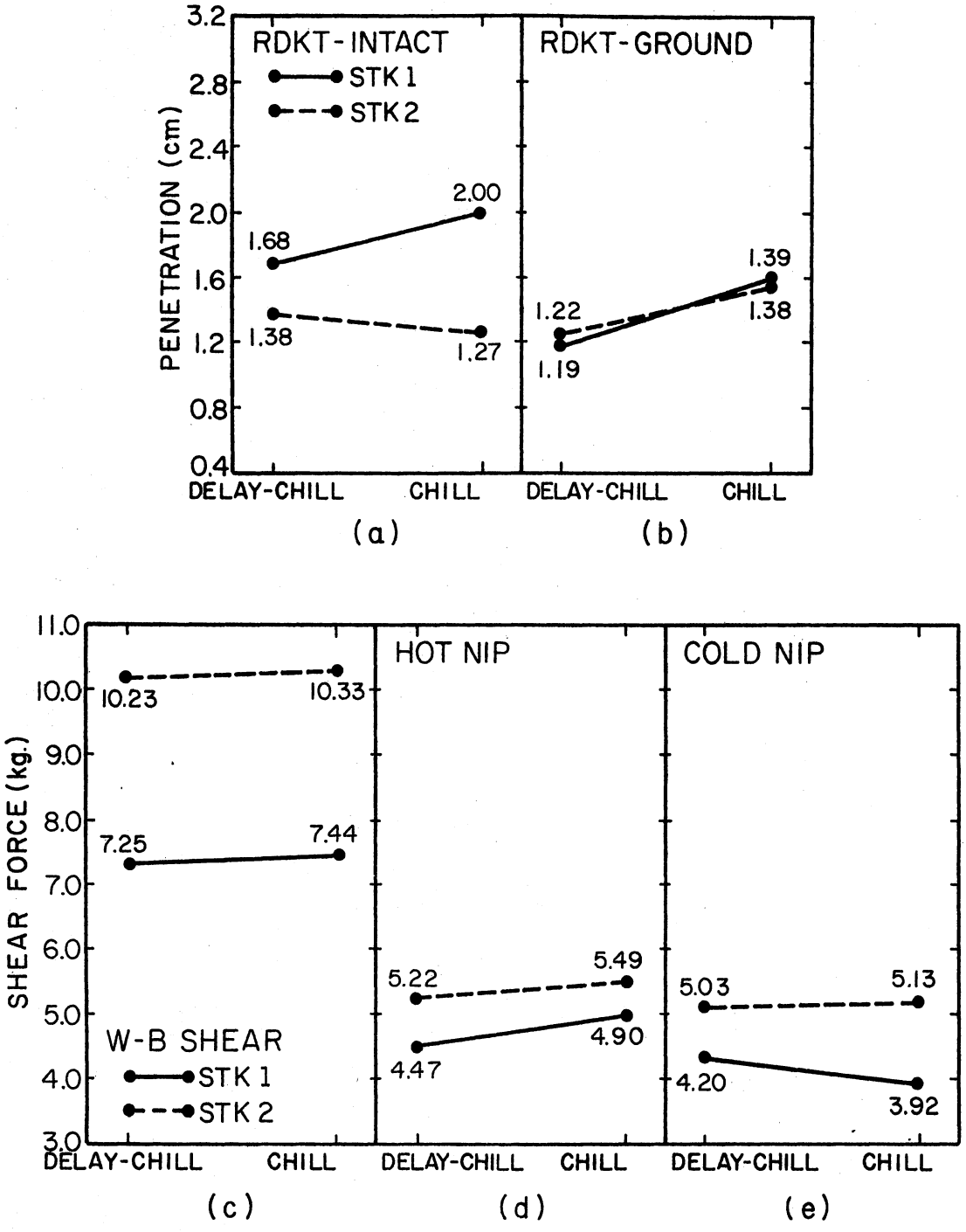

Figure 14. Penetration and Shear Force Measurements of the Semimembranosus for Chill and Delay Chill Treatments at 3 Versus 48 Hour Post-mortem

this study that significant variations within the SM muscle do exist.

Subjective Measure

Sensory Evaluation

The Duo-Trio difference test as outlined by Amerine et al. (1965) and Kramer and Twigg (1970) indicated that sensory panelist were unable to discriminate tenderness between the 48 versus 3 hour treatments. These findings held true for the BF, LD and SM muscles. These findings were noted by the number of right versus wrong responses indicated by the trained panelists (Table II). To achieve statistical significance at the 5% level panelist would have had to correctly pair 32 of 48 samples presented to them. As shown in Table II this level of significance was not attained for the BF, LD, or SM muscle.

The Preference test conducted with the panelist revealed a slightly higher frequency for the selection of the chilled BF, LD, and SM samples to that of the delay-chilled process. This frequency of preference was only a slight trend between the two treatments as significance was not attained for any of the muscles studied (Table II). Process x steak interaction was nonsignificant ($P < 0.05$) for the three muscle systems studied.

Hedonic Scale rating (Table II) for the BF, LD, and SM muscles revealed that panelist scored the 48 hour chilled treatment steaks slightly higher than the 3 hour delay-chill process. These differences only indiage a slight trend as no significance was obtained for any muscle investigated. These Hedonic Scale ratings were in the slightly acceptable category (Figure 15) for both the chilled and delay-chilled processes. As in previous subjective evaluations the process x steak interaction

TABLE II

THREE PANEL MEASURES OF TENDERNESS AS RELATED TO TREATMENT AND MUSCLE

Duo-Trio Test						
n	BF		LD		SM	
	Right	Wrong	Right	Wrong	Right	Wrong
48	26	22	21	27	25	23

Preference Test* (Mean)				
Process Treatment	n	BF	LD	SM
Chill (48 Hr)	48	1.58	1.56	1.56
Delay Chill (3 Hr)	48	1.42	1.44	1.44

Hedonic Scale[a] (Mean)				
Process Treatment	n	BF	LD	SM
Chill (48 Hr)	48	4.35	4.35	4.56
Delay Chill (3 Hr)	48	4.25	4.29	4.38

[a]A score of 1 being highly unacceptable and 6 highly acceptable.

*Range from 1.0 to 2.0.

1 = Delay Chill Process Treatment.

2 = Chill Process Treatment.

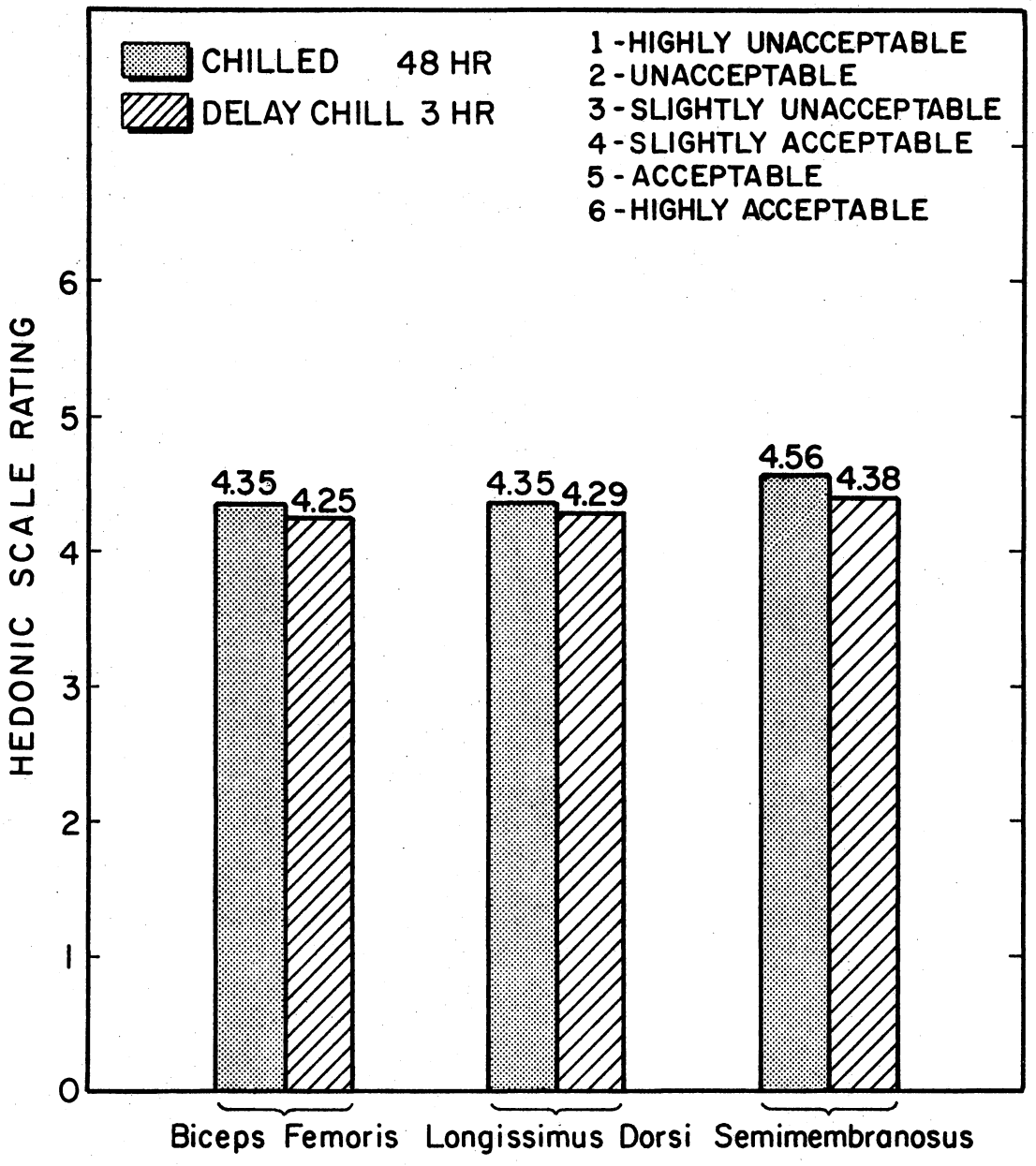

Figure 15. Subjective Measure of Tenderness as Influenced by Muscle and Period of Excision

was nonsignificant (NS).

Conclusions

The results in Experiment I indicated that no major tenderness differences were present between 48 hour post-mortem versus 3 hour post-mortem boned muscles (BF, LD, or SM) as analyzed by five mechanical methods (Figure 16). This conclusion was reinforced by the trained tenderness panel as the Duo-Trio Comparison, Preference Test, and Hedonic Scale Rating indicated no detectable differences. In addition, significant differences within the Semimembranosus muscle were indicated by the different objective methods.

Objective Measures

Experiment II (5 Versus 48 Hours)

Penetration and Shear Force. The penetration and shear force methods of measuring meat tenderness for the BF, LD, and SM muscles at 5 versus 48 hour post-mortem boning periods is shown in Table III. The five mechanical methods of measuring tenderness for the BF muscle indicated steaks of equal tenderness quality between the 48 or 5 hour boning treatment (Table III). Similar results were obtained by Kastner (1972) in BF muscle for the 5 and 48 hour boning treatments. Process x steak interaction was nonsignificant (NS) for all mechanical measurements. The absence of detectable interaction once again indicated that the two steaks from the anterior and posterior portions of the BF muscle responded similarly regardless of the process treatment. Within muscle variation were nonsignificant (NS) for the BF muscle as measured by the five objective methods (Figure 17a,b,c,d,e). However, a trend that the

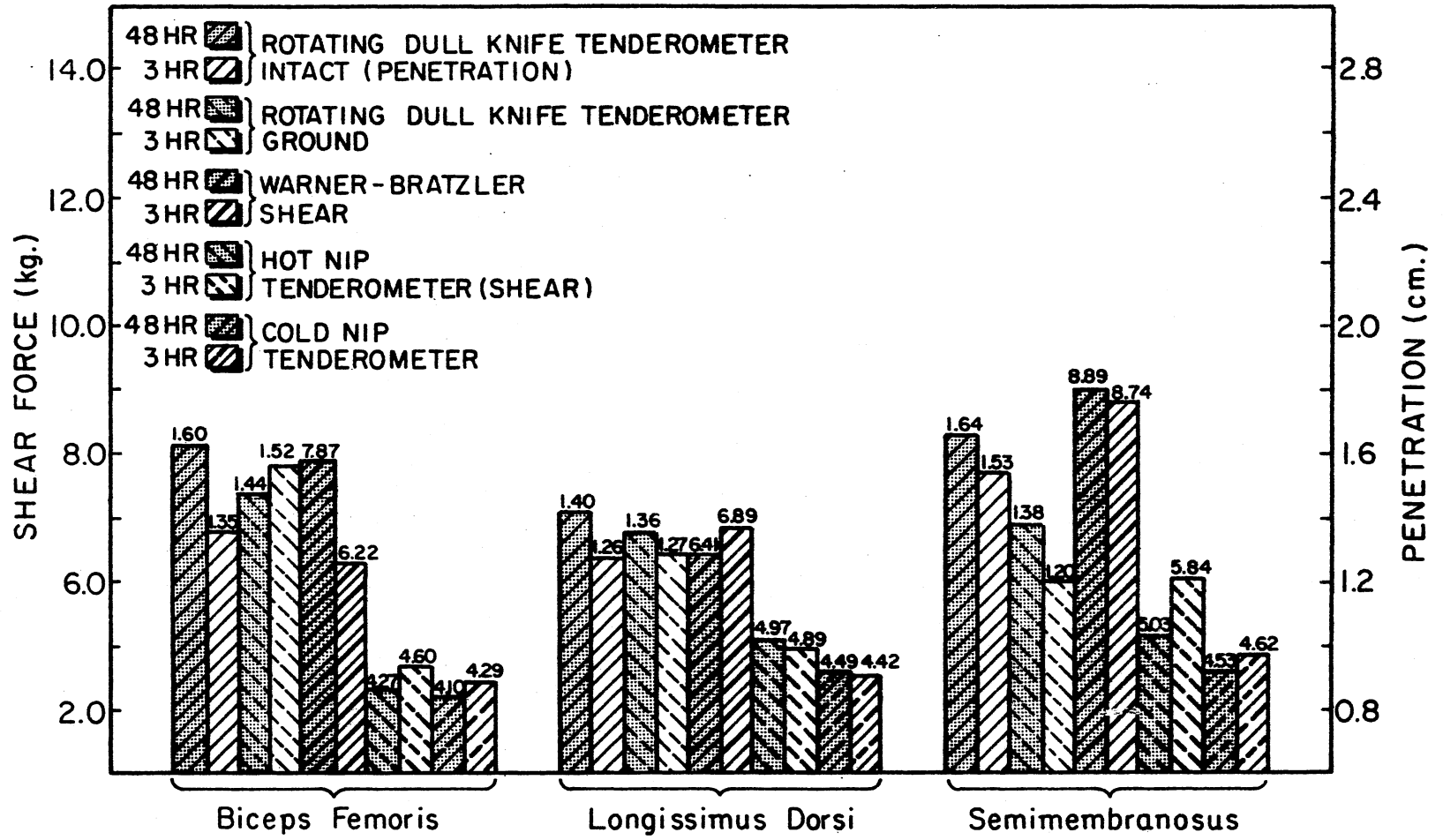

Figure 16. Objective Measures of Tenderness as Influenced by Muscle and Period of Excision

TABLE III

MEAN MECHANICAL MEASURES OF TENDERNESS AS INFLUENCED BY TREATMENT AND MUSCLE

Instrument	Process[4,5] Treatment	n	BF[6]	LD[7]	SM[8]
RDKT[1] Intact	Chilled (48 Hr)	24	1.56	1.54	1.60
cm	Delay chilled (5 Hr)	24	1.43	1.36	1.37
Carcass * Process MS Df = 3			0.47	0.25	0.11
RDKT Ground	Chilled (48 Hr)	16	1.49	1.36	1.48
cm	Delay chilled (5 Hr)	16	1.42	1.28	1.36
Carcass * Process MS Df = 3			0.11	0.04	0.07
W-B Shear[2]	Chilled (48 Hr)	72	6.01	6.28	8.62
Kg	Delay chilled (5 Hr)	72	6.44	6.68	9.06
Carcass * Process MS Df = 3			9.96	9.67	6.93
Hot Nip[3]	Chilled (48 Hr)	40	3.95	5.01	4.50^{b}
Kg	Delay chilled (5 Hr)	40	4.08	4.32	4.62^{b}
Carcass * Process MS Df = 3			2.99	6.74	1.38
Cold Nip	Chilled (48 Hr)	40	4.15	5.35^{b}	5.19
Kg	Delay chilled (5 Hr)	40	4.25	4.77^{b}	4.84
Carcass * Process MS Df = 3			3.24	1.32	0.10

[1]Rotating Dull Knife Tenderometer.

[2]Warner-Bratzler shear.

[3]Nip Tenderometer.

[4]Chilled.

[5]Delay chilled.

[6,7,8]Biceps femoris (BF), Longissimus dorsi (LD), Semimembranosus (SM)

Subscript b denotes significant difference at $P < 0.05$.

Nonsubscript denotes nonsignificant difference.

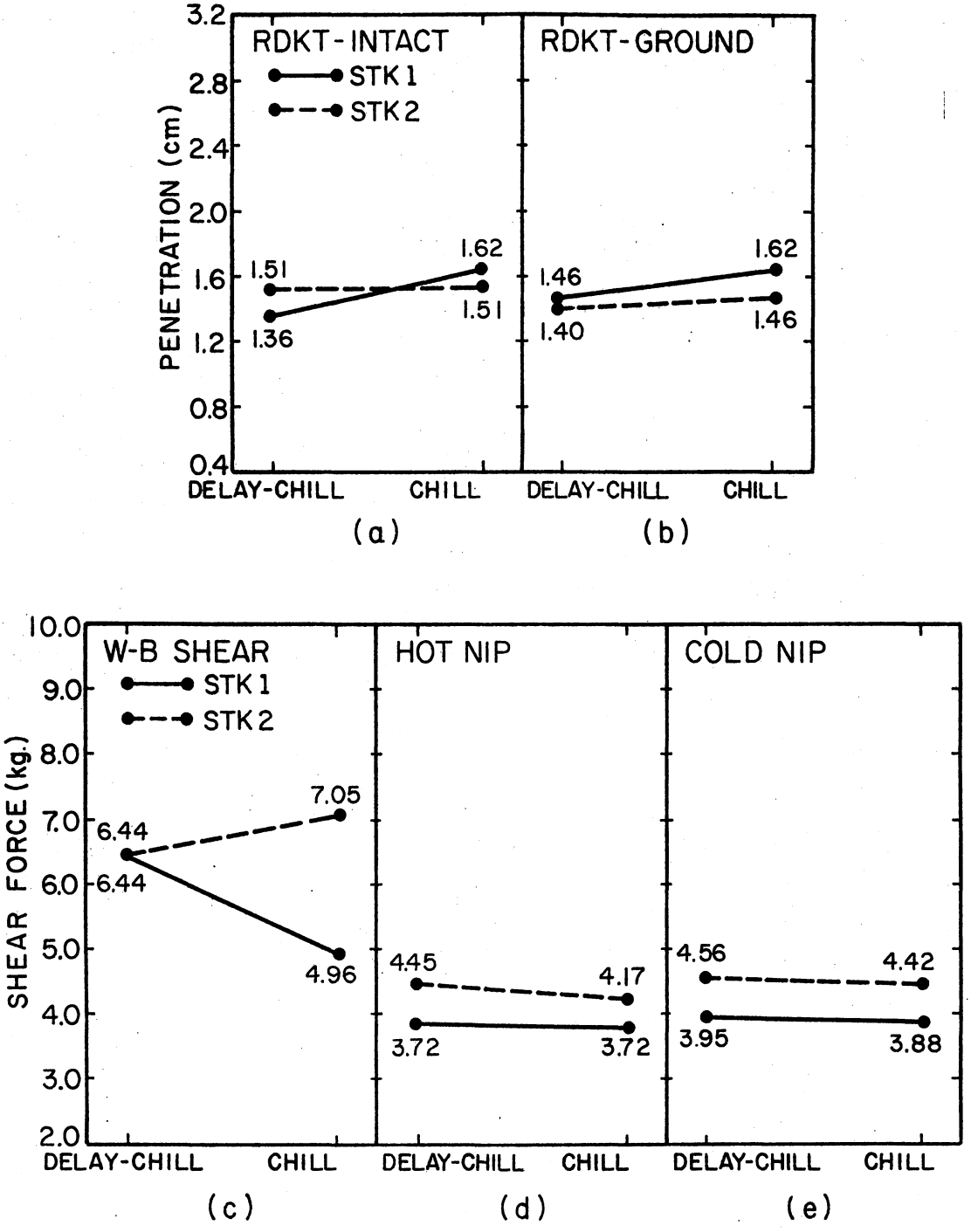

Figure 17. Penetration and Shear Force Measurements of the Biceps femoris for Chill and Delay Chill Treatments at 5 Versus 48 Hour Post-mortem

anterior steak was more tender than the posterior steak was noted. This agrees with the findings in Experiment I and other previously cited researchers.

Shear force readings between chilled and delay-chilled boning treatments for the LD muscle revealed statistical significance ($P < 0.05$) for the NT (cold) measurement (Table III). The NT (cold) reading indicated the 48 hour treatment was less tender than that of the 5 hour holding period. It should be noted that this difference was less than 0.6 kilogram of shear force. Therefore, the difference is of little practical or economic importance. The differences detected by the other four mechanical instruments for the LD muscle revealed tenderness of equal quality for both boning treatments (Table III). the process x steak interaction was nonsignificant for all measurement. Within muscle variation for the LD were also not detected (Figure 18a,b,c,d,e).

RDKT (intact), (ground), W-B shear and NT (cold) values for the Semimembranosus (SM) muscle indicated steaks of equal tenderness for the chilled and delay-chill boned meat (Table III). The NT (hot) measurement noted significance ($P < 0.05$) for the SM muscle indicating the delay boning treatment less tender than the chilled (Table III). This difference was less than 0.13 kilograms of shear force and is of little economic importance, chance may have been responsible for this indication of significance. No process x steak interaction was observed by any of the objective measures. Within muscle variation in the SM muscle was similar to previously cited research and data obtained in Experiment I (Figure 14a,b,c,d,e). The anterior portion of the SM muscle was more tender than that of the posterior end (Figure 19a,b,c,d,e). Statistical significance for the within SM muscle variation was obtained for the

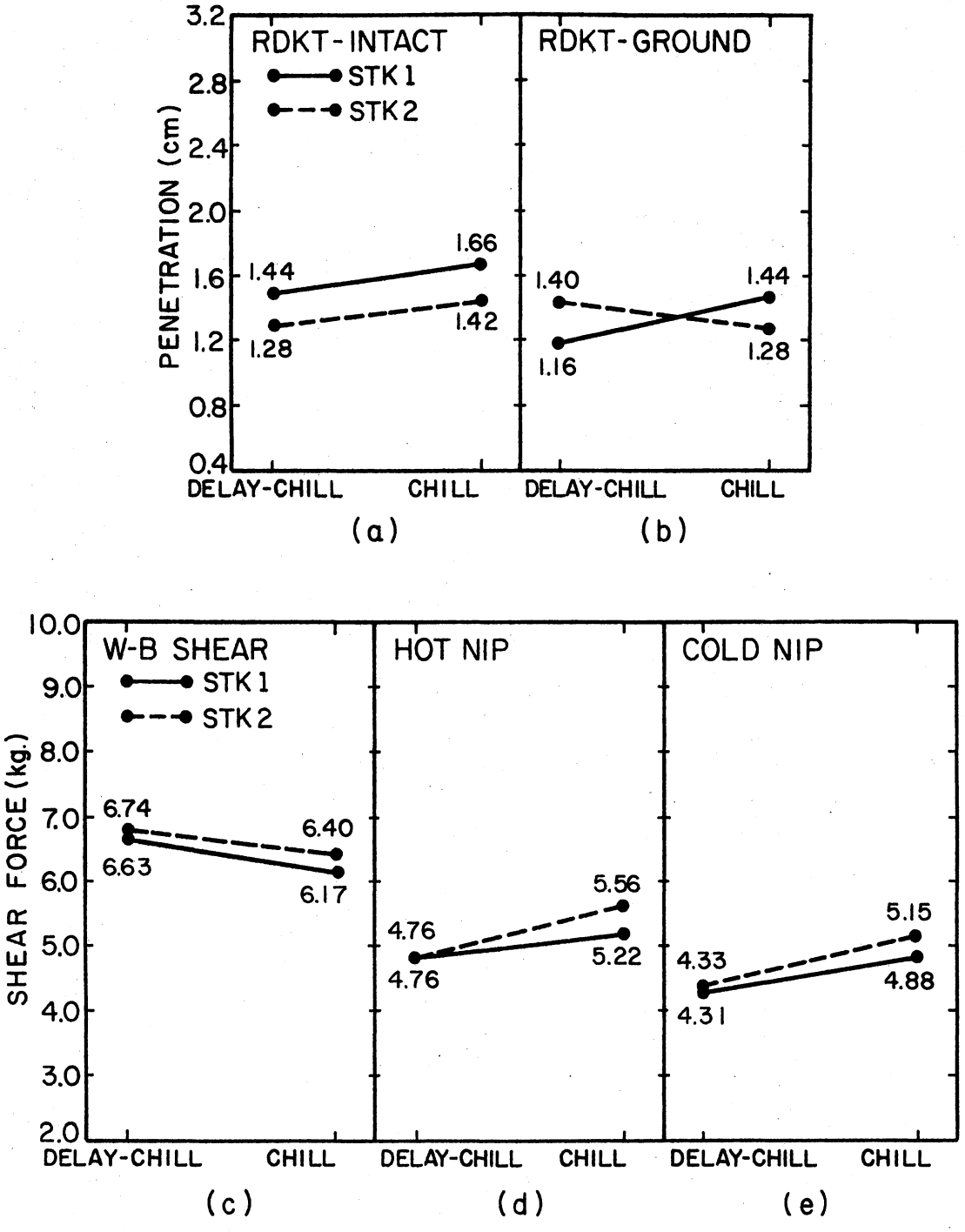

Figure 18. Penetration and Shear Force Measurements of the Longissimus dorsi for Chill and Delay Chill Treatments at 5 Versus 48 Hour Post-mortem

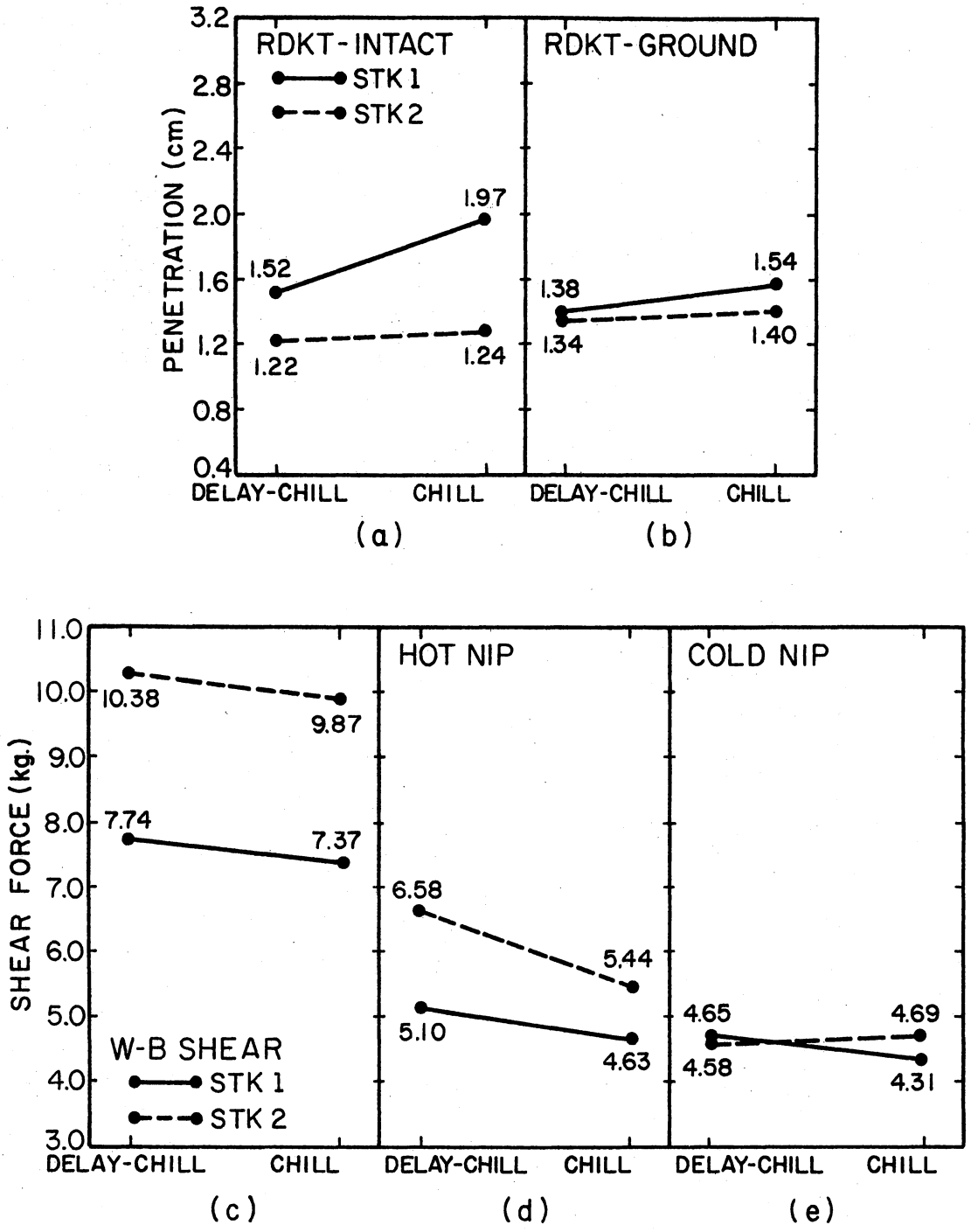

Figure 19. Penetration and Shear Force Measurements of the Semimembranosus for Chill and Delay Chill Treatments at 5 Versus 48 Hour Post-mortem

RDKT (intact) ($P < 0.05$), W-B shear ($P < 0.01$) and NT (hot) ($P < 0.05$) measurements (Figure 19a,c,d).

Subjective Measure

Sensory Evaluation

Sensory panel data as related to muscle tenderness and boning treatment are shown in Table IV. The data indicated that the panelists correctly identified 24, 10, and 18 of the 48 trials held with the BF, LD, and SM muscles, respectively. As previously mentioned 32 correct responses by the judges was required to obtain significance at the 5% level. Therefore, the Duo-Trio comparison test revealed panelists were unable to detect a difference between the two method of beef fabrication for the BF, LD, and SM muscles.

Analysis of the Preference test indicated a slight preference for the 48 hour process treatment to that of the 5 hour treatment for the BF, LD, and SM muscles (Table IV). This preference was only a slight trend as no statistical significance was attained for any of the muscles studied. The preference data also showed the process x steak interaction to be nonsignificant (NS) at the 5 versus 48 hour process treatments for all muscles studied.

Ranking by the panelists of the BF, LD, and SM muscles using the Hedonic Scale revealed a slightly higher level of acceptability for the 48 hour boning process (Table IV), however, the difference in frequency was nonsignificant ($P > 0.05$). Hedonic scale ratings for the three muscles showed that both boning treatments received responses from panelists in the slightly acceptable rating (Figure 20). Once, more process x steak interaction for the 5 versus 48 hour holding periods were found

TABLE IV

THREE PANEL MEASUREMENTS OF TENDERNESS AS RELATED TO TREATMENT AND MUSCLE

Duo-Trio Test

n	BF		LD		SM	
	Right	Wrong	Right	Wrong	Right	Wrong
48	24	24	20	28	18	30

Preference Test* (Mean)

Process	n	BF	LD	SM
Chilled (48 Hr)	48	1.60	1.54	1.62
Delay Chilled (5 Hr)	48	1.40	1.46	1.38

Hedonic Scale Rating[a] (Mean)

Process	n	BF	LD	SM
Chilled (48 Hr)	48	4.35	4.46	4.40
Delay Chilled (5 Hr)	48	4.00	4.38	4.08

[a]A score of 1 being unacceptable and 6 highly acceptable.

*Range from 1.0 to 2.0.

1 = Delay Chill Process Treatment.

2 = Chill Process Treatment.

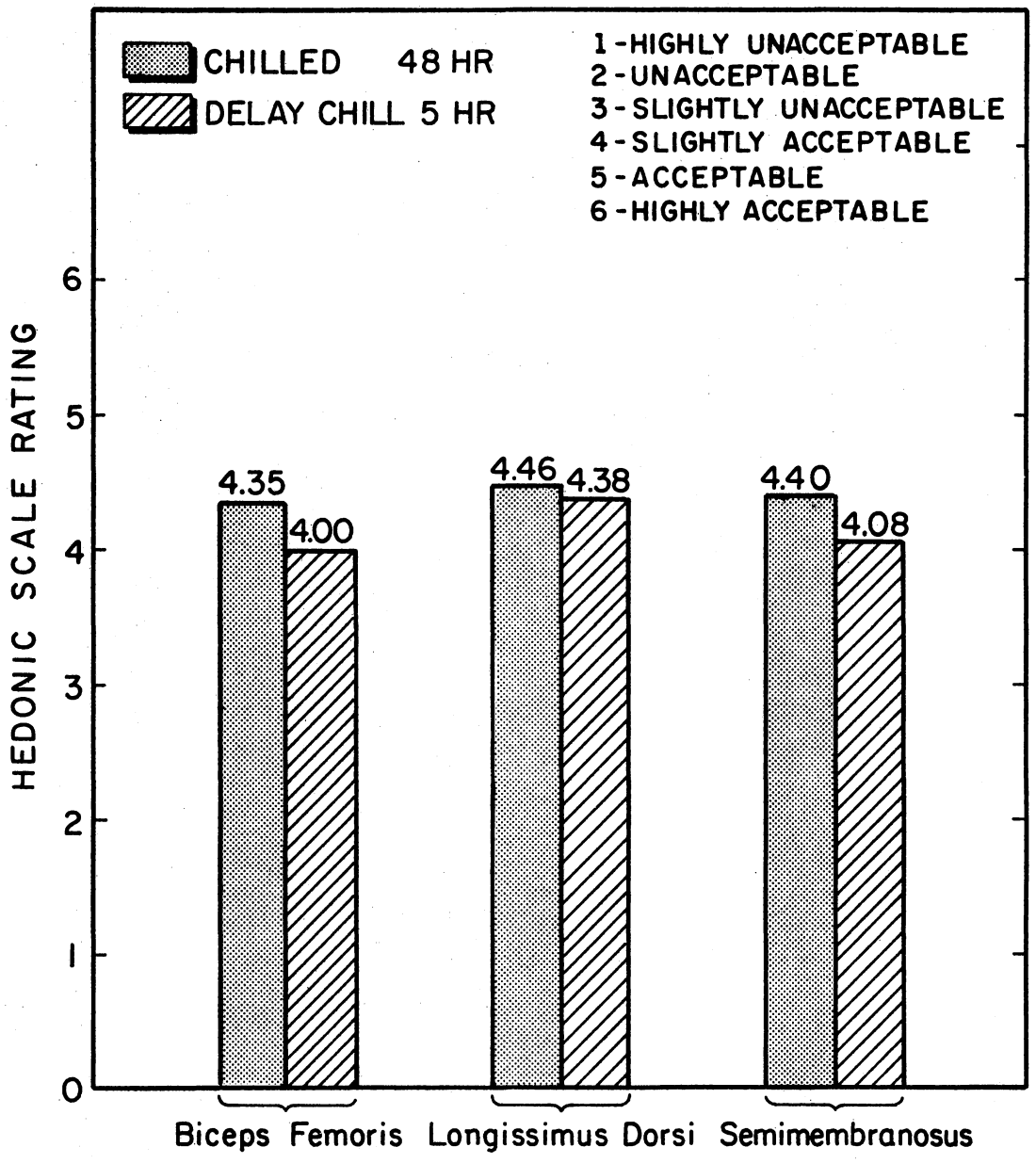

Figure 20. Subjective Measure of Tenderness as Influenced by Muscle and Period of Excision

to be nonsignificant (NS).

Conclusions

In Experiment II no major tenderness differences were found between 48 versus 5 hour holding periods in the BF, LD, or SM muscles. These findings were confirmed by the five objective methods (Figure 21). Tenderness panel evaluation reinforced the mechanical methods findings as the Duo-Trio Comparison, Preference Test and Hedonic Scale Ratings indicated no detectable differences. Difference within muscle location were noted as in Experiment I for the SM muscle by objective evaluation.

Objective Measures

Experiment III (7 Versus 48 Hour)

Penetration and Shear Force. Table V provides data from the BF, LD, and SM muscles for the 48 hour chilled versus 7 hour delay-chill boning treatments. A significant difference ($P < 0.05$) in shear force between the chilled and delay-chilled treatments for the BF muscle was noted for the NT (hot) measurement. This variation indicated that meat boned after a 48 hour holding period was more tender than the 7 hour boning treatment. As is evident from Table V the NT (hot) shear force difference was less than 0.32 kilograms, therefore, being of no practical importance. In addition, a significant process x steak interaction ($P < 0.01$) was present for the NT (hot) measurement, indicating the two steaks sampled from the anterior and posterior portions of the BF muscle responded differently to the 7 versus 48 hour holding periods. The RDKT (intact), RDKT (ground), NT (cold) and W-B shear indicated no significant differences between the process treatments for the BF muscle. With

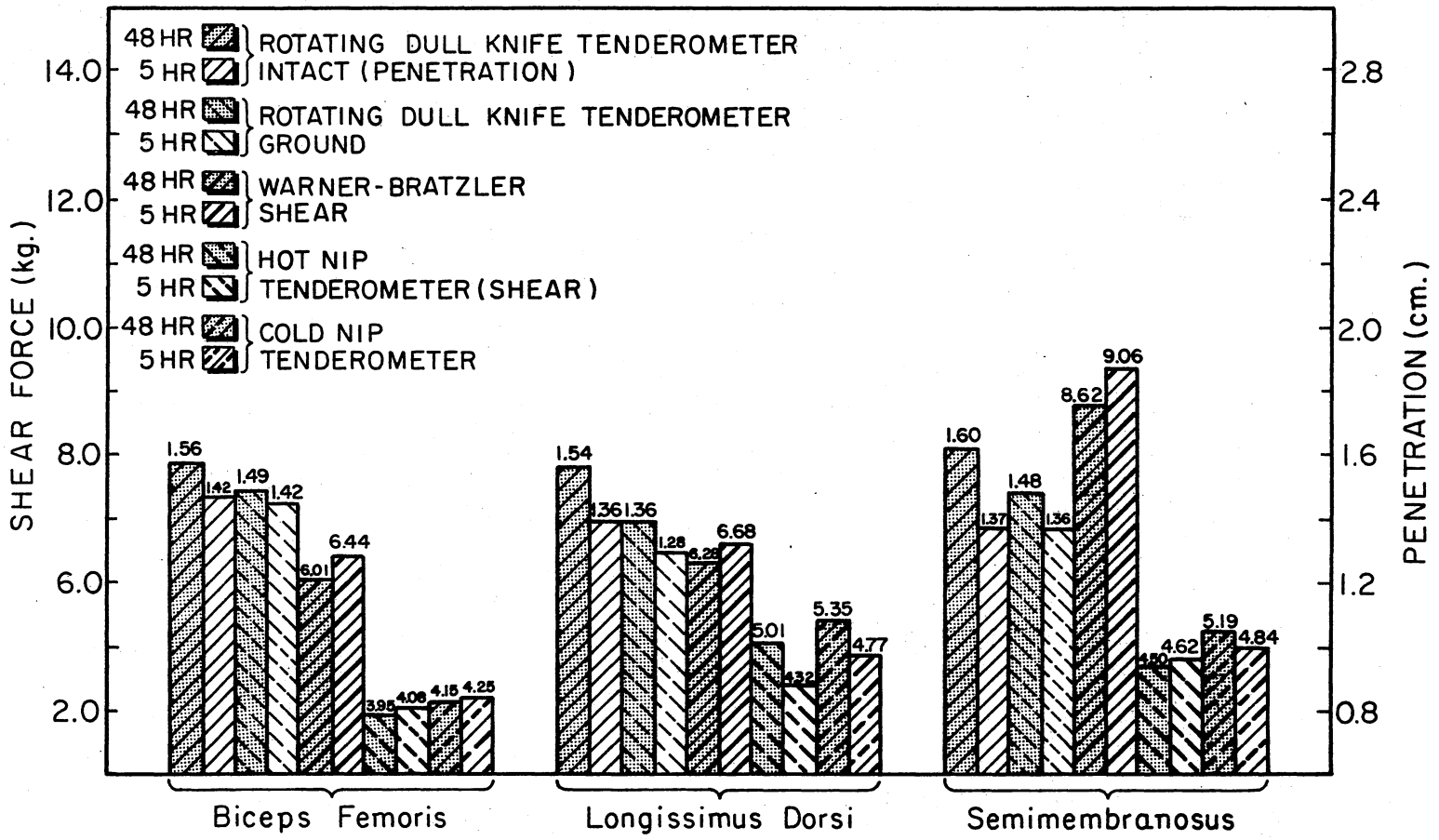

Figure 21. Objective Measures of Tenderness as Influenced by Muscle and Period of Excision

TABLE V

MEAN MECHANICAL MEASURES OF TENDERNESS AS INFLUENCED BY TREATMENT AND MUSCLE

Instrument	Process[4,5] Treatment	n	BF[6]	LD[7]	SM[8]
RDKT[1] Intact	Chilled (48 Hr)	24	1.36	1.53	1.39
cm	Delay chilled (7 Hr)	24	1.52	1.65	1.48
Carcass * Process MS Df = 3			0.14	0.23	0.01
RDKT Ground	Chilled (48 Hr)	16	1.52	1.34	1.26
cm	Delay chilled (7 Hr)	16	1.45	1.38	1.22
Carcass * Process MS Df = 3			0.01	0.04	0.05
W-B Shear[2]	Chilled (48 Hr)	72	7.15	6.17	8.99^{b}
Kg	Delay chilled (7 Hr)	72	6.53	5.42	9.81^{b}
Carcass * Process MS Df = 3			8.56	5.07	2.40
Hot Nip[3]	Chilled (48 Hr)	40	4.04^{b}	4.57	5.15
Kg	Delay chilled (7 Hr)	40	4.35^{b}	4.27	5.18
Carcass * Process MS Df = 3			0.29	6.06	0.78
Cold Nip	Chilled (48 Hr)	40	4.51	4.22	4.71^{b}
Kg	Delay chilled (7 Hr)	40	4.46	4.04	5.01^{b}
Carcass * Process MS Df = 3			2.04	1.47	0.40

[1]Rotating Dull Knife Tenderometer.

[2]Warner-Bratzler Shear.

[3]Nip Tenderometer.

[4]Chilled.

[5]Delay chilled.

[6,7,8]Biceps femoris (BF), Longissimus dorsi (LD), Semimembranosus (SM).

Subscript b denotes significant difference at $P < 0.05$.

Nonsubscript denotes nonsignificant difference.

the small amount of difference indicated by the NT (hot) measurement and no major differences indicated with the remaining instruments for the BF muscle one is lead to conclude that equal tenderness was present in the 7 versus 48 hour boning periods. The difference in penetration and shear force values between steak were found to be significant for the BF muscle (Figure 22). The RDKT (intact) ($P < 0.01$), W-B shear ($P < 0.01$) NT (hot)($P < 0.01$), and NT (cold)($P < 0.01$) all indicated the anterior (steak 1) was more tender than the posterior (steak 2). Similar variation with respect to steak in the BF muscle were obtained by Ramsbottom, et al. (1949); Cover, et al. (1962); and Kastner (1972).

The LD muscle, as estimated by the five mechanical methods of measurement indicated tenderness of equal quality for the 48 versus 7 hour post-mortem boning treatments (Table V). Likewise, variation within the LD muscle was not shown to be significant (Figure 23). No significant process x steak interaction were revealed in the LD muscle by any of the objective estimates of meat tenderness.

Statistically significant shear force values for the W-B shear ($P < 0.05$) and NT (cold) ($P < 0.05$) were noted for the chilled and delay-chill SM muscle (Table V). These data are in agreement with Falk (1974) for shear force measurements on the SM muscle for the 7 versus 48 holding periods. The NT (hot), RDKT (ground) and RDKT (intact) measurements indicated nonsignificance differences between the two processes, however, the NT (hot) and RDKT (ground) followed the same trend as that of the W-B shear and NT (cold) with the 7 hour boning treatment being less tender than the 48 hour treatment for the SM muscle. However, the W-B shear reading differed less than 0.83 kilograms shear force, and the NT (hot) value less than 0.31 kilograms. Such differences as these are

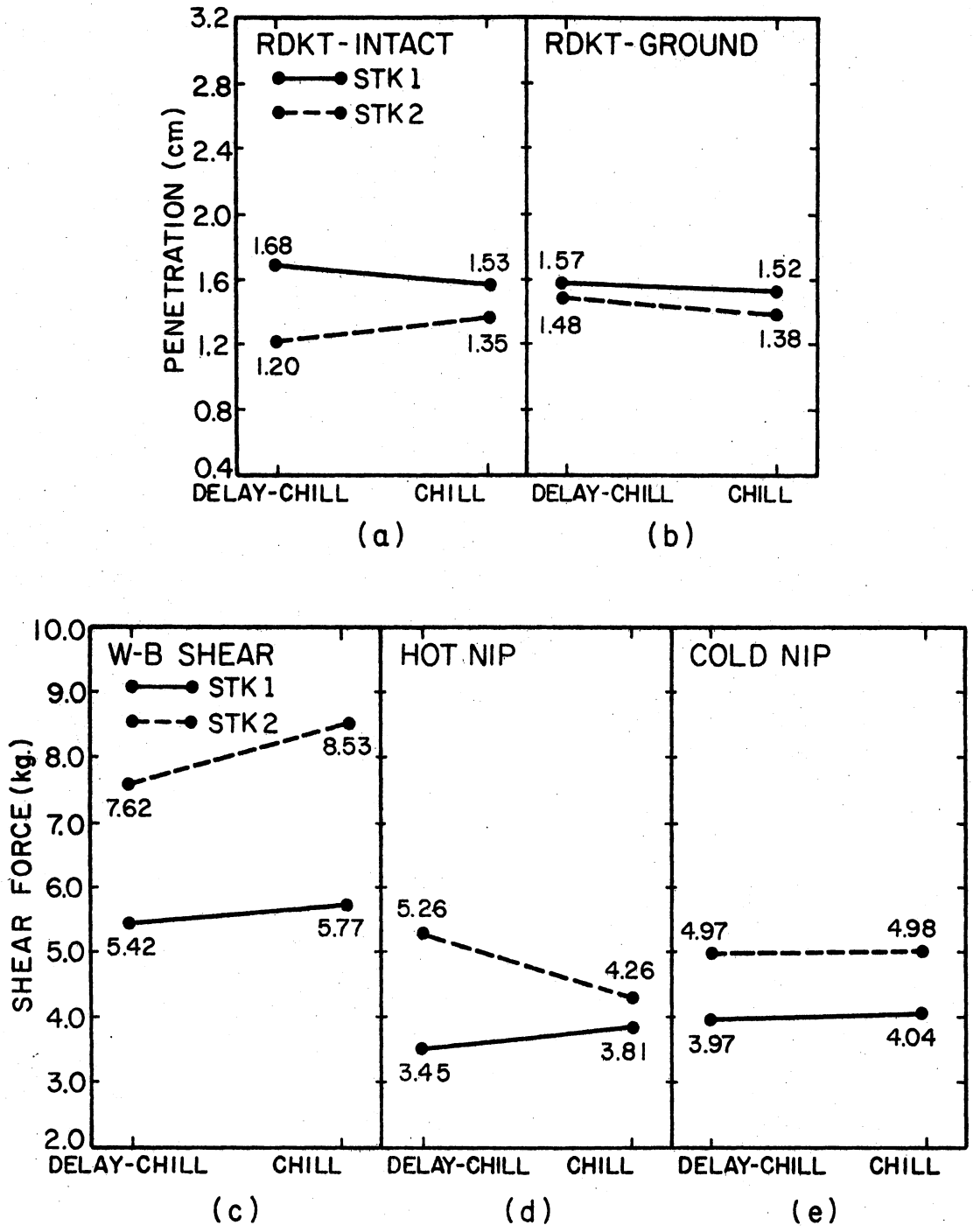

Figure 22. Penetration and Shear Force Measurements of the Biceps femoris for Chill and Delay Chill Treatments at 7 Versus 48 Hour Post-mortem

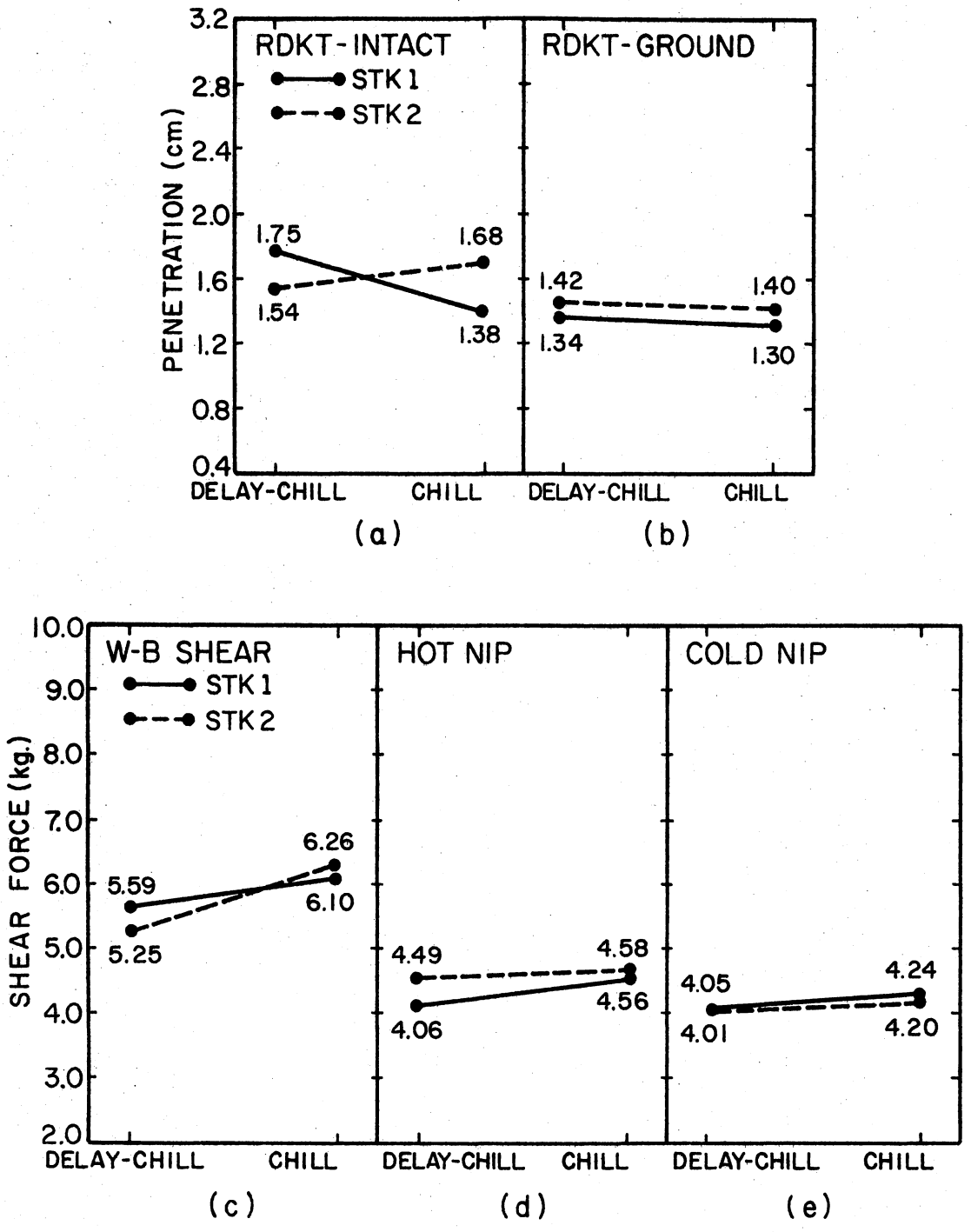

Figure 23. Penetration and Shear Force Measurements of the Longissimus dorsi for Chill and Delay Chill Treatments at 7 Versus 48 Hour Post-mortem

of little economic importance. Process x steak interaction once again were nonsignificant for all objective measurements. Agreement with Experiment I, II and previously mentioned research was noted as within SM muscle difference were significant (Figure 24). The anterior (steak 1) SM muscle was more tender than the posterior (steak 2) as indicated by RDKT (cold) ($P < 0.01$), W-B shear ($P < 0.01$), NT (hot) ($P < 0.01$) and NT (cold) ($P < 0.01$) (Figure 24a,c,d,e). These variations within the SM muscle may be due in part to connective tissue content, manner of attachment, and/or the amount of tension upon the muscle at a particular portion of the muscle as mentioned by Falk (1974).

Subjective Measure

Sensory Evaluation

Results of the trained sensory panel evaluation for meat tenderness as related to treatment are shown in Table VI. The duo-trio tenderness panel analysis of 7 versus 48 hour boned Biceps femoris, Longissimus dorsi, and Semimembranosus muscles showed that the judges were able to correctly pair the reference sample with its corresponding unknown 28, 29, and 24 times out of 48 times. Analysis of these data showed that the panelists were unable to distinguish between the tenderness of the two boning treatments for the BF, LD, and SM muscles (Table VI).

The Preference test agreed well with the previous data as no partiality was indicated statistically in any of the muscles studied. However, a slight trend of preference for the 48 hour boned steak was shown for the BF and SM muscles. The reverse trend was indicated by the panelists for the LD muscle as a slight preference for the 7 hour boning treatment was noted.

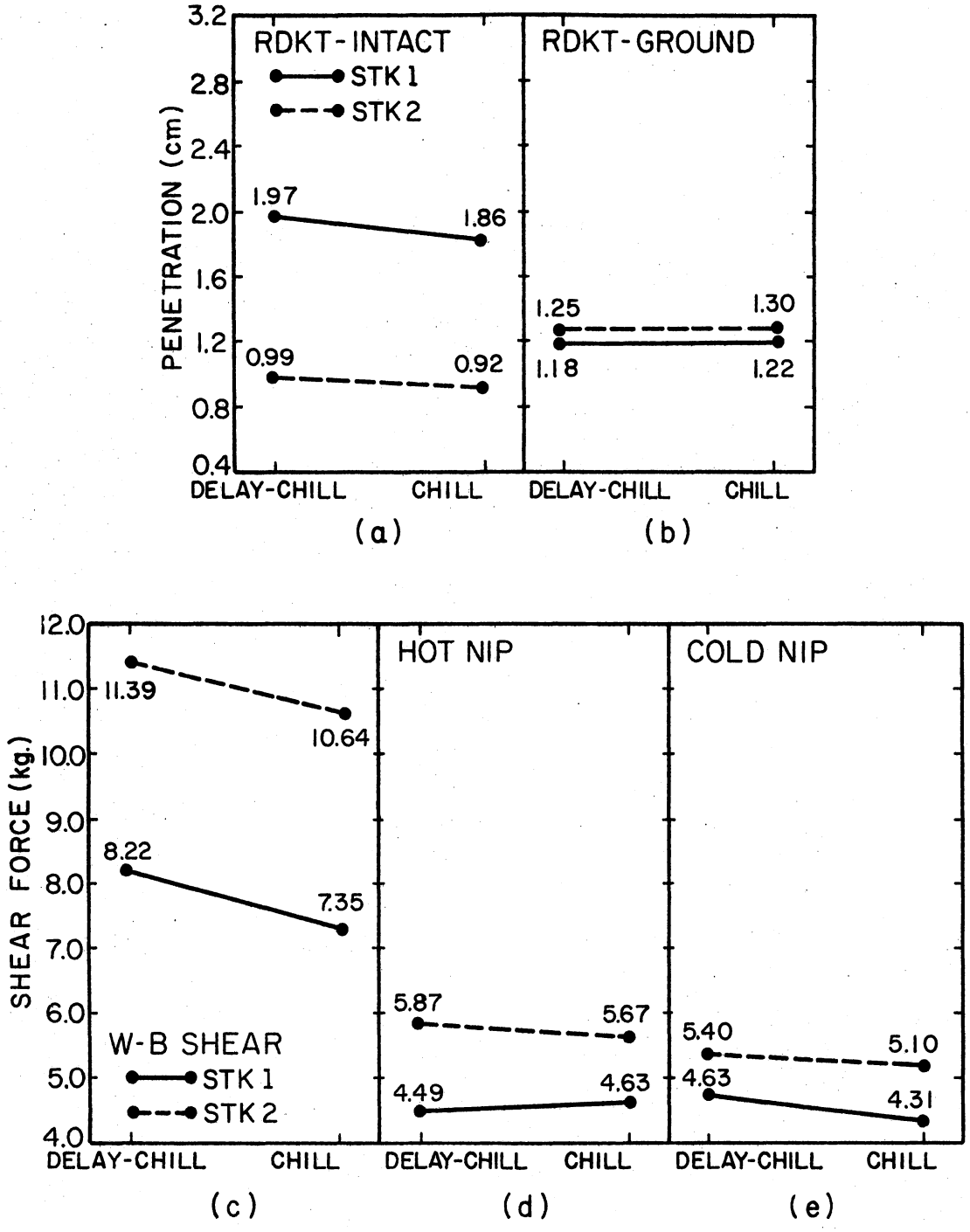

Figure 24. Penetration and Shear Force Measurements of the Semimembranous for Chill and Delay Chill Treatments at 7 Versus 48 Hour Post-mortem

TABLE VI

THREE PANEL MEASUREMENTS OF TENDERNESS AS RELATED TO TREATMENT AND MUSCLE

Duo-Trio Test

n	BF		LD		SM	
	Right	Wrong	Right	Wrong	Right	Wrong
48	28	20	29	19	24	24

Preference Test* (Mean)

Process	n	BF	LD	SM
Chill (48 Hr)	48	1.58	1.38	1.56
Delay Chill (7 Hr)	48	1.42	1.62	1.44

Hedonic Scale Rating[a] (Mean)

Process	n	BF	LD	SM
Chill (48 Hr)	48	4.42^{b}	4.52	4.27
Delay Chill (7 Hr)	48	4.10^{b}	4.81	3.94

[a]A score of 1 being highly unacceptable and 6 highly acceptable.

*Range from 1.0 to 2.0.

Subscript b denotes significant difference at $P < 0.05$.

1 = Delay Chill Process Treatment.

2 = Chill Process Treatment.

Hedonic Scale score analysis for the BF muscle showed that the panelists assigned a higher level of acceptability to the chilled treatment ($P < 0.05$) than that of the delay-chill treatment (Table VI). It should also be noted for the BF muscle that both chilled and delay-chill boning yielded products judged to be in the slightly acceptable rating category (Figure 25). The Hedonic Scale scores of the LD and SM muscle for 7 versus 48 hour holding periods indicated nonsignificant (NS) differences upon rank analysis. A nonsignificant (NS) hedonic rating trend in favor of the delay-chilled treatment over that of the chill boning was noted for the LD muscle, with the reverse trend being indicated for the SM muscle in the 7 versus 48 hour boning treatments (Table VI).

Conclusions

The results in Experiment III indicated no major tenderness differences were present between 48 versus 7 hour post-mortem boned muscles (BF, LD, or SM) as analyzed by five mechanical methods (Figure 26). This finding was reinforced by the trained sensory panel as Duo-Trio Comparison, Preference Test, and Hedonic Scale Rating indicated no interpretable differences. Within muscle variations were indicated for the BF muscle as measured by four of the five objective methods. Variations within the SM muscle were also indicated as previously was noted in the first two experiments of this investigation.

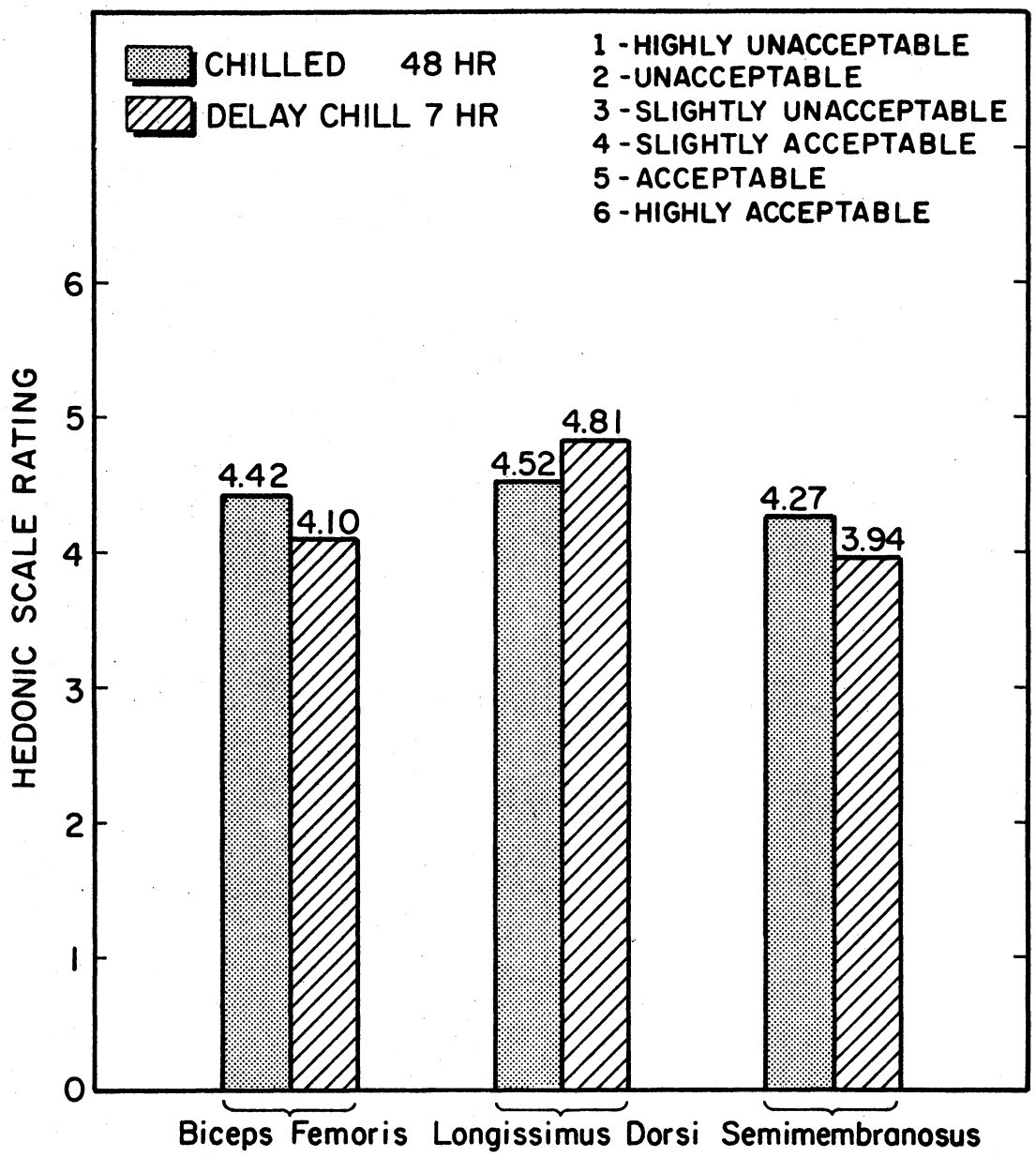

Figure 25. Subjective Measure of Tenderness as Influenced by Muscle and Period of Excision

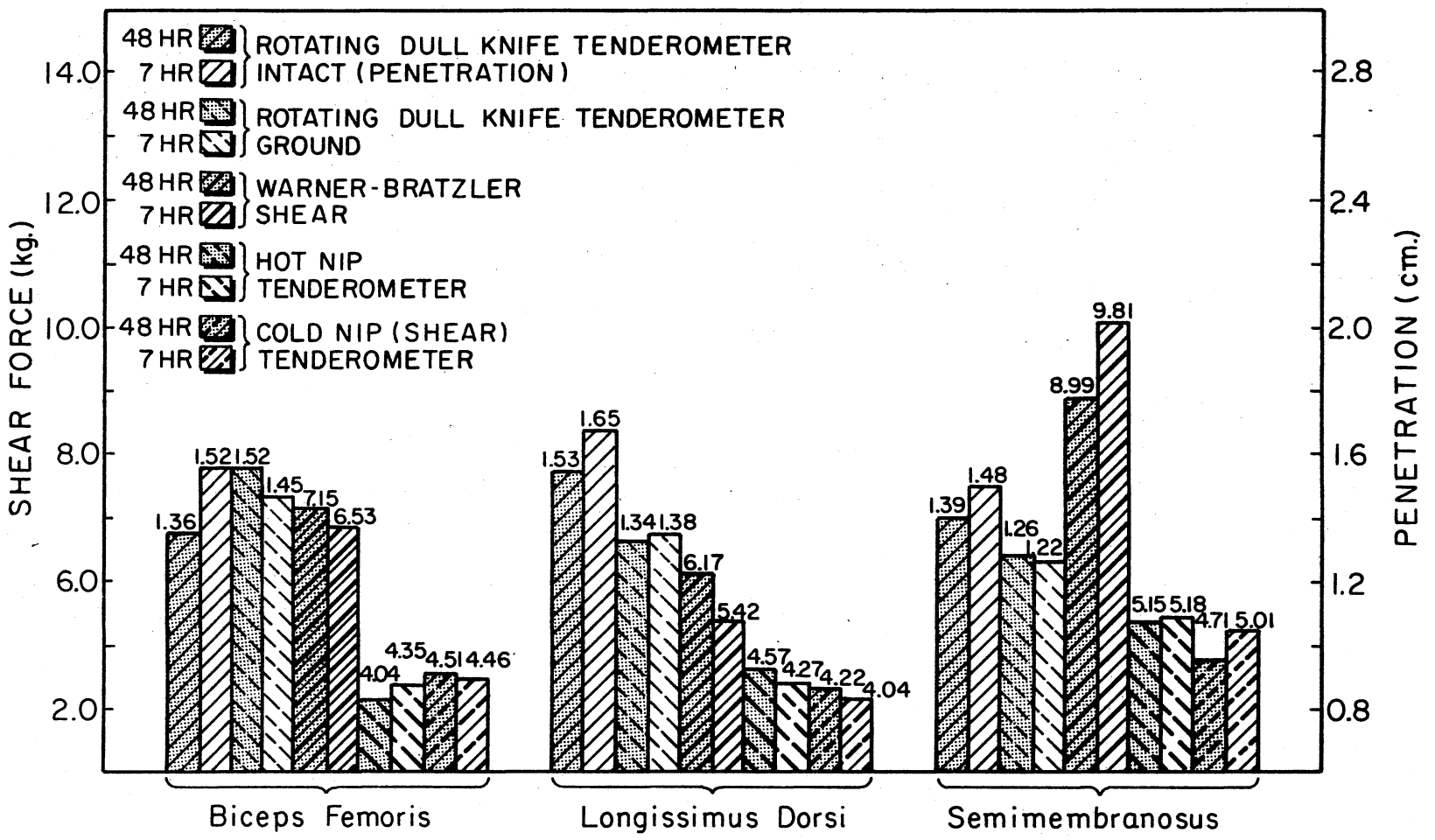

Figure 26. Objective Measures of Tenderness as Influenced by Muscle and Period of Excision

CHAPTER V

SUMMARY AND CONCLUSION

Three conditioning periods (3 vs. 48, 5 vs. 48, and 7 vs. 48 hours post-mortem) were studied to assess the merit of delayed chilling of the bovine carcass as each related to meat tenderness. Five objective methods of measuring meat tenderness were coupled with a trained tenderness panel in determining the tenderness imparted to the final meat product by the delay chill and conventional process treatments. Twelve Angus steer carcasses were used in the investigation. One side of each of the 12 carcasses was randomly designated to the delay chill treatment (3, 5, or 7 hours) with the remaining side being assigned the chilled treatment (48 hours). Sides utilized for the chilled treatment were held at 1.1°C for 48 hours before fabrication was initiated. The opposite pair side evaluated under the delay-chill treatment was likewise fabricated after being held at 16°C for its designated 3,5, or 7 hour post-mortem conditioning. The Biceps femoris (BF), Longissimus dorsi (LD), and Semimembranosus (SM) muscles were utilized in the investigation.

Differences among shear force and penetration values between chilled and delay-chilled treatments were small, averaging less than 0.91 kilograms and 0.25 centimeters, respectively. Shear force and penetration measurements taken by mechanical instruments, therefore, led to the conclusion that no major quality differences attributed to meat tender-

ness existed between beef fabricated 48 hours post-mortem at 1.1°C and that held 3, 5, or 7 hours post-mortem at 16°C.

Detectable variations registered by the trained tenderness panel were small between the two studied. The Duo-Trio test, Preference, and Hedonic Scale Ratings all supported findings indicated by the mechanical instruments that the boning of beef muscle 3, 5, or 7 hours post-mortem before chill provides beef of satisfactory tenderness.

Further research is now necessary to determine if there are means available by which the delay-chill holding time period may be reduced before muscle excision is initiated. In addition research should be begun to further evaluate the Rotating Drill Knife Tenderometer to further confirm its value as an objective measure of meat tenderness. Ease and speed of operation combined with agreement of Sensory data and within steak sensitivity suggested the Nip Tenderometer has good potential for future use as an evaluation tool of meat tenderness.

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A P P E N D I X

TABLE VII

ANALYSIS OF VARIANCE OF WARNER-BRATZLER SHEAR DATA AT THE THREE HOUR HOLDING PERIOD FOR DELAY CHILLED VERSUS CHILLED BICEPS FEMORIS

Source	DF	Sum of Squares	Mean Squares
Total Corrected	143	1668.23	
Main Unit Analysis		286.94	
Carcass	3	57.02	19.01
Process	1	213.92	213.92
Carcass x Process	3	16.00	5.33
Subunit Analysis		1381.28	
Steak	1	431.23	431.23
Process x Steak	1	195.93	195.93
Carcass x Steak + Carcass x Process x Steak	6	104.06	17.34
Carcass x Steak	3	74.15	24.72
Carcass x Process x Steak	3	29.90	9.97
Core (Carcass Process Steak)	32	400.14	12.51
Measurement (Carcass Process Steak)	96	249.92	2.60

TABLE VIII

ANALYSIS OF VARIANCE OF NIP TENDEROMETER DATA AT THE THREE HOUR HOLDING PERIOD FOR DELAY CHILLED VERSUS CHILLED BICEPS FEMORIS

Source	DF	Sum of Squares	Mean Squares
Total Corrected	79	189.15	
Main Unit Analysis	7	33.75	
Carcass	3	12.93	4.31
Process	1	1.45	1.45
Carcass x Process	3	19.37	6.46
Subunit Analysis	72	155.42	
Steak	1	8.19	8.19
Process x Steak	1	1.84	1.84
Carcass x Steak + Carcass x Process x Steak	6	18.38	3.06
Carcass x Steak	3	17.99	5.99
Carcass x Process x Steak	3	0.39	0.13
Measurement (Carcass Process Steak)	64	127.01	1.98

TABLE IX

ANALYSIS OF VARIANCE OF ROTATING DULL KNIFE TENDEROMETER DATA AT THE THREE HOUR HOLDING PERIOD FOR DELAY CHILLED VERSUS CHILL BICEPS FEMORIS

Source	DF	Sum of Squares	Mean Squares
Total Corrected	47	2.30	
Main Unit Analysis	7	0.55	
Carcass	3	0.11	0.04
Process	1	0.33	0.33
Carcass x Process	3	0.11	0.04
Subunit Analysis	40	1.75	
Steak	1	0.0003	0.0003
Process x Steak	1	0.16	0.16
Carcass x Steak + Carcass x Process x Steak	6	0.34	0.06
Carcass x Steak	3	0.23	0.08
Carcass x Process x Steak	3	0.10	0.03
Measurement (Carcass Process Steak)	32	1.25	0.04

VITA

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