

July 11, 1973

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I am submitting herewith a dissertation written by Harriet Perry Corrick, entitled "A Comparison of Four Objective Measures of Beef Tenderness." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

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A COMPARISON OF FOUR OBJECTIVE MEASURES
OF BEEF TENDERNESS

A Dissertation
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
Harriet Perry Corrick

August 1973

ACKNOWLEDGMENTS

The author wishes to express here sincere thanks and gratitude to all those who have contributed throughout the course of graduate study and in the preparation of this dissertation, especially to the following:

Dr. William R. Backus, Food Technology and Science Department, for his planning and supervision of the research and assistance in preparing this manuscript.

Dr. J. T. Miles, Head of the Department of Food Technology and Science, for his support and understanding and his constructive criticism of this manuscript.

Dr. S. L. Hansard, Department Head of Animal Science, for his timely advice and counseling.

Dr. R. R. Shrode, Animal Science Department, for his concern and consideration, his encouragement and faith in the author, his suggestions regarding statistical procedures and his patient fortitude and constructive criticism in the preparation of this manuscript.

Dr. Archie Mathews, Engineering Science and Mechanics Department, for his continued patient and cooperative spirit, his timely comments while using the Instron Universal Testing Instrument and especially for coming to my "rescue" when help was needed by serving on the graduate committee.

Dr. C. C. Melton, Food Technology and Science Department, for his encouragement and assistance in preparing this manuscript.

Dr. J. B. McLaren, Animal Science Department, for his interest and cooperation and his constructive criticism of this manuscript.

Dr. W. W. Overcast, Food Technology and Science Department, for his exceeding kindness and his constructive criticism of this manuscript.

Dr. M. R. Johnson, Food Technology and Science Department, for his classroom contribution and his help in planning this research problem.

Dr. J. K. Bletner, Animal Science Department, for his original suggestion that the author transfer to the Animal Science Department in pursuit of a Ph.D. degree.

Dr. James Neal and Dr. Clyde Lane for their able assistance in computer programming.

To all the taste panel members for being willing to be a variable in the correlation equation.

Miss Ruth Hill, Food Technology and Science Department, for her willing and cheerful assistance in conducting the sensory sessions.

Mrs. Mary Mills, for so cheerfully aiding the author in organizing and typing this manuscript.

Last, but by no means least, my husband, Jim (Dr. J. A. Corrick, Jr.; Animal Science Department) for his continuous encouragement and help and his constant urging "upward and onward".

.....Harriet P. Corrick

ABSTRACT

Measurements of tenderness were made on the semimembranosus muscle using the Armour Tenderometer (AT), Warner-Bratzler Shear (WB), Instron Universal Testing Instrument (Instron) and subjective evaluations.

Muscles used came from 35 beef animals, five from each of seven mating types: Charolais-Hereford (CH) dams bred to Hereford (H) or Charolais (C) bulls, H dams bred to Simmental (S), Maine-Anjou (MA), Limousin (L) or H bulls. Thus, the breed groups represented were: H X H, C X H, H X C H, C X CH, S X H, M A X H and L X H.

Penetration-force values were obtained from raw muscle with the AT. Cores one-half inch in diameter, from cooked muscle were used with the WB and the Instron. Maximum-shear-force values were obtained with the WB while maximum force (IMF) and "area under the curve" (IAR) values were obtained with the Instron. A 10-member taste panel (TP) evaluated each muscle for tenderness on a hedonic scale of 1 (extremely tough) to 10 (extremely tender).

A comparison of the seven breed groups was made within each method of evaluation. The following breed groups were ranked most tender by the various methods: TP, H X CH; WB, H X C H; IMF, H X C H; IAR, L X H and AT, H X H.

Analysis of variance showed no significant variation due to differences between the WB and IMF shear values, differences between

breeds or interaction between instrument and breed. Highly significant product-moment (PM) correlations and rank correlations were found between: TP and WB, TP and IMF, TP and IAR. No indication was found of any relationship between the AT values and TP scores. The PM correlations and rank correlations between the WB values and the IMF values, between WB and IAR values and between IMF values and IAR values were highly significant. The correlations of AT values with other objective measures of tenderness were nonsignificant.

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Chapter I

INTRODUCTION

Tenderness of meat is difficult to define and even more difficult to measure by subjective or objective methods. However, this quality of meat, of all the palatability traits, remains the one most desired by the average consumer.

A combination of juiciness, flavor, aroma and appearance, as well as tenderness, adds to the meaning of tenderness in the judgment of the consumer and, to him, is a subjective evaluation. However, the food technologist or food scientist separates these qualities and measures tenderness as a "physical" property, i.e., the number of chews taken before swallowing, the amount of force required to shear a standard core, etc.

There are two basic methods of measuring tenderness: (1) subjective evaluation, and (2) use of objective devices. Because of the many adverse factors encountered in subjective testing, such as fatigue of human evaluators, cost (money and time) and biological variation between people, researchers have developed many objective (mechanical) devices for the evaluation of meat tenderness which range from the common food grinder, to complex instruments consisting of full dentures, in an attempt to simulate the chewing process. The objective methods used today must be used in conjunction with a taste panel, and it is this limitation that the food scientist would like to eliminate. Objective

testing should be a means within itself for testing tenderness of meat. However, at the present time, no method has been developed which can be successfully used in this manner.

The instrument most widely used today for measuring tenderness of meat is the Warner-Bratzler Shear. This instrument's measurements have been compared with sensory evaluation in many studies. In the reports of approximately two thirds of these studies, relatively high correlations with taste panel evaluations were given, while the others reported poor to very poor agreement. It has been shown also that the variability between instruments is fairly large.

Because of the variability within and between Warner-Bratzler Shears, the shearing unit from the Warner-Bratzler device used in the present study was adapted for use with an Instron Universal Testing Instrument (Instron). This was done to reduce the variability found in the Warner-Bratzler. The use of an Instron in measuring textural properties of food products has been under study since the early 1960's. This instrument has been used in the engineering field since 1949 and is considered to be a highly reliable and valuable device for measuring the physical properties of many materials. It has been found also to be practically free of variability.

The Armour Tenderometer, developed by the Armour Food Company as a nondestructive method of predicting tenderness of cooked meat from raw muscle measurements, has been used by that company since 1969-1970 with reportedly very good commercial success. The Tenderometer's value as a research tool has not been established. Limited information found

in the literature from three evaluations of this instrument (Henrickson, Marsden and Morrison, 1972; Dikeman et al., 1972; Carpenter, Smith and Butler, 1972) indicated that correlations, with Warner-Bratzler shear values and/or sensory evaluations, ranged from a near-zero correlation to a significant relationship (within U. S. Choice grade carcasses).

In recent years new large breeds of cattle, often called "exotics", were introduced into this country. Since then the beef cattle industry has been crossbreeding these new breeds with the British breeds at an increasing rate. The increasing use of "exotic" breeds suggests that the beef producer is interested in increasing size, growth potential and cutability in his cattle. However, the effect of these crossbreeding programs on palatability traits has not been established.

The offspring of Hereford cows mated to Hereford, Simmental, Maine-Anjou, Limousin or Charolais bulls and of Hereford-Charolais cross cows mated to Hereford or Charolais bulls were used in the present study.

There is an abundance of information concerning the relationship of Warner-Bratzler Shear and sensory evaluations of meat of British breeds. However, no data are available using a Warner-Bratzler shearing unit fitted to an Instron. Investigation of the suitability of the Instron for meat tenderness testing and comparison of results obtained with those using the conventional Warner-Bratzler Shear and the Armour Tenderometer using a sensory panel as a reference for comparison was the objective of this study.

The semimembranosus muscles, from 35 bovine carcasses from progeny groups of breeding previously described, were evaluated for tenderness by the following methods:

1. The Warner-Bratzler shearing unit, adapted and fitted to an Instron. Maximum force and "area under the curve" (work) were recorded.

2. The Warner-Bratzler Shear fitted with the same shearing mechanism used for Instron testing, but with shear force recorded by the spring dynamometer.

3. Armour Tenderometer.

4. A 10-member sensory panel.

Progeny groups were ranked from the most tender to the least tender with each method of evaluation. Comparisons were made between the various objective methods and between these objective methods and sensory evaluations.

CHAPTER II

LITERATURE REVIEW

I. Animals

The new European breeds, popularly called "exotics" used in this study were the Simmental, Maine-Anjou and Limousin. These breeds were introduced into the United States via Canada in the last six years and have become very popular with cattle producers. There is very little known about their various characteristics or their adaptability to conditions in this country.

In the information obtained from French et al. (1966), two things are impressive about these three breeds; first, they are much larger in size than the conventional British breeds and secondly, they are all old established breeds in the countries of their origin.

The Simmental breed originated in the Simme valley of the Bernese Oberland now known as Switzerland. This breed is one of the oldest breeds in the world since their ancestors were known to have existed in the middle ages. The average mature weight of the bulls is 2376 pounds, and that of the females is 1650 pounds. The germ plasm of this breed was introduced into the United States in 1967.

The Maine-Anjou breed originated in France in 1839 when native Manceau cows were bred to one British Durham bull. They are probably the largest breed of cattle in France today. The average mature weight

of the bulls is 2750 pounds, and weights of 3000 pounds are not unusual. The females average 1980 pounds. This breed was introduced into North America in 1970.

The Limousin breed, a native of the province of Limousin, France, was established in 1866 and is a branch of the large Aquitaine blond cattle family. The average mature weight of the bulls is 2090 pounds and that of the female, 1320 pounds. The meat of this breed is fine textured, and animals develop marbling at an early age. This breed was introduced into this country in 1968.

Strictly speaking, the Charolais breed is not considered one of the new European breeds, having been in this country since 1936, when the King Ranch of Texas imported them from Mexico. However, it is of interest to know that they originated in France and are considered to be the oldest breed in that country. It is thought they have common ancestors with the Simmental of Switzerland. The average mature bull weight is 2389 pounds; females, 1786 pounds. Their carcasses are noted for their cutability (percent lean) and lack of marbling.

II. Muscle Structure

The average consumer's idea of a piece of meat is simple, he thinks of it as a combination of protein, fat and bone with the price varying inversely with the amount of the last two constituents. However, to the biochemist, meat is a muscle with various components in a complex structural arrangement.

This discussion, unless otherwise noted, is a composite of the descriptions given by Cassens (1971), Bodwell and McClain (1971), Scheer (1963), Birkner and Auerbach (1960), Venable (1963) and Lawrie (1966).

In general, the components of muscle can be listed as: several different proteins, fat deposits, vascular and nervous tissues--all surrounded by the watery intercellular environment typical of most living matter.

Three kinds of muscle are recognized. They are: (1) smooth or involuntary muscle, (2) striated voluntary or skeletal muscle, and (3) striated involuntary or cardiac muscle.

This discussion will be limited to the skeletal muscle, not because the other muscles are not important, but because the meat we eat is mainly of this type.

The skeletal muscle cell is an elongated, cylindrical spindle shaped cell with blunt ends. A skeletal (striated) muscle fiber is a single large cell made up of large numbers of myofibrils which extend the entire length of the muscle fiber. The fiber is imbedded in a conventional cytoplasm called the sarcoplasm. The sarcoplasm contains the mitochondria, many nuclei and all other cytoplasmic apparatus.

The myofibrils are unique, being made up of many fine filaments, myofilaments, and are directly responsible for the characteristic banded or striated pattern of skeletal muscle. These light and dark bands show a difference in optical properties when examined in polarized light or with a phase contrast optical system.

Under the microscope, the stained muscle fibers present both cross striations and longitudinal striations. The cross striations of the myofibrils are so aligned that they produce the appearance of cross banding along the entire muscle fiber. The longitudinal striations are due to the myofibrils which lie parallel to one another.

Bisecting each light band is a line called the Z- line, and the area between two Z- lines is considered to be a structural and functional unit. This area is known as a sarcomere.

In living muscles, proteins are the most important constituents, permitting their physiological functioning, while in meats they provide a major source of high quality protein in the human diet.

The proteins of muscle can be categorized as sarcoplasmic, myofibrillar and connective tissue. The myofibrillar proteins give the structural rigidity to muscle and are the site of the transduction of chemical energy into the mechanical energy of contraction. The connective tissue proteins function, together with the skeletal framework, as the major supportive element of the animal body. The role of the connective tissue proteins, collagen and elastin, as they relate to tenderness, will be discussed elsewhere. These proteins have varied as well as specific functions. They enclose muscle fibers and whole muscles, act as a connection of muscles, organs and other structures to each other and to the skeletal framework and act as a covering for the body (skin and hide).

Three of the major myofibrillar proteins with which we are concerned here are: (1) actin, (2) myosin and (3) actomyosin. Electron

micrographs of myofibrils in longitudinal section show two kinds of filaments, thin ones, designated as actin, extending from one Z- line (in the light band) to a point past the beginning of the thicker filament so that there is an overlapping of the two different filaments, and thicker filaments, called myosin, lying between the actin filaments and extending only through the dark band. Both actin and myosin are contractile proteins. In muscle at rest, or in the prerigor state in dying muscle, the actin and myosin filaments are separate, but, during contraction slide together to form actomyosin.

III. Tenderness of Meat

Consumer studies have indicated that of all the palatability traits of meat, tenderness is the most important as a criterion of desirability.

The importance of tenderness cannot be overestimated. Down through the ages man has tried to tenderize the meat he eats. Archeologists have found evidence that man was cooking meat to improve tenderness and flavor over 500,000 years ago. Many scientists, according to Coon (1963), consider that tenderizing of meat may have been one of the prime factors in human evolution. When food was tough, man had to have large strong jaws with little room for brain expansion; but when fire was discovered and cooked meat became more tender the jaws became smaller, the brain expanded and speech developed. Coon (1963) explained further that some of the oldest writings in existence deal with methods and recipes for cooking and tenderizing meat dishes. He stated that by

2000 B.C., man had learned that some cuts of meat were more tender if boiled, while others were more tender if roasted, and that marination of meats was in use long before the time of Christ.

Statistics amply bear out the fact that meat, especially beef, is one of our most important food products and is a major item in the diet of the average American.

According to the United States Department of Agriculture (U.S.D.A.), Economic Research Service (1973) the amount of red meat consumed in 1962 per person was 187.8 pounds with 115.6 pounds of this total being beef.

One of the largest industries in the world is the production, packing and marketing of meat and meat products. Farm production of meat animals in 1972 was 64 billion pounds in the United States, according to the U.S.D.A. Crop Reporting Board (1973). Cattle and calves accounted for 64 percent of the total meat production; hogs and pigs, 34 percent and sheep and lambs, less than two percent. Cash receipts from farm marketing of meat animals totaled 23.9 billion dollars during 1972. Tennessee ranks twelfth among the fifty states in the number of beef cows (1,124,000), according to the U.S.D.A. Economic Research Service (1973). The Tennessee Crop Reporting Service (1973) reported that the inventory value of livestock and poultry, excluding broilers, on Tennessee farms January 1, 1973, was over 627 million dollars, with cattle and calves accounting for 92 percent of this total. Thus, since meat is important economically as well as nutritionally, tenderness, an important quality of meat also is important.

All this brings up the obvious question: "What is tenderness, or what isn't it?" In answer, Deatherage (1963) explained that tenderness is the primary quality of meat next to its nutritive value. He further stated that tenderness may be defined simply as "the ease of mastication." DeFelice (1965) agreed with Deatherage when he defined tenderness as that characteristic of meat which determines the ease with which the meat can be chewed and swallowed. Perhaps Ramsbottom and Strandine (1948) were the first to define tenderness when they stated that it may be defined as the state of being easily comminuted or masticated. Mastication seems like a simple uncomplicated process until one reflects upon the experiences encountered when chewing a piece of meat, as Shultz (1957) noted. Also, tenderness means different things to different people. It may mean the tenderness of a broiled steak or a well-done or rare roast or it may be the tenderness of a frankfurter.

Tenderness is a complicated property of meat and involves many factors. An all encompassing definition for tenderness cannot be evolved until we understand more of the factors that cause a piece of meat to be considered tender or tough.

IV. Factors Affecting Tenderness

Many factors influence the tenderness of meat; they may broadly be divided into antemortem and postmortem factors. Most tenderness studies have been conducted with beef because beef tenderness exhibits greater variability than does that of pork and lamb which are considered to be naturally tender.

Antemortem Factors

One of the most effective and permanent methods of improving quality of meat, including tenderness, is selection of breeding stock (Niven, 1960). Lawrie (1966) confirmed this by saying that, within a breed, tenderness is more than 60 percent heritable and that progeny of different sires differ appreciably in average tenderness. Knutson (1964) in a study using selected sires, found that tenderness is "inherited". Cartwright, Butler and Cover (1958) and Cover, Cartwright and Butler (1957) confirmed this. Field et al (1970) conducted a study to determine the effect of direct selection for tenderness in beef. They compared two lines and found significant tenderness differences, measured by shear force and panel tenderness scores, between selected yearling bulls from a "tender" line and those from a "lean" line.

Black, Sempler and Lush (1934) demonstrated breed differences in tenderness. Burns, Koger and Kincaid (1958) found that Angus and Hereford steers were more tender than Brahman steers. Cole, Kincaid and Hobbs (1958) found that Angus, Herefords, Jerseys and Guernseys were significantly more tender than Brahmans. Palmer (1963) showed that breed of sire had a pronounced effect upon tenderness. Angus, Hereford and Shorthorn progeny were significantly more tender than progeny of Braham and Brahman-Shorthorn sires. Ramsey, Cole and Temple (1963) reported on an extensive five-year study in which different cuts from 151 steers of seven different breeds were analyzed. Results indicated significant differences in tenderness among breeds. Jerseys and Herefords were the most tender and Brahmans least tender. Kennick

et al. (1965) and Bramblett et al. (1965, 1971) found that meat from straightbred Herefords received slightly higher subjective tenderness scores than did that from crossbred Hereford-Charolais. Skelly and Handlin (1971), in a study comparing barrows and gilts of the Hampshire, Duroc, Poland and Berkshire breeds, found practically no differences between breeds or between sexes in Warner-Bratzler shear values or in palatability ratings (tenderness, flavor and juiciness).

Various physiological factors have been studied as to their influence on meat quality. In general, with increasing age tenderness decreases. Lawrie (1966); Niven (196), Palmer (1963), Mackintosh, Hall and Vail (1936), Goll, Bray and Hoekstra (1963) and Hiner and Hankins (1950) agreed with the above statement. Brady (1937) found cows to be significantly less tender than steers. Tuma et al. (1962) studied the tenderness of 24 Hereford females which were of three ages at slaughter, 18, 42 and 90 months. Tenderness decreased significantly as animal age increased, with the greatest difference being between the ages of 18 and 42 months. The 42- and 90-month-old animals had similar tenderness. Sliger (1966) in a study involving carcasses from Angus and Hereford females ranging in age from three to 211 months found that the longissimus dorsi (LD) muscle from 3- to 5-month old females sheared (WB) significantly more tender than those from females 12 to 17, 60 to 64, 72 to 77 and over 96 months of age. However, shear values of cores from 3 to 5 and 6 to 11-month-old females were not significantly different from those females 78 to 94 months of age. The muscle from animals slaughtered between the ages of 12 and 17 months was less tender

than that from those slaughtered at all other ages under approximately 41 months.

The histological changes which take place in an animal as it matures are probably responsible for the change in tenderness with advancing age. Muscle fiber diameter, muscle and connective tissue composition and marbling have been found to change with age and to have a bearing on tenderness (Szezesniak and Torgeson, 1965).

Hiner, Hankins and Sloane (1953) found that as the age of an animal increased, the diameter of muscle fiber increased. Tenderness of muscles of animals ranging in age from ten week-old calves to nine-year-old cows varied with animal age, and tenderness decreased significantly with increase in fiber diameter. Tendick (1966) found that animals of similar weight and age but of different breed, (Hereford, Angus, Jersey Braham and Charolais) showed significant differences in muscle fiber diameter. The smaller the diameter, the more tender the meat. His ranking of the breeds from smallest fiber diameter to largest diameter was: Jersey, Angus, Hereford, Charolais and Brahman.

Man has known for hundreds of years that the most tender muscles have the least amount of connective tissue and minimum amount of physical activity. As far back as the 1700's, German and French scientists were theorizing that cooking increases tenderness by breaking down and changing the connective tissue. Szczesniak and Torgeson (1965) noted that in 1907, the German scientist, K. B. Lehman, working at the Hygienic Institute at Wurzburg, showed that the amount of connective

tissue directly affects tenderness of meat, i.e., the lesser the amount of connective tissue, the greater the tenderness. Moran and Smith (1929) confirmed this and considered that connective tissue was the major factor contributing to toughness. Strandine, Koonz and Ramsbottom (1949) found in beef a positive correlation of amount of total connective tissue with shear values, thus a negative correlation with tenderness. Nottingham (1956) found the same relationship in a study of sheep muscles. Connective tissue is composed of two tough proteins, collagen and elastin. Most research in the last few years has involved the study of collagen. Husaini et al. (1950) found a significant negative correlation between collagen content and taste panel evaluation of beef tenderness. Wierbicki et al. (1956) found that bulls tended to be less tender and to have a higher collagen content than steers. Smith and Carpenter (1970) pointed out that as total collagen content in sheep increased, tenderness decreased. Other workers, however, have found little or no relationship between collagen and meat tenderness. For example, Herschberger et al. (1951), Carpenter et al. (1963) and McClain et al. (1965) found no relationship between collagen and muscle tenderness.

A relationship between the amount of stress on animals immediately before slaughter and the tenderness of meat from them has been reported by many workers. The most interesting observation of stress is that meat of certain animals which have undergone preslaughter stress undergoes a color change to what is popularly called "dark cutting meat". In this, the muscle color can range from a dark red to an almost purple

color and, while not affecting the edibility of the meat, the consumer objects to it. Niven (1960), Bate-Smith (1948) and Lawrie (1966) found that a high pH and low muscle glycogen are the most notable characteristics of dark cutting beef. Niven (1960) stated that postmortem metabolism of glycogen to lactic acid in carcasses of animals fed just prior to slaughter resulted in a muscle pH of approximately 5.3, while muscle from fatigued animals had a pH in the range of 6.0 to 6.6. Bate-Smith (1948) and Briskey and Kauffman (1971) were in agreement with this. There is general agreement also that there is a great variability between individual animals as to the degree to which they will react to preslaughter stress.

Deatherage (1963) pointed out that tenderness or toughness is a quality representing the summation of properties of the various protein structures of skeletal muscle. Therefore, all the factors affecting proteins are likely to affect tenderness in some way.

Thus, water content, kinds and concentrations of inorganic ions, pH, temperature and time of heating can each, in their own way or acting together, affect tenderness.

Pearson (1971) stated that the pH of meat has a marked effect upon its physical properties, being responsible for dark cutting beef and pale, soft, exudative (PSE) pork muscle. He stated further that high pH values (5.8 or higher) result in an increase in water-binding capacity. This has been confirmed by Hamm (1960) who pointed out also that as water-holding capacity decreases, tenderness decreases.

Bate-Smith (1948), Hamm (1960), Hamm and Deatherage (1960), Deatherage

(1963), Briskey and Kauffman (1971) and Pedersen (1971) indicated that water-holding capacity is at a minimum at the isoelectric points of the major meat proteins (I.P. of myosin is about pH 5.3); then, as the pH decreases from this point, the water-holding capacity increases.

Certain inorganic ions contribute to the water-holding capacity of meat. Swift and Berman (1959) found a highly significant negative correlation between water retention and the concentration of Mg^{++} , Ca^{++} and K^+ in eight beef muscles. Hamm (1960) suggested that the differences in water-holding capacity of beef loin muscles at the same pH value could possibly be due to differences in the amounts of bound Ca^{++} and Mg^{++} . Huffman et al. (1969), in a study of sheep on three different Ca:P ratio and antemortem injections of sodium hexametaphosphate or sodium pyrophosphate, found that loin chops from animals fed a low Ca:P ratio (1:4.2) were significantly more tender than those from animals fed on a high Ca:P ratio (10:1) and that chops from animals injected with both phosphate compounds averaged significantly more tender than those from control animals which were on a normal Ca:P ratio (1:1.5). They found also small but significant correlations of loin chop tenderness with levels of blood calcium, of muscle phosphorus and of bone phosphorus.

Postmortem Factors

Niven (1960) stated that the tenderness of meat is quite markedly changed during the first 24 hours after slaughter. Before rigor mortis begins, beef muscle is comparatively tender, but, with the onset of rigor, muscle fibers contract and become shorter with an accompanying

toughening of the meat. The findings of Bate-Smith (1948), Hamm (1960), Szczesniak and Torgeson (1965), Lawrie (1966) and Pearson (1971) were in agreement with this. After rigor is complete, meat then increases in tenderness to some maximum value, apparently peculiar to each individual carcass. The same pattern for these changes in tenderness postmortem seems to prevail in all species, although the changes in chicken occur much more rapidly, according to DeFremery and Pool (1960). This tenderization process occurring after rigor until the carcass reaches maximum tenderness is known as aging, which, in beef, takes approximately two weeks if the carcass is held at 2° C (35° F).

Many changes occur during this period between slaughter and end of aging. Pearson (1971) stated that one of these changes is the decline in pH from about 7.4 to 5.4-5.6. The rate of the pH reduction can be changed by changing the holding temperature. The higher the temperature, the more rapid the decline in pH. Merkel (1971) stated that as proteolytic enzymes become activated at pH 6.0 or less, their action causes the breakdown of connective tissue and other proteins, which contributes to the process of the tenderization. Niven (1960) stated that the changes during aging are largely enzymatic and, hence, the process can be accelerated by increasing the holding temperature.

Bate-Smith (1948) and Pearson (1971) discussed the complex changes which take place during rigor mortis and aging of beef. Among the characteristic changes during rigor mortis they listed, a decline in pH, conversion of glycogen to lactic acid and disappearance of adenosine triphosphate (ATP). The disappearance of ATP seems to be

the triggering event most closely linked with the onset of rigor mortis. In the absence of ATP, actin and myosin combine to form rigid chains of actomyosin which cause severe contraction or shortening of the muscle fibrils. Pearson (1971) pointed out that there is a similarity between the series of events during muscle contraction and those occurring in rigor. He noted that J. R. Bendall had concluded that rigor mortis and muscle contraction are essentially the same process except that rigor is irreversible under normal conditions. Other changes that occur are the breakdown of adenosine triphosphatase (the enzyme directly involved in the formation of ATP), a decline in the concentration of creatine phosphate and a lowering of the water-holding capacity.

Locker (1960) found that various muscles of the ox go into rigor in widely differing states of contraction as defined by the striation patterns of the myofibrils. He stated further that the final state of a muscle appears to depend on the strain imposed on it in the hung carcass.

Herring, Cassens and Briskey (1966) found variations in the sarcomere lengths of different muscles. They demonstrated that the sarcomere could be greatly altered by changing the amount of tension upon individual muscles during development of rigor. Sarcomere length had a highly significant effect on panel tenderness scores and shear force. Decreased sarcomere length caused a marked increase in shear force (decreased tenderness). They considered that sarcomere length (a measure of contraction state) is only a gross indication of the molecular changes occurring in the actin and myosin of muscles.

Takahashi, Fukazawa and Yasui (1967) found a postmortem contraction of sarcomeres in chicken pectoral muscles.

Locker and Hagyard (1963) were the first to report observing that excised, unrestrained beef muscle shortened more rapidly at 0°C (32° F) than at any other temperature. They observed also that minimum shortening occurs in the temperature range of 14° C to 19° C (57° F to 66° F). They pointed out further that at higher temperatures shortening coincides with the onset of rigor mortis but that at low temperatures it begins rapidly and usually immediately. Marsh and Leet (1966) confirmed these findings and further defined the relationship between tenderness and muscle shortening. They demonstrated that tenderness was not affected by a decrease in length as great as 20 percent but that tenderness decreased rapidly with further shortening beyond this point. Maximum toughness appeared to be attained when the muscle had shortened to about 60 percent of its original length. As the muscle shortened beyond this point, the meat became progressively more tender and, at lengths of 40 to 50 percent of the original length, was about as tender as meat after 20 percent shortening of the muscle.

Thaw rigor is the shortening that occurs upon thawing meat that was frozen in the prerigor state. Pearson (1971) pointed out that it is quite similar to cold shortening in that in both types of shortening the meat is appreciably less tender than control samples.

Buck and Black (1967), in a study of the effect of stretch-tension during rigor of bovine muscle (LD), found that stretched muscle strips were consistently more tender than control strips, extensibility of

individual fibers were significantly less in the stretched strips and the average fiber diameter also was significantly smaller in the stretched fibers. Goll, Henderson and Kline (1964) found that muscles excised immediately after slaughter were less tender than those left attached to the skeleton.

The variation in the method of suspension of carcasses after slaughter has an effect upon tenderness. The common method is suspension from the achilles tendon. Smith, Arango and Carpenter (1971) and Hostetler et al. (1972) demonstrated that with certain positions and methods of hanging beef carcasses, tenderness of certain muscles was improved. Quarrier, Carpenter and Smith (1972) reported similar results with lamb carcasses. Hegarty and Allen (1972) observed similar effects on turkey muscles.

There is considerable difference of opinion regarding the tenderizing effects of freezing and frozen storage of meat. Some investigators have reported no effect, others increased tenderness and others decreased tenderness. The rate of freezing, the time lapse between slaughter and freezing, individual muscles and the temperature of frozen storage all appear to be involved, together or separately, in the effect of freezing on tenderness. Tressler, Birdseye and Murray (1932), Tressler and Murray (1932), Hiner and Hankins (1951), Marsh, Woodhams and Leet (1966) and Berry et al. (1971) found that freezing generally does tenderize meat. Marion and Stadelman (1958), studying poultry, and McBee and Naumann (1959), studying beef, found that freezing

had no effect or a slightly toughening effect. Tuomy and Helmer (1967) found that freeze-drying toughened pork loin.

The tenderizing of meat is big business today and is being subjected to extensive research. At present, tenderizing of meat can be accomplished by: (1) a procedure or technique, (2) a product or (3) a combination of procedure and product. The tenderization may be of a chemical or mechanical nature.

Mechanical tenderizing would be by the use of any device which cuts, tears or shreds the muscle fibers and connective tissue. The oldest meat tenderizer of all, the teeth, would be included here. Also included would be the old steak hammer and the Meat Tenderizer. Grinders with which hamburgers and sausages are made are probably the most widely used of all mechanical meat tenderizers (excluding the teeth), for they permit the use of certain tissues, parts and pieces usually undesirable in themselves, to be made into palatable and desirable meat products.

Ziegler (1962) explained that chemical tenderizers include the second oldest of all meat tenderizers, cooking. They include also the third oldest method, marination (soaking in wine, vinegar or lemon juice). Collagen and elastin enzymes can act only in an acid medium; as a result, meat soaked three or four days in diluted vinegar will have considerable breakdown of these proteins and a marked improvement in tenderness. Sodium chloride in concentrations of two percent will increase beef tenderness appreciably. This was confirmed by Huffman et al. (1967a). Probably the most universally used chemical tenderizers today (with the exception of cooking) are certain proteolytic enzymes

that have the ability to break down collagen and elastin to a soft, gelatinous consistency.

Wang and Maynard (1955) explained that, commercially, there are three enzymes which are used to tenderize meat through their ability to degrade collagen and elastin. They list these as:

- a. Papain, from papaya fruit
- b. Bromelin, from the juice of the pineapple
- c. Ficin, secured from figs

They added that certain molds and bacteria produce enzymes which are effective but are not used to any great extent for commercial products.

Papain appears to be the most popular enzyme used. This enzyme has been used antemortem as well as postmortem. Huffman et al. (1967a, 1967b), Goeser (1961) and Robinson and Goeser (1962) have shown that antemortem injection of papain will tenderize muscles from meat animals. However, this can be objectionable. Smallings et al. (1971) reported that antemortem injections of papain caused dry cured hams to be more tender, but this degree of tenderness was considered objectionable because of the mushy texture of the lean.

The literature on the effect of cooking on tenderness of meat is voluminous. There seems to be general agreement among workers that the effect of cooking in tenderizing meat is involved with the balance between softened collagen and hardened muscle fibers. Collagen when heated in the presence of moisture is converted to gelatin (temperature and time dependent). The protein within the muscle fiber coagulates

and is thereby toughened. Cover (1937, 1943) stated that if cooking is very slow, the muscle fibers eventually undergo tenderization.

V. Objective (Physical) Methods of Measurement of Tenderness

The Warner-Bratzler

Of all the many instruments developed for measuring food texture, the Warner-Bratzler Shear (WB) has enjoyed the greatest popularity and is used today in numerous laboratories. According to Bratzler (1949), this instrument was developed and described by K. F. Warner in 1927. In 1932 and 1933 Bratzler modified the Warner Shear, and it eventually became known as the Warner-Bratzler Shear. Briefly, the instrument measures the amount of force, in pounds, necessary to shear through a sample of meat of a given diameter. Most work has been done and reported on cores one inch or one-half inch in diameter.

There have been many tenderness studies to compare evaluation of tenderness by WB with sensory evaluations. About two-thirds of these studies showed good to very good agreement while the others reported slight to poor agreement. There have been four especially outstanding studies of this type. Deatherage and Garnatz (1952) in a study involving broiled sirloin steaks from 32 steers, obtained nonsignificant to very low but significant correlations between taste-panel evaluations and WB shear values. Cover, Hostetler and Ritchey (1962), in a study of bovine (LD) and biceps femoris (BF) muscles cooked at temperatures of 61°, 80° and 100° C found that correlations differed between muscles

and between cooking temperatures. They found highly significant correlations with all cooking temperatures used for the LD, but with the BF they obtained nonsignificant (at 61° C) to highly significant correlations (80° to 100° C) between WB shear values and sensory evaluations. Fielder et al. (1963), in a study of prefabricated meat (refers to a special cutting procedure used by the Armed Forces in which carcasses are processed into boned and trimmed cuts according to muscle tenderness), found that correlation between the WB shear and panel evaluations varied with the cooking method and with the cut. The correlations ranged from nonsignificant for Swissed bottom round to highly significant for roasted neck. DeFelice (1965), in a study of 334 beef carcasses, found a correlation between WB shear values and sensory scores of -0.76 ($P < 0.01$).

The Armour Tenderometer

A nondestructive instrument for predicting tenderness of meat from beef carcasses would be a major contribution to the meat industry and would be invaluable as a research tool. The Armour Food Company has developed such an instrument, the Armour Tenderometer, which has been used in this manner with reportedly great commercial success. According to Hansen (1971), the Tenderometer was designed to measure penetration forces on the rib-eye muscle of carcasses hanging on the rail. Basically, it consists of a probe with ten needles on a manifold with a strain gage transducer, which is manually pressed two inches into the rib-eye muscle. The signal is read from a peak force indicator which is

calibrated in pounds and housed in a small accompanying recorder. He stated further that measurements of maximum force during penetration into the cold rib-eye on the day after slaughter correlated well with subjective panel tenderness scores on the meat cooked after one week of aging.

In an evaluation of the Tenderometer, three studies are reported here. Henrickson, Marsden and Morrison (1972), in a study using the LD muscle from Angus steer carcasses found no significant correlation between tenderometer values and WB shear force values. They stated further that the units probably measure a different element of tenderness. Dikeman et al. (1972) found small but significant correlations among Tenderometer values, WB shear values and taste-panel scores. Carpenter, Smith and Butler (1972) found that the Tenderometer can be utilized to select groups of carcasses (classified as to tender or tough) with more desirable tenderness scores and with reduced variability in tenderness. They found significant correlations of taste-panel and WB tenderness measures with Tenderometer values on carcasses in the U. S. Choice grade.

The Instron Universal Testing Instrument

The Instron Universal Testing Instrument (Instron) has been described in detail by Bourne, Moyer and Hand (1966) as a research tool to study the rheological properties of food materials. Examples were given of the manner in which the force-distance curves are used to obtain maximum force, slope, area, plateau height, relaxation and recovery and the application of these parameters in evaluating different food products.

An objective measuring device, the Slice Tenderness Evaluator (STE) was studied by workers at the United States Department of Agriculture (U.S.D.A.) laboratories at Beltsville, Maryland. Kulwich, Decker and Alsmeyer (1963) reported that the STE, used in conjunction with an Instron, first punctures then shears off portions 3/8 inch in diameter using a stainless steel penetrator, with the force necessary to do this being recorded by the Instron. Results were then correlated with taste panel and WB values. Correlations obtained were significant ($P < 0.01$). Alsmeyer, Kulwich and Hiner (1962) reported a study using the STE on rib roasts from 84 cattle and loin roasts from 70 swine. The meat was cooked and rated for tenderness using the STE, a taste panel and WB. They obtained highly significant multiple correlations involving STE readings and panel scores. Simple correlations among STE punctures, STE shear and panel scores were significant ($P < .01$).

Simon et al. (1965) reported the use of an Instron to obtain stress-strain data. From these data they were able to develop a simplified instrument for objective evaluation of frankfurter texture.

Pool (1967) reported on an objective measurement of connective tissue tenacity of poultry meat, which he believed could be used for other meats as well, designed to fill the need for a rapid, simple objective method of measuring cohesiveness. Measurements were made by the Instron as to the work required to pull apart uniform size pieces of cooked poultry meat by applying a gradually increasing force at right angles to the fibers. The most meaningful and reproducible value in

relation to cohesiveness was found to be the total work required (area under the curve) rather than the maximum force.

Stanley, Pearson and Coxworth (1971) reported an investigation of the physical properties of meat measured by the Instron and proposed methods for evaluating these properties. By the use of pneumatically controlled gripping jaws, the following tensile properties were evaluated: breaking strength or breaking load in pounds force per gram of sample, break elongation or strain required to rupture the sample as a percentage of the original 3.5 cm sample between the jaws and specific work of rupture. Time effects measured included elasticity and relaxation. The muscles used were uncooked tenderloin and shank beef and rabbit LD (restrained and unrestrained during rigor). The results showed that the instrument (Instron) is capable of discerning variation in physical properties of uncooked muscle. They stated further that it is possible that one or more of these tests will prove useful as a predictor of meat tenderness.

Bouton, Harris and Shorthose (1971) reported on a study involving muscles from sheep that were injected with epinephrine antemortem to control the ultimate pH which ranged from 5.6 to 7.0. Water-holding capacity (WHC) was determined by a high speed centrifugal method. Measurements were made using the WB and an Instron. Compression forces were measured by the Instron by the use of a flat-ended plunger 0.63 cm in diameter which was driven vertically 80 percent of the way through a sample of cooked meat 1.30 ± 0.01 cm thick. Results showed a high

correlation between WHC and ultimate pH, and both the WB shear and the Instron compression values were highly correlated with subjective evaluation.

Bouton and Harris (1972) described a method of measuring the tensile properties of meat by the use of the Instron. This study involved the effects of cooking temperature and time on certain mechanical properties of meat (compression, shear and tensile properties). The WB was used for shear and the Instron for the tensile and compression properties. The compression method was described earlier by Bouton, Harris and Shorthose (1971). Tensile measurements were made by the use of pneumatic grips of the Instron which measured the force and work required to pull apart samples of meat. The deep pectoral and BF muscles from cattle of three age groups (birth to 2 months, 1 to 1 1/2 years, and 5 to 7 years). Changes in tenderness produced by heating meat at 90° C were dependent on animal age and heating time. At 50, 60 or 70° C, the effect of time was much reduced. Temperatures up to 50° C had a toughening effect. Changes during heating in the range 50 to 60° C were probably related to connective tissue changes. The increase in toughness on heating at temperatures between 60 and 75° C was attributed to increased moisture loss and fiber shortening along with changes in the properties of the connective tissue.

Other Objective (Physical) Methods

Organoleptic tenderness is evaluated by chewing, which is a physical process, and, theoretically, the property of tenderness should be measurable by an objective physical method.

All the methods which have been developed have as their primary purpose the reflection of the experiences of a person chewing a piece of meat. This involves the principles of cutting, shearing, tearing, grinding and squeezing (Shultz, 1957). It is difficult to design an instrument which will incorporate all these principles, consequently, most of the ones developed and tested are based upon only one of these principles.

Mechanical methods of measuring tenderness of meat have been reviewed by Shultz (1957) and Szczesniak and Torgeson (1965). There have been many instruments designed, but the two most universally used devices are based upon the shearing principle. These are the Warner-Bratzler shear, described previously, and the L.E.E.-Kramer Shear Press (KSP).

The KSP was developed by A. Kramer in 1951 primarily for use on fruits and vegetables and has subsequently been applied in research with meat. According to Szczesniak and Torgeson (1965), a new model developed in 1959 consists of a test cell, a hydraulic drive system and a proving ring dynamometer. Force required to shear the sample is measured by the compression of a proving ring dynamometer and read from an appropriately calibrated scale. The device may be equipped also with a recorder, and a time-force relationship may be obtained. Different laboratories have generally found highly significant ($P < .01$) correlations between KSP value and sensory evaluation.

Tressler, Birdseye and Murray (1932) and Tressler and Murray (1932) described their modification of the New York Testing Laboratory standard

penetrometer (used for determining the consistency of bituminous materials). They fitted the N.Y. penetrometer with a different needle, 1 3/8 inches long and 0.15 inches in diameter and rounded at the point to a radius of approximately 0.07 inches. The meat sample was held in a metal frame with perforated plates containing eight holes. The average of the eight readings was a measurement of firmness of the sample. Tressler, Birdseye and Murray (1932) concluded that this penetrometer gave more uniform results than the WB, but its correlation with sensory evaluation for tenderness has not been high, possibly because of the lower variation of the penetrometer values.

Another penetrometer, the Slice-Tenderness Evaluator (STE) has been developed and described by Kulwich, Decker and Alsmeyer (1963), cited earlier.

Devices have been designed and developed in a series of attempts to measure the textural properties of meat under conditions approaching those of mastication. Szczesniak and Torgeson (1965) reviewed reports of these, giving complete descriptions of each instrument. Included in these are the Volodkevich Bite Tenderometer, in which the resistance to a squeezing force was measured by two wedges with rounded points; the M.I.T. Denture Tenderometer, in which a complete set of human dentures is utilized; and the General Foods Texturometer, which is a modification of the M.I.T. tenderometer and consists of a mechanical masticator.

Perhaps the simplest method, designed by Miyada and Tappel (1956) was an ordinary food grinder equipped with special devices to measure meat tenderness.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. Source of Data

The animals used in this study were offspring from Hereford (H) dams bred to H, Simmental (S), Maine-Anjou (MA), Limousin (L) or Charolais (C) bulls and Charolais-Hereford (CH) dams bred to H or C bulls.

Thirty-five animals--seven breed groups of five animals per group were evaluated. The following breed groups were represented: (1) H X H, (2) C X H, (3) H X C H, (4) C X C H, (5) S X H, (6) M A X H and (7) L X H, as shown in Table 1.

The above animals were a culmination of a project conducted at the Middle Tennessee Experiment Station at Spring Hill, Tennessee. From the Station herd, H cows were randomly assigned to be bred to H, S, MA, L or C bulls and CH cows were randomly assigned to C or H bulls during the 1970 breeding season. Dams of the calves ranged in age from 3 to 12 years.

All the calves were born in the spring (January through March) of 1971. The calves nursed their dams, without creep feed, during the spring and summer grazing season. All calves and cows were pastured together and grazed on orchard grass-clover and/or fescue-clover-lespedeza

Table 1
Breed Groups^a Represented

1. Hereford	x	Hereford
2. Charolais	x	Hereford
3. Hereford	x	Charolais-Hereford
4. Charolais	x	Charolais-Hereford
5. Simmental	x	Hereford
6. Maine-Anjou	x	Hereford
7. Limousin	x	Hereford

^aFive animals per group.



pasture until the weaning of the calves at approximately 256 days of age.

During the first 140 days of the postweaning period the calves were housed in a pole-type barn and fed a ration of 6 to 7 lb. of shelled corn, 3 lb. of hay and corn silage fed ad libitum. During the latter part of this 140 day period, the grain intake was gradually increased and silage decreased, and from the end of this period until slaughter the ration consisted of concentrates ad libitum, 3 lb. of hay and approximately 10 to 12 lb. of silage per head per day.

When the subcutaneous fat thickness at the 12-13th rib area was 10 millimeters, measured by a Branson Model 12 Sonoray, the animals were transported to The University of Tennessee Meat Laboratory and slaughtered.

After one week of aging at 36° F (2.2° C) the semimembranosus (SM) muscles of the right sides of the carcasses were excised, wrapped in moisture proof paper and immediately frozen in a blast freezer at -20° F (-28.9° C). Samples were stored at -10° F (-23.3° C) $\pm$ 2° until tested.

Five muscles were randomly selected within breed and assigned to each testing group to provide the maximum number of breed comparisons. The muscles were removed from freezer storage and allowed to equilibrate to 36° F (2.2° C) for 48 hours before testing.

II. Armour Tenderometer Tenderness Evaluation

Prior to cooking, measurements of tenderness were made with an Armour Tenderometer (AT). The operation of the AT is adequately described by Hansen (1971). It is necessary to hold the excised muscle firmly while testing with the AT. This was accomplished by the use of an adjustable plexiglass holder as shown in Figure 1. The raw muscle was placed in the holder so that the dorsal surface was exposed while testing with the AT. Three measurements of penetration force were made on each muscle and the average of the 3 readings was used as the AT value. Care was taken to reposition the probe after each reading.

III. Subjective Tenderness Evaluation

After the trimming off of any excess fat or connective tissue, a dial-type thermometer was inserted into the center of each muscle which was then placed in a preheated Dispatch Oven at 375° F (190.5° C). The meat was cooked at an oven temperature of 325° F (162.7° C) to an internal temperature of 163° F (72.8° C). After cooking, the sample was trimmed of all the hard outer crust. That part of the SM muscle in which the muscle fibers did not lie parallel to each other was trimmed off and discarded. Consequently, the area used for taste panel and objective tenderness measurements could be broadly defined as the central, posterior portion of the muscle.

A slice three-fourth inch thick was removed from the dorsal end of the muscle and divided into 10 sections to be presented to a ten-member

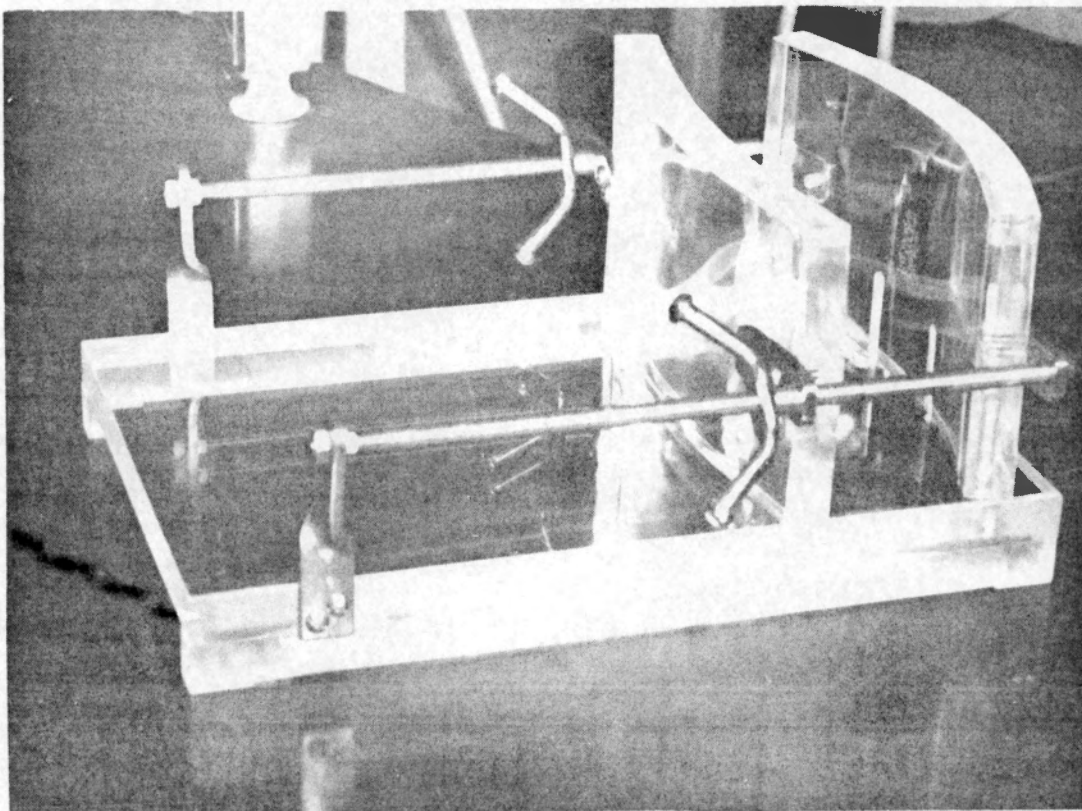


Figure 1. Muscle Holder Used in Armour Tenderometer Testing.

trained taste panel. The anatomical location of each panel member's sample remained constant for all evaluations made. The panel evaluated each sample for tenderness only, on a 10-point hedonic scale (10 being extremely tender, 1 extremely tough).

The remainder of the sample was chilled overnight at 36° F (2.2° C) before coring for objective measurements of tenderness. These cooked cores were used for the remainder of the objective methods reported in this study. A slight modification of the method described by Kastner and Henrickson (1969) for obtaining uniform cores was used. A 3/8 inch electric drill was fitted to a one-half inch diameter coring device by use of a coupler designed by the author and fabricated by The University of Tennessee Agricultural Engineering Department. The drill was hand held since it was easier to guide the coring device in the direction desired.

Twelve cores from each muscle were cut parallel to the orientation of the muscle fibers so that shearing was done perpendicular to the direction of the fibers. Alternate cores were designated for use with an Instron Universal Testing Instrument and for shearing with a Warner-Bratzler Shear (Figure 2).

IV. Warner-Bratzler Shear Evaluation

The Warner-Bratzler (WB) Shear is motorized to insure a constant rate of pressure on the sample. According to Bratzler (1949), the instrument consists of a shearing blade 0.04 inches thick with an opening that is an equilateral triangle circumscribed about a circle

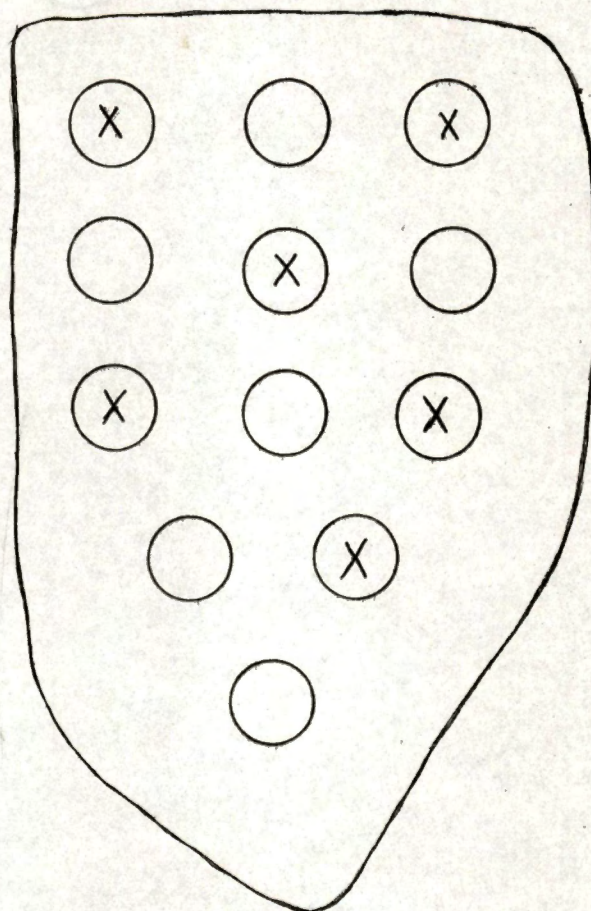


Figure 2. Sampling Procedure for Cores.

Circles marked "X" were designated for Instron evaluation; the remaining ones for WB.

one inch in diameter. The cutting or shearing edge is rounded to an arc of a circle of 0.2 inch radius. The blade is led through a slit between two shearing bars and has a shearing speed of nine inches per minute. The amount of force required to shear the sample is recorded on a dead hand spring dynamometer calibrated in pounds. The greater the force, the tougher the meat.

Six cores one-half inch in diameter, each sheared three times, were evaluated for each sample by the WB. The average of the eighteen shears was used as the shear value for each muscle.

V. Instron Universal Testing Instrument

The Instron used in this study is a TT-D model located in The University of Tennessee's Engineering Mechanics Department of the College of Engineering. This instrument possesses the English scale of measurement and has a crosshead speed range of 0.02 to 20 inches per minute.

The force-measuring system which measures tensile or compression forces is capable of sensing and recording loads of tremendous range. This instrument is capable of sensing and recording accurately loads from 0.007 ounces (0.02 g) to 20,000 pounds (44,100 Kg).

This sensitivity range is made possible by the use of interchangeable load cells. These cells are selected according to the resistance to force characteristic of the material being tested. They consist of electric bonded-wire strain gages which sense the forces being applied and relay this information to a strip-chart on the recorder.

Basically, the force-measuring system consists of a stationary crosshead at the top of the unit where the tensile load cell being used is located and a bed plate at the bottom where a compression load cell is located at time of use. Between these is a movable crosshead controlled by twin lead screws which permit the rate of speed to remain absolutely constant during the complete downstroke of the crosshead. The length of the stroke of the crosshead can be controlled by dials located on the side of the unit.

The recording system consists of a recorder with a strip chart, and, by a system of change gears, the time axis of the strip chart can be either a direct measure of, or a simple multiple of the movement (speed) of the crosshead. A continuous force-distance curve is recorded for each test run.

Hindman and Burr (1949) described in detail the general characteristics and engineering aspects of the Instron. Bourne (1966) pointed out that the working parts of any instrument for measuring textural properties of food products which has linear, vertical movement can be adapted for use with the Instron.

The shearing mechanism from the WB used in this study was removed from the WB and fitted for use with the Instron. Figure 3 is an exploded view of the various parts and illustrates the order of assembly. To permit installation of the unit in the Instron, the following items were devised:

- a. An intermediate coupler at the top to attach the shear bars to the tensile load cell.

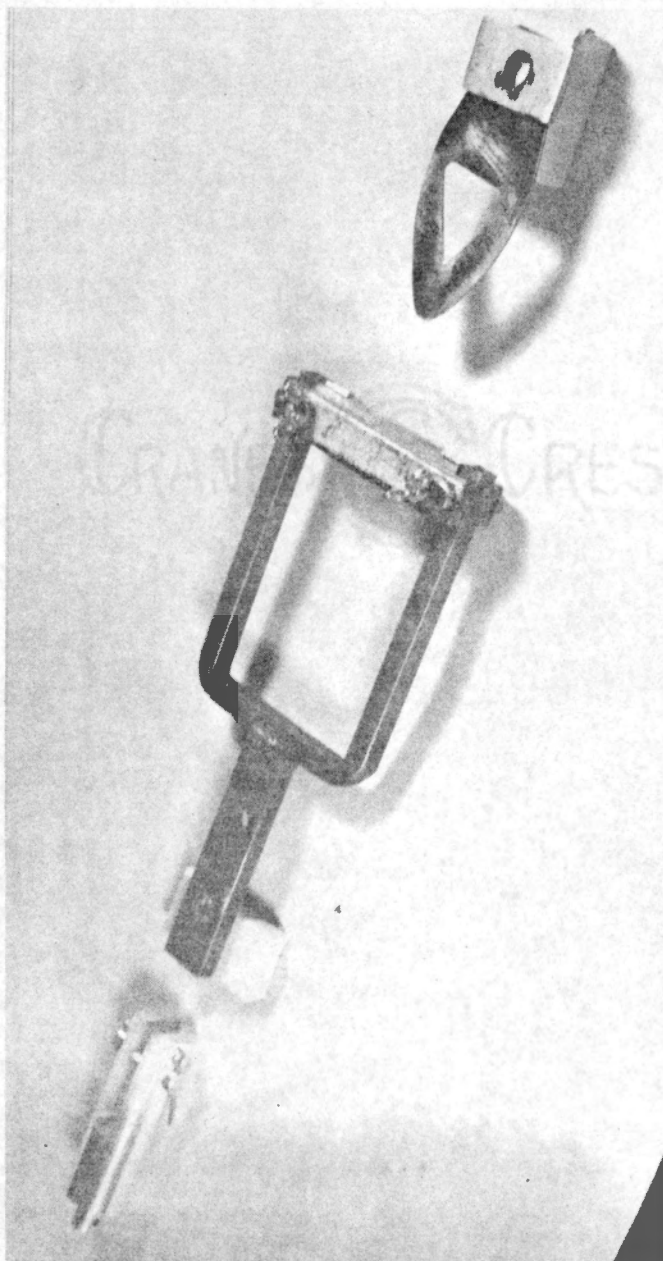


Figure 3. Warner-Bratzler Unit Assembly.

From left to right: (a) Intermediate coupler, (b) metal frame holding shear boars, (c) Blade and spacer bar.

- b. A metal frame, shaped as a square "Y", to hold the shear bars.
- c. Two spacer plates attached with the blade to the coupler on the movable crosshead. These plates also positioned the blade.

Two C-clamps, not shown in Figure 3, were used when the assembly was installed to hold the blade rigid. These were placed on each side of the blade and held the two spacer plates tightly together.

When installed, the blade moved very easily between the two shearing bars with the up and down movement of the crosshead. This is the same action as in the original instrument except that when mounted in the Instron the blade moves and the bars remain stationary.

Because of the characteristic pulling motion of the WB unit, a Tensile Load cell (CT) was used with full scale deflection of 5, 10, 20, 50, 100 and 200 pounds. The term "full scale" refers to the range of the force measuring capacity being used. Full scale of 20 pounds was used in this study with a crosshead and chart speed of 10 inches per minute.

Six cores from each muscle, sheared three times each were recorded as eighteen force-distance curves. From the curves obtained, two parameters were derived: (1) the maximum force (MF) needed to shear the sample and (2) the area under the curve. The area under the curve represents work (work is the product of force and distance), so that in the data reported the word "area" represents the total work (energy) used to shear the muscle core. The area was measured by the use of a

planimeter. An average of 18 values per muscle was used as the MF and the area for each sample.

VI. Statistical Procedures

To test for differences between the Instron and the WB maximum force shear values, comparisons were made on within-breed basis.

Two types of correlation were calculated: product-moment correlations and rank correlations.

Estimation of product-moment correlation was by the conventional formula:

$$r = \frac{\Sigma(xy)}{\sqrt{(\Sigma x^2)(\Sigma y^2)}}$$

where x and y are deviations from mean values.

All samples were ranked from 1 to 5 within each testing group with respect to mean panel tenderness scores, mean WB and Instron shear values and mean AT penetration values. Rank correlation was estimated by Spearman's (1904) formula:

$$r_s = 1 - \frac{\sum_{i=1}^n d_i^2}{N^3 - N}$$

where d_i equals the differences between the two ranks assigned to the i^{th} individual ($R_1 - R_2$).

CHAPTER IV

RESULTS AND DISCUSSION

Beef tenderness is the most sought after component of beef palatability (Deatherage and Garnatz, 1952). An objective measurement of tenderness which correlates highly with the subjective assessment of the human palate has been the basis for much research. In this study subjective tenderness values given by a trained sensory panel were compared with four objective measures of this parameter.

However, the data were collected and aligned on a breed-group basis and it is of interest to consider the rankings of groups by the different methods used.

I. Breed Group Comparisons

The data presented in Table 2 are mean values obtained from 5 animals per breed group. The taste panel (TP) scores are based on a 10-point hedonic scale, with the higher scores indicating greater tenderness. The objective values are based upon the amount of force necessary to shear or penetrate the muscles, with the higher values indicating the greater toughness. The range of values within each method seems to indicate little or no breed differences. Three of the methods; TP, WB, and Instron maximum force (IMF) show that the 3/4 Hereford-1/4 Charolais group was estimated to be the most tender; however, there is little difference in tenderness of all the groups

Table 2
Mean Values of All Methods by Breed

Breed Group	TP	WB (lbs.)	Instron		AT (lbs.)
			MF (lbs.)	Area (in-lb.)	
H X C H	<u>6.68</u>	<u>8.6074</u>	<u>9.0680</u>	1.7432	21.606
H X H	6.62	10.0543	9.6456	1.8489	<u>15.112</u>
L X H	6.44	10.8773	9.4731	<u>1.7102</u>	19.706
M A X H	6.04	9.6780	10.0071	1.8688	21.320
C X C H	5.96	10.0827	10.2410	1.8967	17.886
S X H	5.80	12.0143	9.6242	1.7334	20.418
C X H	5.76	11.7217	11.2731	2.1472	19.128

First ranking is underlined.

TP: Taste Panel, WB: Warner-Bratzler, MF: Maximum Force,
AT: Armour Tenderometer

represented. An analysis of variance was made on a within-breed group basis between the WB and IMF shear values (Table 3). The results indicated no significant difference within breed groups. Tables 8, 9, 10, 11 and 12 in the Appendix show these results listed individually and with breed groups ranked by the different methods used.

The question may arise as to why the Instron area (IAR) and the IMF values fail to reflect the same degree of tenderness of the same sample. Actually, the two methods are measuring different phenomena, in that the IMF is the peak force required to shear the sample while the IAR is a measure of the total energy (work) needed. The texture of the meat at the point of shear will influence both these measurements, as illustrated by Figure 4. The force-distance curves shown there were obtained from four cores from the SM muscle of a L X H animal. The last curve has a larger MF (14.10 lb.) but a smaller area (2.25 in.-lb.) than the curve preceding it (MF of 11.78 and area of 2.26). This pattern was observed more frequently on muscles from the L X H group than on those from any other breed group. Consequently, the L X H group was ranked the most tender by the IAR measurements.

The main objectives of the present study were to correlate the various objective methods with a subjective evaluation and to compare the different instruments to determine which provided the best description of tenderness. The mean values of the different breed groups by method used are graphically depicted in Figure 5. Both scales on the vertical axes progress upward from tender to tough. The left side indicates the force values obtained from the objective methods used and

Table 3
Mean Squares from Analysis of Variance of Warner-Bratzler
and Instron Maximum Force Shear Values

Source	Degrees of Freedom	Mean Square
Treatment	1	4.8986
Breed	6	6.9472
Tmt x Breed	6	2.6828
Residual	56	5.5616

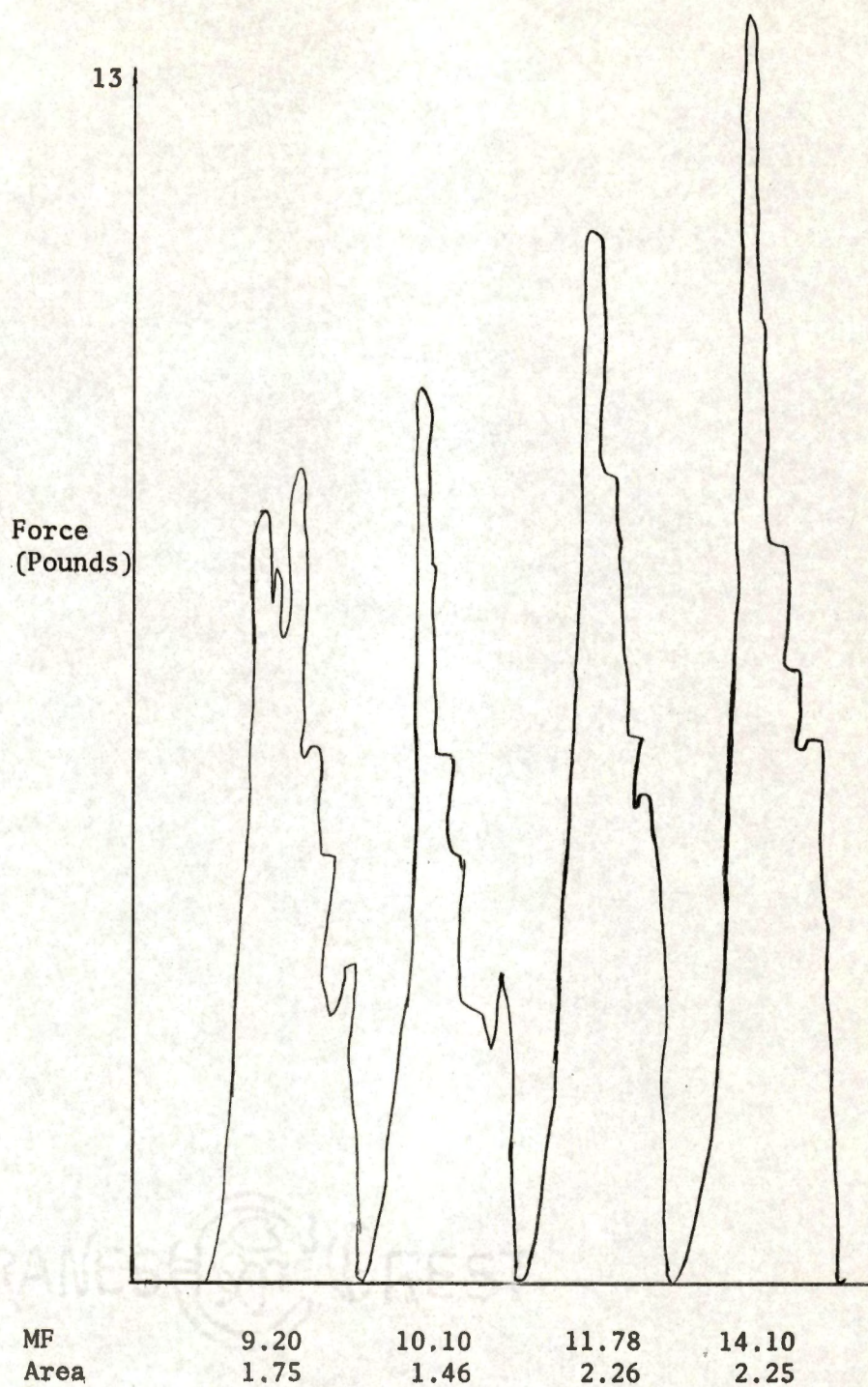


Figure 4. Force-Distance Curves of Four One-Half Inch Cores from the Same Muscle Recorded by Instron.

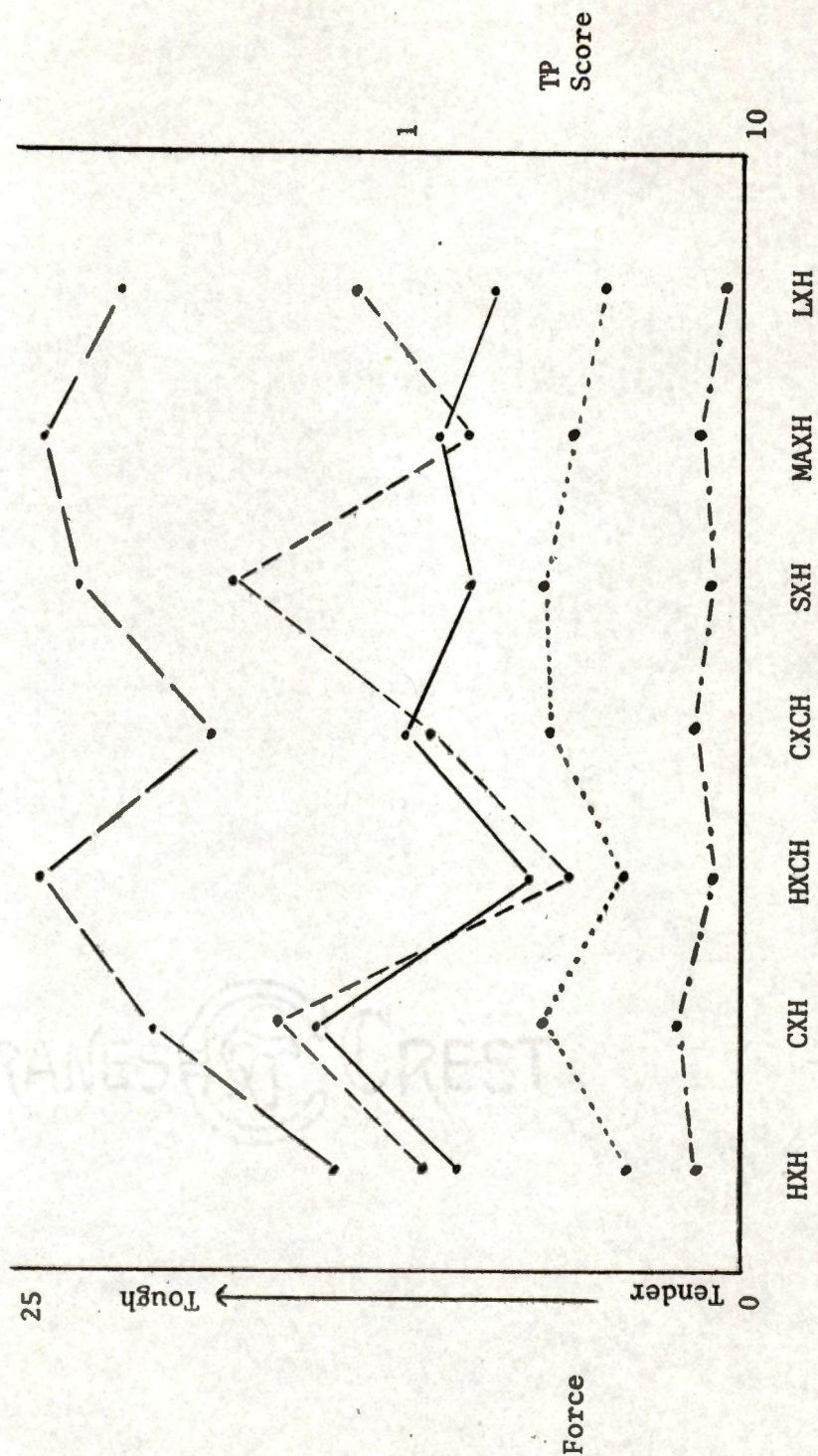


Figure 5. Means Values by Breed for Five Measurements of Tenderness.

AT ———; WB - - - - -; Instron (MF) ———; TP (plotted on right-hand scale); Instron (Area) .-.-.-.-.

begins in the conventional way with zero, since the higher the value, the tougher the meat. The TP scores are plotted on the right-hand scale, and the scale begins at 10 and goes upward to 1, in keeping with the TP scoring system in which the higher the value, the more tender the muscle. Winfree (1973), in a study of LD muscles of these same animals found that the TP judged the H X C H (6.94) the most tender and the L X H (5.74) the least tender. He reported further that breed mean WB shear values ranged from 16.90 to 24.45 lb. for H X H and M A X H roasts, respectively. Cores one-inch in diameter were used. A preliminary report, of a project in progress, issued by the U. S. D. A. Meat Animal Research Center (1971) indicated the least-squares means of TP evaluations of LD steaks from breed groups to be as follows: (1) H X H, 7.3; (2) C X H, 7.3; (3) S X H, 6.8 and L X H, 6.8. The WB shear values, using cores one-half inch in diameter were: (1) C X H, 7.1 lb.; (2) H X H, 7.2 lb.; (3) S X H, 7.5 lb. and (4) L X H, 7.6 lb. The fact that the LD muscle was used in these two studies makes difficult any comparison of their results with those obtained in the present study using the SM muscle. This is especially true of the Winfree (1973) results obtained from the same animals. However, this emphasizes a fact well-known to food scientists, namely, that one muscle from an animal will not necessarily predict the relative tenderness of another muscle from the same animal.

II. Comparisons of Objective Measures

The amount of variation within each method is presented in Table 4. The minimum and maximum values indicate the range to be fairly

Table 4

Overall Means, Minimum and Maximum Values, Standard Deviations and Coefficients of Variation of Tenderness Measurements

Method	Mean	Min. Value	Max. Value	Std. Dev.	CV
TP	6.1857	3.1000	8.4000	1.1813	19.10
AT	19.8823	14.2700	24.7300	2.4728	12.44
WB	10.4337	5.1050	15.6267	2.6031	24.95
IMF	9.9045	6.3939	15.1716	2.0208	20.40
IAR	1.8498	1.2199	2.8289	0.3756	20.30

TP: Taste Panel, AT: Armour Tenderometer, WB: Warner-Bratzler, IMF: Instron Maximum Force, IAR: Instron Area.

extensive; however, the standard deviations show that most values lie fairly close to one another. A considerable amount of this variation can be explained on the basis of known variability of tenderness within each muscle. As stated previously, the variability of tenderness in beef muscle is tremendous between muscles and within muscles. It has been observed also that the tenderness varies more within a tough muscle than within a tender muscle. This is illustrated in Figure 6 which compares the force-distance curves obtained from the Instron. The curves are foreshortened at the base; however, the two can be compared easily. The tough muscle from a M A X H animal has a difference of 14.85 lb. in MF measurements (4.29 to 19.14) and of 2.56 in.-lb. in area (0.96 to 3.52). The averages for this animal were 11.5588 lbs. MF and 2.2339 in.-lb. area. While in the curves from the tender muscle obtained from a H X C H animal, the difference in MF is 4.0 lb. (5.50 to 9.50) and in area 0.70 in.-lb. (1.14 to 1.84). The averages of this muscle were 7.3272 lb. MF and 1.4799 in.-lb. area. Eighteen curves were obtained from each muscle, and the maximum and minimum values for each are depicted.

The general consensus among food scientists is that the variability between and within WB shear instruments is quite large. The installation of the WB shearing unit was done with the expectation that one source of that variation might be eliminated by using the measuring system of an Instron, which has been shown to be practically free of variability. A 2 x 7 factorial experiment on a within-breed basis was used to assess any differences between the MF values of the WB shear and the Instron shear. The analysis of variance shown in Table 3, page 48, indicates

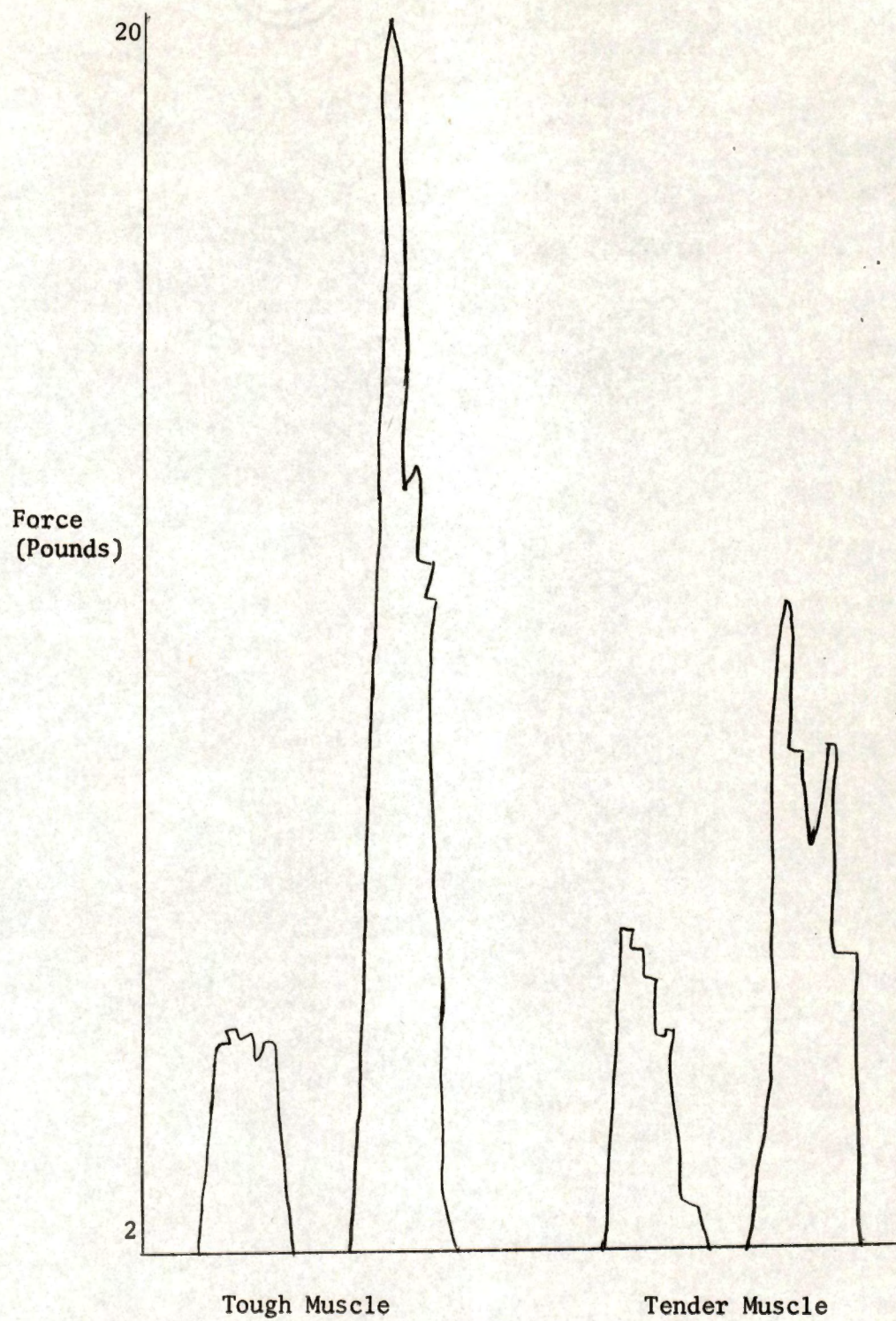


Figure 6. Comparison of Tenderness Measurements Recorded by Instron.

no significance of variation due to instrument or breed differences or interaction between these two effects. Winfree (1973), cited previously, also found that breed influence on WB shear values was nonsignificant.

Two statistical approaches were used to study correlation: product-moment (simple) correlation and rank correlation.

The product-moment (PM) correlation coefficients are shown in Table 5. As indicated, the coefficient (-0.577) of the WB shear values and TP scores is highly significant. This is similar to the findings of Deatherage and Garnatz (1952), Cover, Hostetler and Ritchey (1962) and many others who have compared the WB shear with sensory evaluations.

No association is indicated between the AT values and the TP evaluations. Dikeman et al. (1972) found low but significant correlations between AT values and sensory scores. Carpenter, Smith and Butler (1972) obtained significant correlations between tenderness measures of the AT values and TP scores on U. S. Choice grade carcasses but found no relationship of values from U. S. Good grade carcasses. In searching the literature, no reports were found of studies in which the WB shearing unit was installed in an Instron to obtain values for correlation with TP scores. The three instrument evaluations, WB, IMF and IAR, according to the correlations shown in Table 5, appear to be good predictors of tenderness as evaluated by a TP.

There is little or no relationship between the AT and the other objective evaluations. This is in agreement with Henrickson, Marsden and Morrison (1972) who found no significant correlation between the AT values and WB shear values. The highly significant coefficient of

Table 5
Product-Moment Correlation Coefficients

	IAR	IMF	WB	AT
TP	-0.687**	-0.687**	-0.577**	-0.041
AT	0.020	-0.003	0.066	
WB	0.708**	0.784**		
IMF	0.967**			

**Indicates significance ($P < 0.01$).

TP: Taste Panel, AT: Armour Tenderometer, WB: Warner-Bratzler,
IMF: Instron Maximum Force, IAR: Instron Area.

correlation between the two Instron values was to be expected, but with some difference, as explained earlier and shown in Figure 4, page 49.

There has been considerable research effort devoted to attempts to develop objective methods for accurately predicting subjective evaluations of tenderness. However, very little work has been directed toward developing new statistical approaches in analyzing the data obtained from existing objective methods and from measurement of tenderness with sensory scores. The distribution of meat tenderness values is unquestionably not a normal distribution.

An approach which does not depend on any assumption as to the nature of the distribution sampled was used here in analyzing the data by nonparametric methods of which rank correlation is one example.

Parametric statistics are values used in statistical inference which relies on sampling from populations of known or validly assumed distributions. Nonparametric methods are used when samples are small or when some evident peculiarity of the distribution of the parent population, such as marked asymmetry, makes commonly used assumptions of normality of sampling distributions suspect. These methods are valid whatever form the population distribution may have.

Rank correlation, then, can be used to test the hypothesis that the two variables X and Y are independent, and no assumptions are made about the distribution of X or Y . Spearman's rank correlation coefficient is similar to ρ (product-moment correlation coefficient) in that its values range from -1 to $+1$ with $+1$ indicating perfect agreement

and -1 exact oppositeness in ranking. The largest value is ranked number 1, second largest ranked number 2, etc.

All samples were ranked from 1 to 5 within each testing group with respect to mean panel tenderness, mean WB and Instron shear values and mean AT penetration values. Rank correlation was estimated by Spearman's formula. Table 6 shows the mean values of the different test groups. The rank correlation coefficients (r_s) are shown in Table 7. The degree of association was not changed a great deal from the relationships found with the product-moment correlation. It must be remembered that the minus values shown here are reflecting the two systems of measuring tenderness; higher values from a TP indicating greater tenderness, while, in the objective methods, the higher the value, the tougher the sample. The rank correlation between TP scores and the objective measurements of tenderness: IMF, IAR and WB, may be interpreted in another way. It may be said that the coefficients indicate that the panel members actually were able to detect fairly small differences in tenderness.

Table 6
Mean Measurements of Tenderness by Test Group

Test No.	TP	AT	WB	IMF	IAR
1	6.08	19.4380	10.3523	10.1677	1.8663
2	6.94	18.5960	8.4157	9.0221	1.6183
3	5.44	19.0180	9.7203	10.5616	2.0930
4	6.00	21.4600	12.1470	10.8848	2.0419
5	6.38	19.3200	10.0997	9.8795	1.8603
6	5.98	22.6780	12.6433	10.0812	1.8730
7	6.48	18.6660	9.6573	8.7351	1.5958
Overall	6.1857	19.8823	10.4337	9.9046	1.8500

TP: Taste Panel, AT: Armour Tenderometer, WB: Warner-Bratzler,
IMF: Instron Maximum Force, IAR: Instron Area.



Table 7
Spearman Rank Correlation Coefficients

	IAR	IMF	WB	AT
TP	-0.688**	-0.660**	-0.559**	-0.122
AT	0.013	-0.043	0.072	
WB	0.736**	0.842**		
IMF	0.946**			

**Indicates significance ($P < 0.01$).

TP: Taste Panel, AT: Armour Tenderometer, WB: Warner-Bratzler,
IMF: Instron Maximum Force, IAR: Instron Area.

CHAPTER V

SUMMARY

Measurements of tenderness were made on the semimembranosus muscle using the Armour Tenderometer (AT), Warner-Bratzler Shear (WB), Instron Universal Testing Instrument (Instron) and subjective evaluations.

Muscles used came from 35 beef animals, five from each of seven mating types: Charolais-Hereford (CH) dams bred to Hereford (H) or Charolais (C) bulls, H dams bred to Simmental (S), Maine-Anjou (MA), Limousin (L) or H bulls. Thus, the breed groups represented were: H X H, C X H, H X C H, C X C H, S X H, M A X H and L X H.

Penetration-force values were obtained from raw muscle with the AT. Cores one-half inch in diameter, from cooked muscle were used with the WB and the Instron. Maximum-shear-force values were obtained with the WB while maximum-force (IMF) and "area under the curve" (IAR) values were obtained with the Instron. A 10-member taste panel (TP) evaluated each muscle for tenderness on a hedonic scale of 1 (extremely tough) to 10 (extremely tender).

A comparison of the seven breed groups was made within each method of evaluation. The following breed groups were ranked most tender by the various methods: TP, H X C H; WB, H X C H; IMF, H X C H; IAR, L X H and AT, H X H.

Analysis of variance showed no significant variation due to differences between the WB and IMF shear values, differences between breeds or interaction between instrument and breed. Highly significant product-moment (PM) correlations and rank correlations were found between: TP and WB, TP and IMF, TP and IAR. No indication was found of any relationship between the AT values and TP scores. The PM correlations and rank correlations between the WB values and the IMF values, between WB and IAR values and between IMF values and IAR values were highly significant. The correlations of AT values with other objective measures of tenderness were nonsignificant.



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APPENDIX

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Table 8
Taste Panel Means for Tenderness

Breed Group	Rank	Tenderness Score
H X C H	1	6.68
H X H	2	6.62
L X H	3	6.44
M A X H	4	6.04
C X C H	5	5.96
S X H	6	5.80
C X H	7	5.76

Table 9
Warner-Bratzler Shear Means

Breed Group	Rank	Value (lbs.)
H X C H	1	8.6074
M A X H	2	9.6780
H X H	3	10.0543
C X C H	4	10.0827
L X H	5	10.8773
C X H	6	11.7217
S X H	7	12.0143





Table 10
Instron Maximum Force Value Means

Breed Group	Rank	Maximum Force Value (lbs.)
H X C H	1	9.0680
L X H	2	9.4731
S X H	3	9.6242
H X H	4	9.6456
M A X H	5	10.0071
C X C H	6	10.2410
C X H	7	11.2731

Table 11
Instron Area Under the Curve Mean Values

Breed Group	Rank	Area Value (in.-lb.)
L X H	1	1.7102
S X H	2	1.7334
H X C H	3	1.7432
H X H	4	1.8489
M A X H	5	1.8688
C X C H	6	1.8967
C X H	7	2.1472

Table 12
Armour Tenderometer Means

Breed Group	Rank	Value (lbs.)
H X H	1	15.1120
C X C H	2	17.8860
C X H	3	19.1280
L X H	4	19.7060
S X H	5	20.4180
M A X H	6	21.3200
H X C H	7	21.6060

VITA

The author was born in Elkins, West Virginia on October 4, 1912. She did undergraduate work at the University of Louisville and Davis-Elkins College. She received her Bachelor of Science degree in 1935 from Davis-Elkins College with a major in Zoology and a minor in Chemistry and Mathematics. She was married to James A. Corrick, Jr. in 1937. She was a member of the SPARS (U. S. Coast Guard) during World War II and is a graduate of the U. S. Coast Guard Academy (SPAR, Training). She was retired to inactive duty in 1945. From 1945 to 1963 she was a Navy wife busily engaged in raising a family at various Naval duty stations throughout the world. In the fall of 1963, she entered The University of Tennessee to do graduate work which lead to a Master of Science degree in Food Technology in 1968. On the same day, her husband received a Ph.D. degree in Animal Science, their son a Bachelor of Science in Zoology, their daughter a Bachelor of Science in Chemistry. Since 1968, she has been doing graduate work leading to a Ph.D. degree in Animal Science.