BLADE TENDERIZATION EFFECTS ON SUBJECTIVE AND INSTRON OBJECTIVE TEXTURAL MEASUREMENTS OF LONGISSIMUS STEAKS FROM CATTLE FED VARIOUS NUTRITIONAL REGIMES

by

LARRY HARLAND HAYWARD

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Approved by:

Melvin C Hunt
Major Professor

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Chapter I

GENERAL INTRODUCTION

Consumers enjoy tender cuts of meat which creates a demand for high quality products. Thus, meat scientists have tried to develop accurate tenderness prediction and measurement technology to assure adequate meat supplies of sufficient quality. These researchers have developed methods using taste panelists (subjective testing) and laboratory techniques (objective testing). Although useful information has been produced, both testing methodologies have serious drawbacks (Pearson, 1963; Szczesniak, 1968; Harries, 1972; Voisey and Larmond, 1974; Harris, 1976; Larmond, 1976; Voisey, 1976). The ideal predictor of meat tenderness is yet to be developed (Harris, 1976).

Researchers have relied primarily on the Warner-Bratzler method to predict taste panel evaluations. This has lead to frustration with low correlations between objective and subjective measurements (Szczesniak, 1968), and it has been concluded that objective tests and taste panels measure different textural characteristics (Harris, 1976; Stanley and Swatland, 1976). However, the use of several structural parameters of meat, might alleviate some of this frustration (Harris, 1976).

Advances in electronics have resulted in equipment which measure force and distance relationships very rapidly and accurately. The incorporation of old objective testing methodology to state-of-the-art equipment, such as the Instron, has exposed new avenues of research. Pioneering work with texture profiling (Friedman et al., 1963) and Instron force-deformation curve analysis (Pool and Klose, 1969; Bouton et al., 1971; Bouton et al., 1975a; Bouton et al., 1975b) has developed methods which show promise as effective tenderness predictors. However, much work is needed to substantiate their results and to establish specific operational techniques.

Livestock producers are constantly striving to produce animals with high percentages of tender, flavorful and juicy retail cuts which grade USDA Choice, but with only minimum amounts of waste fat trim (Guenther et al., 1965). With high feed costs and the influx of competitively priced foreign beef, economical production is a necessity. Animal production with combinations of shorter feeding times, lower energy rations and greater roughage utilization is a possible solution. Blade tenderization, one of the newer and most widely applied mechanical methods of meat tenderization (Miller, 1975), may insure acceptable tenderness in meat from low grade beef (Glover et al., 1977; Savell et al., 1977) and in meat from beef fed lower energy rations (Davis et al., 1975).

The purpose of our research was to study the effects of mechanical blade tenderization, ration energy level, and time on feed on subjective and Instron objective measurements of beef quality.

Chapter II

REVIEW OF LITERATURE

Tenderness Versus Texture

Meat tenderness is extremely important for consumer acceptability of meat (Bailey, 1972; Harries et al., 1972). Hence, the ability to predict and measure the components of meat tenderness is imperative to meat scientists. Stanley et al. (1971) described texture as the mechanical properties of meat which can be measured objectively, whereas tenderness results from subjective evaluations. Sherman (1970) describes texture as the composite of those properties which arise from the structural elements, and the manner in which it registers with the physiological senses. Szczesniak (1977) emphasized Sherman's definition contains three important components of texture: (1) it is a sensory quality; (2) it has origins in the structural parameters of the food; and (3) it is composed of several properties. Among these, the mechanical properties are probably the most important and have received the greatest attention in terms of definition, understanding, and measurement (Szczesniak, 1977).

Need for Objective Measurements of Texture

Knowledge of textural components of meat has evolved through development of subjective and objective methodology.

Since meat consumption is of primary importance, subjective measurements, or taste panel testing, will remain the ultimate testing method (Harris, 1976; Larmond, 1976). Sensory measurements more closely approximate actual tenderness measurements occurring under normal conditions of eating (Pearson, 1963). However, Dikeman (1977) stated that we need not be "married" to sensory evaluations since several instrumental methods can produce analytical data adequate for many research studies.

Problems exist with taste panel assessments because they are subjective and rely on individual human interpretations which are often vague (Harris, 1976). This makes it difficult to compare results between laboratories and different sittings of the same panel (Pearson, 1963; Larmond, 1976). Furthermore, taste panel evaluations are time consuming and expensive (Harries, 1972) especially if recommended training and testing procedures are followed (AMSA, 1978). Therefore, it would be advantageous to have precise objective measurements of meat texture.

Objective Measurement Requirements

Numerous devices have been developed to objectively measure meat texture; however, none of these devices are ideal predictors of meat tenderness (Harris, 1976). Stanley and Swatland (1976) suggest that an objective measure should have: (1) a firm foundation on known principles of tissue organization, chemical composition, and physical forces; (2)

wide applicability within raw and cooked skeletal muscles; (3) close agreement with sensory tests; and (4) high precision, accuracy, ease of performance, and low cost. It is very difficult to use a mechanical test on raw meat to predict tenderness of cooked meat and thus much work is needed (Kapsalis, 1976).

The integration of objective measures will depend on their correlation with taste panel scores (Kapsalis, 1976; Larmond, 1976) and their sensitivity to meat structural differences (Harris, 1976). A major inhibiting factor for development of the ideal objective test lies in the conflicting correlations with sensory tests. Apparently, mechanical devices and taste panelists measure different structural characteristics of meat (Harris, 1976; Stanley and Swatland, 1976). Szczesniak (1968) believes correlations between objective and sensory methods are controversial and have frustrated many researchers. She further states that conditions under which both measurements are performed and how results are expressed will have a tremendous bearing on correlations. Szczesniak concludes that instruments which closely simulate conditions which the sensory properties of the sample are assessed should correlate most consistantly with sensory methods. The use of slow deformation speeds to predict oral reaction should be viewed with caution (Voisey, 1975). He states that research is required to establish optimum instrumental test speeds that maximize correlations with consumers. If higher deformation rates are to be used adequate recorder response is needed to minimize induced errors (Voisey and Kloek, 1975).

Voisey (1976) suggested the following factors may affect predictive precision of mechanical devices: (1) experimental design and sampling techniques; (2) improper instrument design or operation; (3) lack of control of experimental parameters; and (4) interpretation of the results. Voisey (1976) feels that all test factors should be fully explained including test conditions, sample size, the texture test cell employed, condition of test call, and the definition of terms used. Voisey also indicates the most improvement on empirical tests can be realized through interpretation of results based on common sense, careful observation and theoretical analysis of sample reactions.

Segars et al. (1975) suggests that if high objective-subjective correlations are desired, a destructive objective testing device should be used. His rational for destructive tests is related to sample destruction of subjective analyses.

Sensory measurements could use ratio scales through magnitude estimations to more closely approximate values obtained through instrumental analysis which can also be expressed in ratios (Larmond, 1976).

Khan et al. (1973) found that samples differing in shear force by 0.5 kg or more were readily detected by the taste panel regardless of the level of tenderness or method of cooking. Thus, factors other than shear force, which may interfere with judgement of tenderness, become "less important" at high shear force values. It was also suggested that taste panel discrimination might be enhanced when samples differ in texture as well as shear force, and when the same sample is used for both shear force and taste panel assessments.

Harris (1976) indicates that a single device will not be sensitive to all factors influencing taste panel assessment and, therefore, combination of results from several objective measures each of which relate to a different structural component may solve this problem. Thus, no matter what the solution, there will always be room for error in objective and subjective measurements due in part to meat heterogeneity and human interpretation which will continue to limit the degree of correlation between the two methods (Harris, 1976).

Mechanical Measurements of Meat Texture

Numerous objective methods based on chemical, histological, and mechanical techniques have been developed for objective measurements of meat texture. Chemical approaches often measure characteristics of connective (Pearson, 1963) or myofibrillar tissue (Olson and Parrish, 1977). Histological methods classify texture based on structural appearance of muscle (Pearson, 1963). Various mechanical methods are simpler, easier to apply and thus have been widely accepted (Pearson, 1963).

The Warner-Bratzler Apparatus

The Warner-Bratzler Shear (Warner, 1928; Bratzler, 1932, 1933, 1949) is the most widely used objective apparatus (Deatherage, 1951; Hostetler et al., 1964; Stanley and Swatland, 1976). The principle involves moving a blade slot 1.143 mm wide at a uniform rate of 22.85 cm/min over a 1.016 mm wide blade containing a triangular shaped hole (Bratzler, 1949). Usually, a cylindrical shaped sample, 0.5 to 2.5 cm in diameter (Voisey, 1976), is placed in the blade's triangular hole. A spring scale attached to the blade records the maximum force required to cut the sample in half.

Shortcomings of the Warner-Bratzler Apparatus

Warner-Bratzler peak shear force has been used as an index of meat tenderness with conflicting correlations to sensory tests (Szczesniak, 1968). Voisey and Larmond (1974) and Voisey (1976) suggest inconsistent Warner-Bratzler measurements are engineering related. The term shear appears incompatible with forces developed in a Warner-Bratzler test (Voisey, 1976). Voisey (1976) states that shear forces develop parallel to and in the same plane of force direction. He suggests that a better term would be "cutting." Since meat is a pliable material, a deforming force is converted to tensile stress in individual fibers, and when they yield it is a failure due mainly to tension rather than shear (Pool and Klose, 1969).

Voisey (1976) states that changes in sample deformation rates are introduced by spring scale deflection and these rate changes are most critical at sample rupture point. Compressibility of the sample and the spring scale capacity are compounded with the spring scale deflection problem. Samples should be deformed at a constant rate, but are not because of variable spring scale deflection. Voisey (1976) also suggests that the rate of sample deformation is too slow and does not approximate the 150 cm/min rates achieved in chewing as described by Borne (1975).

Standardization of the Warner-Bratzler Apparatus

Standardization of the Warner-Bratzler test is needed (Voisey, 1976). Shearing rate, blade thickness, clearance between blade and slot, shape of the hole in the blade, and condition of the hole edges should be carefully controlled (Voisey, 1974). There may be an advantage in using cutting edges at a greater angle than the 60^{o} currently used (Voisey, 1974).

Coring techniques also need standardization for Warner-Bratzler testing. Hostetler and Ritchey (1964) reported large differences in shear values for one-half inch cores from steaks cooked taken without regard to fiber direction.

Kastner and Henrickson (1970) developed a method to make cores more uniform in diameter. They found that pork muscle cooked to $72^{o}C$ and chilled to $4^{o}C$ before coring, was firmer, drier and able to hold its shape better during coring than muscle cooked at $60^{o}C$ and cored warm. Furthermore, they developed a meat coring device that produced cores with less variation in diameter at 1.90 cm and 1.27 cm sizes than those cored by hand. The machine produced significantly larger cores at these sizes which produced larger shear forces. The same was true for 2.54 cm cores except the cores were not significantly larger. They also state that doubling the shear values from 1.27 cm cores did not equal 2.54 cm core shear forces.

Force-Deformation Measurements

Jacobson et al. (1962) eliminated the spring scale deflection problem by using a horizontal Warner-Bratzler apparatus connected to an electronic force transducer and recording system. This system was more sensitive, reliable, and provided more accurate load-time histories than those obtained by Hurwicz and Fischer (1954) who manually transcribed a load-time curve from a movie of the Warner-Bratzler scale hand and an electric timer.

The Kramer Shear Press (Kramer et al., 1951) gained popularity because it could yield force-time curves (Pearson, 1963). An offshoot of the Volodkevich Tenderness Device (Volodkevich, 1938) gave rise to the M.I.T. Denturometer (Szczesniak, 1963) a prototype for the General Foods Texturometer (Friedman et al., 1963) which pioneered the way for Instrumental Textural Profile Analysis using the Instron machine (Bourne, 1968; Breene, 1975).

Pool and Klose (1969) adapted the Warner-Bratzler blade and guide to an Instron Universal Testing Instrument which provides a graphic analog record of knife movement and forces applied to the knife. They were able to measure maximum force exerted, the slope of the force curve versus distance, and the sample area at any point along the force deformation curve.

Voisey (1976) suggested that all test conditions and critical points should be discussed and a typical force-time (deformation) curve presented. Parameters which may fit specific research objectives are: (1) maximum or initial yield force representing tensile rupture; (2) sample area at rupture, indicating compression required to initiate rupture; (3) slope of the force-time curve; (4) force per unit sample area to the original area at any selected point; (5) forces and areas in the period following rupture points.

Non-Shearing Techniques

Several non-shearing techniques have been developed to measure structural characteristics of meat. Friedman et al. (1963) modified the M.I.T. Tenderometer into a texturometer which made several penetrations of a plunger into a sample contained in a cup. Their force-distance curves were termed texture profiles which included: (1) hardness; (2) cohesiveness; (3) elasticity; (4) adhesiveness; (5) brittleness; (6) chewiness; and (7) gumminess.

Bouton et al. (1971) defined similar parameters: (1) hardness; (2) cohesiveness; and (3) chewiness using Instron compression methodology. A 0.63 cm diameter flat-ended plunger was driven perpendicular to fibers 80% of the way through a 1.00 $\pm$ 0.01 cm thick cooked sample. Both the compression method and Warner-Bratzler shear values (using rectangular shaped samples) were highly correlated with tenderness assessments. The compression measurements were found to depend on fiber strength, as well as on adhesion between the fibers (Bouton and Harris, 1972a) but were more strongly influenced by the strength of the "material" holding the meat fibers together (Bouton and Harris, 1972b). Muscle fiber tensile strength had the most influence on Warner-Bratzler shear measurements (Bouton and Harris, 1972b). Bouton et al. (1975a) measured five basic parameters from the Warner-Bratzler force-deformation curve. They were: (1) initial yield force; (2) peak force; (3) initial yield distance; (4) final yield distance: and (5) slope of curve at initial yield. They found: (1) the force at the initial yield represented the force required to compress and initiate shear fracture planes through the myofibrillar structure and was primarily dependent on myofibrillar strength, and (2) that the difference between the initial yield force and the peak force was an indication of the strength of connective tissue and other structures remaining after yield of the myofibrillar structure.

Bouton and Harris (1972a) introduced Instron adhesion and tensile measurements. Adhesion was reported to measure intramuscular connective tissue strength (Bouton and Harris, 1972a), and was strongly related to Instron compression measurements (Bouton and Harris, 1972b). Tensile values measured muscle fiber tensile strength and were highly correlated with Warner-Bratzler results (Bouton and Harris, 1972b).

Terminology of Instron Parameters

General Terms

1. Force: A push or a pull always applied by one material object on another. It is characterized by both its magnitude and the direction in which it acts (Cromer, 1974). The unit of force is the kilogram (kg).

2. Work: Work = Force X distance. In the meter, kilogram, second system, the unit of work is the joule (J) (Cromer, 1974).

3. Joule (J): The unit of work in the mks system. 1J = 1 newton-meter (N-m) (Cromer, 1974). In our work: 1J = 1 kilogram-meter (kg-m).

4. Newton (N): A unit of force in the mks system (Cromer, 1974). A force of one newton causes a mass of one kilogram to have an acceleration of one meter per second (Cromer, 1974).

5. Force-deformation curve: An electronically plotted curve during an objective test. On the Instron instrument the chart and drive motors are synchronized, so it is also a force-distance curve.

Warner-Bratzler Apparatus

1. Shear: Results from the application of force where the test material is separated into two (or more) parts, with

one part sliding beyond the other part (Kramer and Twigg, 1966). A force that is developed parallel to and in the same plane of force direction (Voisey, 1976). This force does not apply to meat (Pool and Klose, 1969; Voisey, 1976).

2. Cutting: Occurs when force is applied in such a way that the test unit is divided, so that the portions remain in their original position in relation to each other (Kramer and Twigg, 1966). This may be the best term for the forces developed during a Warner-Bratzler test (Voisey, 1976).

3. Initial Yield Force: Force (kg) at which the sample first begins to yield; it appears as the first inflection in the force-deformation curve (Bouton et al., 1975a).

4. Second Yield Force: Force (kg) at which the sample begins to yield a second time; appears as the second inflection in the force-deformation curve.

5. Peak Force: Maximum force (kg) recorded on the force-deformation curve (Bouton et al., 1975a).

6. Initial Yield, Second Yield, or Peak Force Distance: Distance (cm) traveled by the Warner-Bratzler knife after initial contact with the sample and the first inflection, second inflection, and peak force, respectively (Bouton et al., 1975a).

7. Slope at Initial Yield: The rate of change of force with distance (slope) at the initial yield inflection point (kg/cm) (Bouton et al., 1975a).

8. Initial Yield Angle: The angle between the base line and a tangent to the force-deformation curve at the initial yield.

9. Area of Force Deformation Curve: Total area under the force-deformation curve from initial contact with the sample separation. Determined with an integrator or a planimeter.

10. Total Work Done: The amount of work (joules) needed to move the Warner-Bratzler knife through the sample.

11. Cross-Sectional Area of Sample at Initial Yield, Second Yield, or Peak Force: Test sample area at point of initial inflection, second inflection, or peak force, respectively (cm^2).

12. Measurement of Cross-Sectional Areas: The Instron is programmed for a direct relationship between blade travel (through an equilateral triangle) and time.

13. Relative Force per Unit Area of Sample at Initial Yield, Second Yield, or Peak Force: Force (kg) at the appropriate inflection points divided by the cross-sectional area (cm^2) of the meat at the corresponding inflection points.

Adhesion

The force or work required to pull apart samples with a 1 cm^2 rectangular cross section (usually 1.5 X 0.67 cm). Fibers are orientated perpendicular to the direction of strain (Bouton and Harris, 1972a).

Tensile Strength

The force or work required to pull apart samples with a 0.44 cm^2 cross-sectional area. Fibers are oriented parallel to the direction of strain (Bouton and Harris, 1972a).

Parameters Common to Instron Tensile and Adhesion Measurements

1. Force at Initial Yield: Force (kg) at the first major inflection on the force-deformation curve (Bouton et al., 1975b).

2. Peak Force: The maximum force (kg) measure on the force-deformation curve (Bouton et al., 1975b).

3. Initial-Yield Distance: The distance from the first registering of force to the initial-yield point (Bouton et al., 1975b).

4. Final-Yield Distance: The distance between the first registering of force and when the sample finally yielded (Bouton et al., 1975b).

5. Slope at Yield: The rate of change of force with distance (slope) at the initial yield inflection point (kg/cm) (Bouton et al., 1975b).

6. Work Done: The total work performed (joules) during the stressing and final breakage of the sample (Bouton et al., 1975b).

Compression

1. Compression: Squeezing together of the test material so that it still remains as a single undivided unit, but may occupy less volume (Kramer and Twigg, 1966).

2. Instron-Compression: The force required or the work done to drive a 0.63 cm diameter flat ended plunger 0.80 cm through a 1.0 cm thick cooked meat sample, with fibers lying perpendicular to the direction of plunger travel. The plunger is then withdrawn and driven into the same, now damaged, area to measure the reduction in the force or work done (Bouton et at., 1971).

3. Hardness: The maximum compression force (kg) required to drive the plunger the first time 80% of the way through the sample (Bouton et al., 1971).

4. Area of First Compression: The area under the first compression force-distance curve as determined by an integrator or planimeter (cm^2).

5. Work of First Compression: The total work (joules) needed to compress the sample the first time.

6. Second Compression Peak Height: The maximum force (kg) required to drive the plunger 80% into the now damaged sample the second time.

7. Area of Second Compression: The area (cm^2) under the second compression force-deformation curve as determined by an integrator or a planimeter.

8. Work of Second Compression: The total work (joules) needed to compress the sample the second time.

9. Cohesiveness: The ratio of the work done during the second penetration to that done on the first (Bouton et al., 1971).

10. Chewiness: The product of compression hardness and cohesiveness (Bouton et al., 1971).

Factors Affecting Force-Deformation Measurements

Connective Tissue and Animal Age

Marsh (1977) stated that collagen, the principle fibrous protein of connective tissue, has a major effect on meat tenderness. But, collagen quantity is of less significance than its quality (Bailey, 1972; Marsh, 1977). Collagen properties vary considerably with animal age; the collagen becomes more thermally stable and much less soluble as age increases (Bailey, 1972). Tropocollagen molecules, the basic structural units of collagen, are assembled in a quarter-stagger formational overlap with periodic crosslinking to prevent slipping under tension in the living tissue (Marsh, 1977). Youthful or recently formed crosslinks, known as Schiff bases, are relatively unstable when exposed to denaturing conditions and thus break down quite readily when heated (Bailey, 1972). In the mature animal, these crosslinks stabilize and become more heat resistant (Marsh, 1977).

Bouton and Harris (1972a) found that Warner-Bratzler shear, Instron compression, adhesion, and tensile strength values for samples cooked at various temperatures were strongly affected by animal age. Thus, these objective measures are influenced by connective tissue.

Bouton and Harris (1972b) found that Instron compression (chewiness) forces significantly increased in semimembranosus

(SM), longissimus dorsi (LD), gluteus medius (GM), and semitendinosus (ST) muscles from steers 3 to 4 years old compared with 1 to 1.5 year old stears. In addition, compression and adhesion values were highly correlated. Low adhesion values were noted in veal, whereas, older animals required a longer cooking time to achieve comparable adhesion values. Warner-Bratzler and adhesion values were lowly correlated. Only the GM showed a significant animal-age effect on Warner-Bratzler values. These results indicate that compression values and adhesion values are more dependent on connective tissue strength, than are Warner-Bratzler measurements.

Bouton et al. (1972) found that Warner-Bratzler values were not significantly affected by animal age in ovine SM, LD, ST, and biceps femoris (BF) muscles, whereas Instron compression, adhesion, and tensile strength measures significantly increased with increasing animal age in the majority of these muscles.

Bouton et al. (1975a) developed force-deformation curves with the Warner-Bratzler instrument using a strip chart recorder attached to a force transducer. When stretched calf and steer deep pectoral (DP) muscles were cooked at 60 C for one hour, increasing animal age: (1) did not significantly affect initial yield-force values; (2) increased significantly the peak forces; and (3) quadrupled differences between initial yield and peak force.

Muscle Fiber Characteristics

Sarcomere Length and Cold Shortening: Locker (1960) concluded that relaxed muscles were more tender than partially contracted muscles. Twenty percent shortening had little effect on tenderness, 40% contraction maximized toughness, above 40% shortening tenderization occurs, and at 60% shortening tenderness is equivalent to that at 20% contraction (Marsh et al., 1966). With increased shortening, toughness can rise until the tissue may be 4 to 5 times as tough as its unshortened control (Marsh and Leet, 1966). Sarcomere contraction to below 1.8 to 2.0 µm increases toughness, but meat becomes more tender at sarcomere lengths of 1.2 to 1.3 µm (Harris, 1976). This tenderization effect could be due to the inability of connective tissue to accommodate large changes in myofibril diameter as the sarcomeres contract to below 1.2 to 1.3 µm and thus cause myofibrillar disruption (Harris, 1976).

Sarcomere shortening is affected by temperature after slaughter (Locker and Hagyard, 1963). Minimum contraction occurs at 15°C, extensive contraction occurs at temperatures less than 10°C, and above 25°C, the contraction due to rigor is less rapid (Bailey, 1972). Jones (1977) used scanning electron microscopy to visualize cold-shortened LD muscle of a steer. The fibers were severely contracted and exhibited extreme waviness. The sarcomeres were contracted to 1 µm which produced complete overlap of actin and myosin filaments.

The Z-lines were more prominant probably due to buckling of myosin filaments. No other bands were observed. Cold induced shortening is also known to increase cooking weight loss and shrinkage across the meat grain (Davey and Gilbert, 1975a).

Bouton and Harris (1972b) found high correlations between Warner-Bratzler peak force and Instron fiber tensile strength ($r = 0.85$) in SM and LD muscles with sarcomere lengths of 1.8 to 2.1 μm, and between Warner-Bratzler and fiber strength values ($r = 0.86$) in stretched LD with sarcomere lengths of 2.0 to 2.3 μm. A comparatively low correlation ($r = 0.59$) was found for stretched SM muscles with sarcomeres 2.6 to 2.8 μm. Correlations between Instron compression (chewiness) and the Warner-Bratzler instrument were all very low for LD and SM muscles of any sarcomere length. These results demonstrated a strong relationship between Warner-Bratzler and fiber tensile strength measurements, whereas compression values were more strongly influenced by the strength of the material holding the meat fibers together than by the strength of the fibers themselves.

Bouton and Harris (1972c) varied muscle contraction state using an aitch bone hanging method for both beef and lamb. The mean sarcomere lengths for older animals were 1.83 and 2.54 μm for control and stretched SM; and 1.89 and 2.11 μm for control and stretched LD, respectively. Instron compression (chewiness) values significantly decreased with muscle stretching in young steers and old cows. Instron tensile strength measurements decreased in the stretched LD muscle, but significantly increased in stretched SM muscle. This was explained by an increase in the fiber packing density of the SM over the LD. The SM had been stretched to a greater extent than the LD thereby increasing the number of fibers per unit area and consequently increasing the connective tissue contribution.

Bouton and Harris (1972c) found a significant decrease in Warner-Bratzler peak force measurements in stretched SM and LD muscles from young and old beef animals. Furthermore, stretching of ovine LD, SM, and BF muscles also resulted in lower Warner-Bratzler and Instron compression (chewiness) measures. Results from both the beef and lamb experiments demonstrated that stretching significantly reduced Instron adhesion values. These data suggest that both the muscle fiber at various contraction states, and their associated connective tissue affect objective textural measurements.

Bouton et al. (1973a) determined that ovine myofibrillar toughness as assessed by the Warner-Bratzler instrument is independent of sarcomere length for muscles with sarcomere lengths greater than 1.8 μm. Considering muscles with sarcomere lengths of less than 2.0 μm, peak force values decreased exponentially as sarcomere length increased.

Bouton et al. (1975b) connected the Warner-Bratzler output to a strip chart recorder obtaining force deformation curves. Initial yield force, peak force, and initial yield distances increased with cold shortening in cooked beef DP muscles reflecting an increased rigidity of the myofibrillar structure associated with increased actin-myosin overlap. Differences between the initial yield and peak force values were significantly greater for control and stretched samples compared with the cold shortened samples. This illustrated that further extension/compression was required to strain the connective tissue network and remaining structures to the breaking point after the myofibrillar structure had yielded. Differences between the initial and final yield distances were smallest for the cold-shortened samples since the connective tissue and the remaining structures were strained to near-breaking at the point of initial yield.

Instron tensile initial yield force and distance were greater for stretched raw and cooked (60°C for 1.5 hrs.) than similar unstretched muscle due to a higher connective tissue contribution (Bouton et al., 1975b). Tensile peak force values, which represent forces required to complete the rupture of the myofibrillar structure and then further extend and break the connective tissue network increased with muscle stretching in raw and cooked (60°C for 1.5 hrs.) samples (Bouton et al., 1975b). Tensile final yield distances increased as myofibrillar contraction increased because the collagen fibers of the connective tissue network lie at a less acute angle to the long axis of the meat fibers in contracted muscle and thus can extend farther.

Instron adhesion initial yield force, peak force, slope at initial yield, and work all increased as the DP muscle sarcomere length decreased (Bouton et al., 1975b).

Cold shortening negated differences due to animal age on the Warner-Bratzler instrument (Bouton et al., 1975a). No significant differences between initial yield force, peak force, difference between initial yield force and peak force, initial and final yield distance or slope at yield were noted.

Sarcomere Length and Aging: Storage of meat at temperatures above freezing results in gradual tenderization. Hard, contracted, and tough muscles become soft, relaxed, and more tender during postmortem aging (Szcnesniak and Torgeson, 1965).

During aging of bovine muscle, changes in the myofibrillar cross-strition pattern occurs. Z-lines disappear and A-bands lengthen at the expense of I-bands (Davey and Gilbert, 1967). Davey and Gilbert (1969) reported that meat aging is due to disruption and possible dissolution of Z-line material which leads to weakening of inter-myofibrillar linkages and to loss of myofibrillar tensile strength. Furthermore, a loss of adhesion between adjacent myofibrils occurs. During postmortem storage of bovine LD muscle the myofibrils became shorter, more fragmented at the region of the Z-disk, and the Z-disks degrades (Parrish, 1977). These changes generally coincide with improved tenderness (Parrish et al., 1973).

Natural (endogenous) tenderization appears to be due in part to a calcium activated factor (CAF) which is a protease in muscle cells (Parrish, 1977). CAF activity weakens the Z-disk and degrades tropinin-T to a 30,000-dalton component. Detection of this component on electrophoresis gels may be an objective method for detecting early aging changes in tenderness (Parrish, 1977).

Davey et al. (1967) reported that myofibrillar shortening during rigor mortis onset largely determines the extent of beef aging. Meat stored at 15°C for 3 days shortened 0 to 20% of rest length and had low Warner-Bratzler values, whereas, with 40% shortening, a four- to five-fold increase in toughness was noted. A decline in toughness occurred at between 40 to 55% shortening. Meat aging effectiveness progressively decreases with muscle shortening beyond 20%, and at 40% shortening aging affects decline to zero (Davey et al., 1967).

Bouton and Harris (1972b) found that aging beef SM, LD, GM, and ST muscles at 0° to 1°C for 0 to 3 weeks before cooking at 90°C for 1.5 hrs., had significant effects on Instron compression and Warner-Bratzler values. After 3 weeks of aging, Warner-Bratzler peak force values were reduced nearly 50%; compression (chewiness) values were reduced 20%.

Bouton and Harris (1972c) found Warner-Bratzler, Instron compression (chewiness), and Instron fiber tensile measurements to decrease with aging of beef LD and SM muscles from either young or old animals. Aging did not significantly change the adhesion between the fibers.

Bouton and Harris (1972c) found aging of ovine LD, SM, and BF muscles to significantly improve tenderness as assessed by Instron compression (chewiness) and Warner-Bratzler measures. However, the aging effect on Warner-Bratzler peak force was greater for normal muscles than for stretched muscles. Adhesion values were not significantly affected, which agreed with earlier work (Bouton et al., 1972). Thus, it was concluded that changes in connective tissue were unlikely to contribute significantly to the increase in tenderness during aging (Bouton and Harris, 1972c).

Bouton et al. (1973a) noted that conditioning at 0^{o} to 1^{o} C produced cold shortening effects which reduced tenderness, assessed by Warner-Bratzler and adhesion measures, in many of the larger muscles of the lamb carcass. Subsequent aging partially compensated for increased fiber toughness. But, if the contraction was too severe, aging was not effective.

Bouton et al. (1975a) noted that Warner-Bratzler initial yield force values decreased with aging in calf LD muscle. The difference between initial yield and peak force values was unaffected by aging in young or old cattle. However, the slope at yield values decreased significantly with aging which Bouton suggested was due to decreases in the load-bearing capacity of the weakened myofibrillar structure of aged meat.

<u>Sarcomere Length and Cooking Temperature</u>: Cookery is perhaps the most important processing event affecting overall meat tenderness (Leander et al., 1977).

Machlick and Draudt (1963) found that collagen shrinkage of beef ST muscle occurs at 56^{o} to 59^{o}C, myofibrillar hardening reactions occur at 65^{o} to 75^{o}C, and collagen solubilization occurs around 80^{o} to 90^{o}C. Harris (1976) reported that meat fiber heat-contraction starts at 55^{o} to 60^{o}C, with the fastest rate of contraction occurring at 70^{o} to 75^{o}C.

Leander et al. (1977) studied the ultrastructural changes in surface and internal morphology of bovine ST and LD muscles using scanning and transmission electron microscopy. Heating ST and LD steaks to 63^{o}C internal temperature resulted in slight coagulation of endomysial connective tissue and only minor changes in myofibrillar proteins. At 68^{o}C, ST collagen was more coagulated and granular appearing than at 63^{o}C, but only some sarcomere shrinkage was apparent. The LD at 68^{o}C contained substantial sarcomere shrinkage and the banding pattern was becoming indistinct. The ST at 73^{o}C contained appreciable endomysial collagen coagulation and Z-line and I-band degradation, although the banding pattern was still visible. Extensive reduction (29%) in sarcomere length resulted when heating the LD to 73^{o}C and only the Z and M lines were discernable. Thus, their data suggests that cookery may affect the ultrastructure of various muscles differently.

Bouton and Harris (1972a) noted that cooking at 90^{o}C produced changes in the mechanical properties of muscles from beef animals of three age groups. Compression and adhesion values were more sensitive to cooking effects at 90°C than were Warner-Bratzler and Instron tensile measures. Adhesion values decreased rapidly with cooking time in calf SM, ST, and BF muscles, whereas, after cooking 45 min. at 90°C, compression values increased over raw controls for ST, SM, and BF calf muscles, but stayed the same for DP muscle. They suggested that this increase was due to myofiber hardening. After this initial increase, compression values declined in parallel with adhesion values. Young (1 to 1.5 yr.) steer muscle adhesion values did not change significantly until samples had been cooked for 1 hr., after which they decreased rapidly. Compression values for muscle from young steers increased significantly from the raw to the samples cooked for 1 hr. They decreased in samples cooked for longer periods. This, they felt, was due to a higher background strength of the connective tissue which allowed the heat-induced fiber hardening to be observed. Compression values of samples cooked for 1 hr. from 5 to 7 year old cows were greater than the raw controls. The extent of this increase was greater than that found in the younger cattle. In addition, cow muscle had significant increases in fiber adhesion values after 1 hr. of cooking. Further cooking rapidly decreased adhesion values.

Bouton and Harris (1972a) also cooked beef samples at 50, 60, and 70°C for various times. Instron compression and

Warner-Bratzler measurements did not significantly change in veal DP muscle after being cooked for 30 min. at any of the cooking temperatures. However, similar measurements for 2 to 3 year old steer DP muscle significantly increased after 2 hours cooking at 50°C. With steer BF muscle, Warner-Bratzler and adhesion measurements significantly decreased after cooking 8 hours at 70°C.

In yet another trial, Bouton and Harris (1972a) cooked samples at 40, 50, 60, or 75°C for 1 hour. Adhesion and compression values in muscles from three cattle age groups significantly increased from raw to a 50°C cooking temperature. Adhesion and compression values decreased after cooking at 60°C in veal and young steers. Compression values decreased with cooking at 60°C in the old cow muscle; but, adhesion values remained the same. Warner-Bratzler and Instron tensile values showed no significant temperature effects.

Bouton et al. (1974) studied cooking temperature and time effects on properties of calf BF and SM muscles. Warner-Bratzler values for unshortened muscles were much lower than for cold-shortened samples cooked at 60°C. The Warner-Bratzler values significantly increased from a 60°C to 90°C cooking temperature regardless of contraction state. Cold-shortened, contracted samples cooked at 60°C, had significantly greater Warner-Bratzler values than those for samples cooked at 50°C, whereas the muscles prevented from shortening had lower Warner-Bratzler values at a 60°C cooking temperature than at a 50°C cooking temperature. Adhesion values for samples cooked at 50°C were nearly five times those for samples cooked at 60°C regardless of contraction state. Adhesion values significantly decreased when cooking time at 90°C was increased from 1 to 3 hours. Thus, they felt, adhesion and Warner-Bratzler measures could not be affected by the same structural parameter.

Bouton et al. (1975a), using a Warner-Bratzler instrument to produce force-deformation curves, recorded changes in fresh and aged calf LD muscle cooked at 60 or 90°C. Initial yield force, peak force, initial yield distance, and slope at yield force all increased with the increase in cooking temperature. Differences between initial yield and peak force values were small for samples cooked at either 60 or 90°C. Initial yield and peak force values from LD muscles of steers 2 to 4 years old also increased with cooking temperature reflecting a myofibrillar hardening effect between 60° and 80°C. Samples cooked at 80°C exhibited a greater decrease in initial yield force and peak force values due to aging than was obtained for samples cooked at 60°C.

In another trial Bouton et al. (1975a) found that prolonged cooking at 90°C significantly reduced initial yield and peak force values for both cold-shortened and stretched ST muscle, although values for contracted samples were still very high even with 16 hours of cooking.

Bouton et al. (1975b) found Warner-Bratzler peak force values to increase significantly as the sarcomere length of raw DP muscle increased. This, they felt, was due to the inextensible connective tissue which provided the main resistance to deformation under load. However, peak force values for cooked DP muscle were inversely related to the sarcomere length. This demonstrated that myofibrillar protein coagulation was required before toughening associated with cold-shortening could be demonstrated. In addition, initial yield force, and initial yield distance values were found to increase with cooking temperature.

Bouton et al. (1976) studied the effects of thermal contraction of meat during cooking and its influence on tenderness. Thermal shortening occurred in both cold shortened and stretched meat, but the relative contraction during cooking was less for the cold shortened compared with stretched samples. Restraining samples from thermal shortening generally increased tensile initial yield force, peak force and slope at yield, but decreased initial yield distance values. Tensile total work done and final yield distance values increased in controls and stretched muscles restrained from thermal shortening. However, values of these parameters decreased in restrained cold-shortened samples. Warner-Bratzler initial yield force and peak force were not affected by restraint in control or cold-shortened samples. Restraint significantly increased Warner-Bratzler values for the stretched samples. Restrained samples had lower Warner-Bratzler initial yield distances. Slope at yield values significantly increased in the restrained, stretched samples. Adhesion values were significantly lower in samples restrained from thermal shortening. This, they felt, indicated that restrained samples have reduced connective tissue strength. They concluded that adhesion measures are most affected by the number of collagen cross-links between adjacent muscle fibers which are inversely proportional to sarcomere length; but, not by the number of muscle fibers per unit cross-sectional area which is directly proportional to sarcomere length.

pH - Water Holding Capacity - Cooking Loss

Bouton et al. (1971) varied ultimate pH in mutton using pre-slaughter drug administration. Cooking losses at 65°C decreased linearly with increasing raw or cooked muscle pH. Cooking losses at 90°C changed little until a pH of 5.9 for uncooked meat or about 6.2 for cooked meat, then they decreased linearly with increasing pH. Tenderness, as assessed by Warner-Bratzler and Instron compression, increased three-fold with increases in ultimate pH from about 5.9 to 7.0.

Bouton et al. (1972) reported that Instron tensile and adhesion measures of ovine SM muscles were significantly affected by ultimate pH. Significant linear regression lines were fitted to compression, adhesion, and fiber tensile strength measures with all of them decreasing as pH increased. Adhesion measurements changed the least while fiber tensile strength had the greatest changes with pH. A negative curvilinear relationship was noted between Warner-Bratzler measures and increasing pH. Warner-Bratzler values were less affected by pH changes in aged samples. Fiber tensile strength values were not related to pH in aged samples. However, adhesion values remained negatively linearly related to pH in aged muscle.

Bouton et al. (1972) also varied the contraction state of ovine muscles. The extent of cold shortening obtained for the psoas major (PM) and ST muscles was pH dependent. Compression and Warner-Bratzler values decreased linearly with increasing pH in both control and cold-shortened muscles. They concluded that the measurements most affected by pH were those which indicated fiber structural strength.

Similar pH studies on bovine muscle were presented by Bouton et al. (1973b). As pH increased the sarcomere length of ST muscle significantly decreased. Similar trends also occurred in DP muscle. Adhesion and Warner-Bratzler peak force values were negative and linear with increasing pH for both cold-shortened and stretched DP and ST muscles. Significant differences existed between the regression line slopes for the two contraction states. This was due to the significantly different values of stretched and cold-shortened samples at the control pH of 5.6. These differences, attributable to fiber contraction state, decreased with increasing pH and were nonsignificant at pH 7.0. Thus, they indicated that increasing pH and hence increasing water holding capacity (WHC) could counteract effects due to cold shortening. Myofibrillar contraction state had little or no effect on connective tissue strength at high pH or WHC values.

Water holding capacity and water retained after cooking both were found to increase with increasing pH for both DP and ST muscles regardless of contraction state (Bouton et al., 1973b). WHC of stretched DP muscle was significantly greater than that of the contracted muscle. ST muscle WHC followed a similar trend except at a lower significance level.

Bouton et al. (1973c) found that increasing ultimate pH generally increased tenderness whether tenderness was assessed by objective or subjective methods. Increases in tenderness were accompanied by increased water holding capacity. Compression, Warner-Bratzler peak force and fiber tensile strength were all negatively linearly related to pH. However, at high pH's no reduction in shear force or compression values was produced by muscle stretching or aging. Likewise, when fiber tensile strength was reduced by aging, no significant relationship with pH was observed. Bouton also stated that the relationship between adhesion and pH was influenced by thermal contraction. Adhesion measurements of muscles cooked at 60°C showed no relationship with pH, but at 80°C, where there was large thermal contraction, adhesion values decreased significantly with increased pH.

<u>Muscle Differences</u>

It is generally accepted that muscles containing more connective tissue are less tender than those containing little connective tissue (Szczesniak and Torgeson, 1965). Connective tissue is considered to be of more importance to the texture of SM than LD muscle (Ledward and Lawrie, 1975). Thus, the best measure of collagen contribution to toughness would be the product of its amount and its relative stability (Marsh, 1977).

Instron compression (chewiness) and adhesion measurements were considerably smaller for beef PM muscle than those of DP and BF muscles (Bouton and Harris, 1972a). Bouton and Harris (1972b) found compression measurements to be more strongly influenced by connective tissue than myofibrillar factors since beef SM and ST muscles produced higher compression values than LD and GM muscles. Beef ST muscle had significantly higher adhesion peak force values than GM or PM muscles. The PM had significantly lower Warner-Bratzler peak force values compared with either the ST or GM muscles (Bouton et al., 1975b).

Aging effects on beef LD muscles were greater than on corresponding SM muscles, whether assessed by Warner-Bratzler or Instron fiber tensile strength measures (Bouton and Harris, 1972c). Once fiber toughness had decreased with aging the relative importance of connective tissue toughness increased. Thus, Bouton and Harris concluded that muscles inheritantly high in connective tissue toughness would remain tough even after aging.

Ledward and Lawrie (1975) found a significant increase in Volodkevich Tenderometer values as the sample temperature was lowered. As product temperature decreased from 70°C to 20°C, increases in toughness were greater in SM than LD muscle. They stated this toughening was due to formation of hydrogen bonded collagen folds at the lower temperature.

Cold shortening capacity is related to animal growth (Davey and Gilbert, 1975). The rate and extent of cold shortening of beef sternomandibularis muscles varied with muscle size and presumably also with animal size. This, they stated, has important implications in meat chilling, since surface muscles could shorten to a different degree than deep tissue muscles.

Size of individual muscle fibers, which may vary between muscles, have been implicated with conflicting results with tenderness (Szxzesniak and Torgeson, 1965). Muscle bundle size may also affect tenderness differences between muscles (Szczesniak and Torgeson, 1965).

Blade Tenderization Effects on Objective and Subjective Meat Characteristics

In contrast to the endogenous tenderization processes of aging, exogenous tenderization technology including proteolytic enzymes, pressure-heat induced tenderization, electrical-stimulation and mechanical tenderization have been developed (Parrish, 1977). Mechanical blade tenderization is one of the newer and most widely applied mechanical methods of meat tenderization, especially in HRI businesses (Miller, 1975). Miller (1975) stated four benefits or justifications for using mechanical tenderization: (1) it insures acceptable tenderness of normal table-grade cuts; (2) it equalizes tenderness in portioned items containing two or more muscles of differing tenderness; (3) it up-grades cuts not previously utilized for steaking without enzymatic tenderization; and (4) blade tenderization is more uniform and more easily controlled than enzyme treatments which require more floor space and cleanup.

Generally, blade tenderization has been found to significantly reduce Warner-Bratzler values in a variety of cooked meat cuts (Goldner et al., 1974; Schwartz and Mandigo, 1974; Goldner and Mandigo, 1974; Davis et al., 1975; Glover et al., 1977; Tatum et al., 1978). Furthermore, Allo-Kramer penetrometer forces decreased with mechanical tenderization (Hinnergardt et al., 1975).

Conclusions regarding the effect of blade tenderization determined by Warner-Bratzler values alone are not necessarily the same as those reached through sensory panel tenderness ratings (Seideman et al., 1977). Davis et al. (1975) stated that mechanically tenderized, unaged beef loin steaks had lower Warner-Bratzler values than their non-tenderized counterparts aged 12 and 16 days. However, taste panel evaluations indicated the non-tenderized aged steaks were more tender. Based on Warner-Bratzler values, Seideman et al. (1977) found that beef ST muscle which had been passed two times through a blade tenderizer was as tender as non-tenderized PM muscle. Yet, taste panel assessments did not confirm the low

Warner-Bratzler values. Over-estimation of tenderness differences by the Warner-Bratzler apparatus may be due to the instrument following fracture planes created by the tenderizer blades (Bowling et al., 1976).

Mechanically tenderized meat has higher sensory panel scores for overall tenderness (Hinnergardt et al., 1975; Davis et al., 1977; Savell et al., 1977), initial tenderness (Glover et al., 1977), muscle fiber tenderness (Bowling et al., 1976), residual tenderness (Glover et al., 1977), and less detectable connective tissue (Bowling et al., 1976, Savell et al., 1977).

Seideman et al. (1977) stated that mechanically tenderized cuts which have relatively high amounts of connective tissue may not necessarily be used interchangeably with non-tenderized cuts which are low in connective tissue because of other effects of mechanical tenderization on sensory properties. Juiciness scores decreased significantly with mechanical tenderization (Glover et al., 1977; Savell et al., 1977) or tended to be less juicy than non-tenderized controls (Bowling et al., 1976; Davis et al., 1977). Savell et al. (1977) found increased mealiness scores for LD muscle samples tenderized with either one or two passes through a mechanical tenderizer; but blade tenderization did not affect overall palatability ratings which agreed with Bowling et al. (1976) and Davis et al. (1977). Flavor was not generally affected by mechanical tenderization (Davis et al., 1977).

There are conflicting reports on other beneficial or detrimental effects of mechanical tenderization. Decreased cooking times for mechanical tenderized meat were reported by Goldner et al. (1974); Schwartz and Mandigo (1974); Goldner and Mandigo (1974); and Glover et al. (1977); whereas others have noted little or no effect on cooking time (Bowling et al., 1976; Seideman et al., 1977; Tatum et al., 1978). Total cooking losses significantly increased in mechanically tenderized meat (Davis et al., 1975). However, Goldner et al. (1974); Schwartz and Mandigo (1974); Savell et al. (1977); Davis et al. (1977); Glover et al. (1977); and Tatum et al. (1978) reported non-significant differences for total cooking losses of non-tenderized and tenderized cuts. Drip losses were higher for mechanical tenderized meat (Glover et al., 1977) but no differences in drip loss were reported by Schwartz and Mandigo (1974); Savell et al. (1977); and Tatum et al. (1978). Thaw losses increased significantly with mechanical tenderization (Goldner et al., 1974) but were not different in the work of Schwartz and Mandigo (1974) and Seideman et al. (1977).

Mechanical tenderization reduced the variation of tenderness of rehydrated, grilled, freeze-dried beef steaks (Hinnergardt et al., 1975). Mechanical tenderization accounted for 69% of the variance in tenderness components by Allo-Kramer shear press analysis and 40% as measured by a taste panel.

The number of mechanical tenderizer repetitions needed to produce acceptably tender meat has been studied. Schwartz and Mandigo (1974) studied three mechanical tenderizer conveyor speeds, 2.54, 3.81, and 7.62 cm per movement. Conveyor speed did not affect Warner-Bratzler values. Lower, but not necessarily significant, Warner-Bratzler values were generally observed in BF, SM, and LD muscles of beef from steer, cow, and bull carcasses with each additional pass through the mechanical tenderizer (Tatum et al., 1978). Savell et al. (1977) found that one pass through a mechanical tenderizer reduced Warner-Bratzler values in samples from GM, SM, and LD muscles. Two passes through the tenderizer reduced Warner-Bratzler values in SM and BF muscle samples. A third pass reduced Warner-Bratzler values in the BF with concurrent increases in cooking loss. Thus, initially tender cuts can be tenderized with one pass through a mechanical tenderizer, whereas less tender cuts may require more than one pass through the tenderizer (Bowling et al., 1976). Miller (1975) states that USDA Choice top butts are usually blade tenderized one time. However, Choice and Good grade bottom butt cuts are usually blade tenderized twice or more before steaking. Furthermore, Miller (1975) indicates that round cuts, chuck rolls, and clods also require multiple passes to be acceptable for steaks. More research is needed to determine the optimum number of tenderizer passes or the number of penetrations per unit area of meat required.

The potential for mechanical tenderization to increase tenderness of meat from older animals to that of youthful beef has been studied. Tatum et al. (1978) found that according to Warner-Bratzler values, mechanically tenderized BF and SM muscles from C and D maturity bulls or Utility grade cows could not be made as tender as muscles from Choice and Good grade steer carcasses. Warner-Bratzler values of mechanically tenderized LD muscles from bulls and cows were as low as for LD steaks from steers; but, taste panel tenderness results indicated only bull LD steaks were as tender as the steers. Overall palatibility scores (flavor, juiciness, tenderness) for tenderized steaks were not as high for bull and cow muscles compared with non-tenderized steer muscles.

Nutritional Regime and Time on Feed Effects on Objective and Subjective Mean Characteristics

The current fluctuation in feed grain prices compounded with the influx of cheap foreign beef has demanded that research focus on producing beef economically with continued consumer acceptance. Cattle must yield a high percent of high demand, tender, flavorful, juicy, retail cuts, with only minimum fat trim (Guenther et al., 1965). High feed costs are reflected in high beef prices, and the deposition of fat is greatly influenced by feeding and management practices (Moody et al., 1970). This suggests beef production with some combination of shorter times on feed, lower energy rations and greater roughage utilization, including grass pasture. However, type of feed and length of finishing time influence product palatability (Allen et al., 1977).

Effects on Subjective Evaluations

The effect of nutritional regime on palatability has been widely researched. Wanderstock and Miller (1948) reported that roasts from yearling steers grazed on pasture only were significantly poorer in palatability and in overall appearance than those fed concentrate rations. Jacobson and Fenton (1956) found that as nutritional level increased for Holstein dairy cattle, the fat content, flavor, and tenderness of the cooked LD muscle increased. Differences in tenderness, juiciness, and flavor become more apparent with wider differences in degree of finish and carcass grade (Simone et al., 1958). Their taste panel consistently and significantly assigned more desirable quality scores to meat from carcasses showing the most intramuscular fat. Flavor also appeared to be related to intramuscular fat. Graham et al. (1959) also noted increases in taste panel juiciness and tenderness scores as nutritional level increased from a maintenance ration to a fattening ration. However, if these animals were placed on pasture after concentrate feeding, previous nutritional effects were reduced.

When comparing steaks from grass-fed, short-fed (70 days on concentrate) and long-fed (150 days on concentrate) cattle, Kropf et al. (1975) stated that taste panels scored flavor, tenderness, and over-all acceptability highest for steaks from long-fed cattle, intermediate for short-fed, and lowest for steaks from the grass-fed cattle. In addition, steaks from long-fed groups were juicier than the short- and grass-fed groups. However, no differences in juiciness were found for steaks from short-fed and grass-fed cattle. Allen et al. (1977) presented similar results, reporting that juiciness, tenderness, flavor and overall acceptability increased for steaks from grass-fed to short-fed (grass plus 49 days on 80% concentrate and 20% corn silage) to long-fed (grass plus 98 days on 80% concentrate and 20% corn silage) groups. They stated that beef from cattle fed only grass was not evaluated as undesirable, but was usually less juicy, tender, flavorful and acceptable than meat from silage-fed (grass plus 98 days on 60% corn silage and 40% concentrate) or long-fed cattle. Furthermore, samples from short-fed cattle were frequently comparable in juiciness, tenderness, flavor, and acceptability to those from silage-fed and long-fed cattle. Their results indicated that cattle fed approximately 100 days will yield a product of desirable juiciness, tenderness, and flavor.

Animal age limits the increase in subjective tenderness associated with nutritional regime. Zinn et al. (1963) found that LD muscle from steers and heifers fed identical growing-fattening rations were more tender after 150 days compared with controls slaughtered at 0 days in the test. However, with 270 days of feeding, no significant differences were observed between treatment and control groups. The 6-7-8 rib section from cattle fed 56 days on a high silage ration was more desirable in flavor, juiciness, and overall satisfaction than those from cattle fed 28 and 112 days (Moody et al., 1970). In addition, intramuscular fat increased with time, but it was not significant between 84 and 112 days on feed.

Effects on Objective Evaluations

Warner-Bratzler values were not significantly related to low, medium, and high nutritional levels in raw or cooked meat from Holstein dairy cattle (Jacobson and Fenton, 1956). Prior et al. (1977) found that varying dietary energy levels in large and small type cattle fed to specific weight endpoints producing constant carcass compositions, had little effect on Warner-Bratzler values. Similarly, mean Warner-Bratzler values reported by Allen et al. (1977) did not differ between steaks from grass-fed, short-fed (grass plus 49 days 80% concentrate and 20% corn silage), long-fed (grass plus 98 days 80% concentrate and 20% corn silage), and silage-fed (grass plus 60% corn silage and 40% concentrate) cattle. Conversely, Graham et al. (1959) reported that Warner-Bratzler values decreased as a maintenance ration changed to a fattening ration in steers. Correspondingly, lower Warner-Bratzler values were found for steaks from long-fed (150 days on concentrate) and short-fed (70 days on concentrate) beef steaks versus those from grass-fed beef steaks (Kropf et al., 1975). Similarly, Shinn et al. (1976) found a decrease in Warner-Bratzler values for steaks from cattle fed high energy rations for 56 or 112 days following pasture compared with pasture-fed cattle.

Warner-Bratzler values are also influenced by days on feed. Zinn et al. (1970) obtained Warner-Bratzler values from triceps brachii (TB), LD, and SM muscles from cattle slaughtered at 30 day intervals over a 270 day feeding period. Warner-Bratzler values for the three muscles generally were lowest for steaks from cattle fed 150 and 180 days than at all other slaughter periods. They stated that the first 180 days on feed benefited tenderness, but after this period animal age appeared to exert a greater influence on tenderness than did nutrition. However, tenderness in the three muscles responded differently to time on feed. The TB was more tender than the LD at 0, 60, 90, 120, 240, and 270 days. The SM was more tender than the LD at 60, 90, and 120 days. The LD was the most tender muscle at 150, 180, and 210 days.

Leander et al. (1977) noted no differences in Warner-Bratzler values between steers and heifers fed fescue grass and those fed a high concentrate ration for 56 days. But, Warner-Bratzler values were lower for those fed high concentrate ration for 112 days after grazing compared with the grass group.

Total cooking losses varied slightly between roasts from yearling steers on pasture, grain-on-pasture, grain-after-pasture, or grain-in-dry lot (Wanderstock and Miller, 1948). Similarly, the percent total, drip, and evaporative losses during cooking were not significantly related to low, medium, or high nutritional levels in Holstein dairy cattle (Jacobson and Fenton, 1956). Kropf et al. (1978) stated that total cooking-loss percentages from boneless top loin steaks prepared by modified broiling did not differ between short-fed (70 days concentrate) and long-fed (150 days concentrate) cattle, but about 1% more was lost by steaks from grass-fed cattle.

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Chapter III

BLADE TENDERIZATION EFFECTS ON LONGISSIMUS SENSORY AND INSTRON OBJECTIVE TEXTURAL MEASUREMENTS

INTRODUCTION

Mechanical blade tenderization is one of the newer and most widely applied mechanical methods of meat tenderization (Miller, 1975). Miller (1975) stated four justifications for using mechanical tenderization: (1) it insures acceptable tenderness of normal table-grade cuts; (2) it equalizes tenderness in portioned items containing two or more muscles of differing tenderness; (3) it upgrades cuts not previously utilized for steaking without enzymatic tenderization; and (4) blade tenderization is more uniform and more easily controlled than enzyme treatments which require more floor space and clean-up.

Mechanically tenderized meat had higher sensory panel scores for overall tenderness (Hinnergardt et al., 1975; Davis, et al., 1977; Savell et al., 1977), initial tenderness (Glover et al., 1977), muscle fiber tenderness (Bowling et al., 1976), residual tenderness (Glover et al., 1977), and less detectable connective tissue (Bowling et al., 1976; Savell et al., 1977) than non-tenderized meat. Flavor scores are not generally affected by mechanical tenderization (Davis et al., 1977); however, juiciness scores tend to decrease with mechanical tenderization (Glover et al., 1977; Savell et al., 1977; Bowling et al., 1976; Davis et al., 1977). Total cooking losses significantly increased in mechanically tenderized meat (Davis et al., 1975); however, Goldner et al. (1974), Davis et al. (1977), Glover et al. (1977), and Tatum et al. (1978) reported no significant differences in cooking losses.

Generally, blade tenderization significantly reduces Warner-Bratzler values in cooked meat (Goldner et al., 1974); Goldner and Mandigo, 1974; Schwartz and Mandigo, 1974; Davis et al., 1975; Glover et al., 1977; Tatum et al., 1978). But, the Warner-Bratzler apparatus may overestimate tenderness differences by following fracture planes created by the tenderizer blades (Bowling et al., 1976). The use of several objective tests, which measure different structural parameters of meat (Harris, 1976) might alleviate some problems associated with using a single test to predict tenderness, particularily in blade tenderized meat. Force deformation curve analyses of Warner-Bratzler tests (Pool and Klose, 1969; Bouton et al., 1975a), compression tests (Friedman et al., 1963; Bouton et al., 1971; Bouton and Harris, 1972a; Bouton and Harris, 1972b), and adhesion measurements (Bouton and Harris, 1972a; Bouton and Harris, 1972b) show promise as objective texture predictors.

Beef production must be done economically. Animal production systems involving combinations of shorter times of high concentrate feeding, lower energy rations, and greater roughage utilization should help reduce feeding costs. However, type of feed and length of finishing time may influence product palatability (Allen et al., 1977). Generally, animals fed low nutritional levels have poorer palatability and over-all appearance scores than those fed concentrate rations (Wanderstock and Miller, 1948; Jacobson and Fenton, 1956; Simone et al., 1958; Graham, 1959; Kropf et al., 1975; Allen et al., 1977). However, results with objective measures are less conclusive. Warner-Bratzler values have not been related to dietary energy levels (Jacobson and Fenton, 1956; Prior et al., 1977; Allen et al., 1977), or they have decreased as nutritional level increased (Graham et al., 1959; Kropf et al., 1975; Shinn et al., 1976). Little work has been done to study the effects of blade tenderization on meat from animals fed on different nutritional regimes.

The purpose of this research was to study the effects of mechanical blade tenderization on meat from animals fed rations differing in energy levels and feeding times, and to assess numerous Instron objective measurements for detecting textural changes.

MATERIALS AND METHODS

Source of Materials

One hundred twelve Angus yearling steers of similar background were randomly assigned to 14 nutritional regimes (Table 1) after a 21-day adjustment feeding period. A control group

Table 1 - Nutritional Regimes

(8 cattle/treatment)

Treatment #	Nutritional Level	Days on Feed
1	Control	0
2	Submaintenance[a]	28
3	Low Energy[b]	56
4	Medium Energy[b]	56
5	High Energy[b]	56
6	Low Energy	91
7	Medium Energy	91
8	High Energy	91
9	Low Energy	119
10	Medium Energy	119
11	High Energy	119
12	Medium Energy	147
13	High Energy	147
14	High Energy	175

[a]Cattle expected to loose 0.5 kg/day.

[b]Low, medium, high energy rations calculated to contain 0.77, 1.0, and 1.3 Mcal/kg feed on NEp basis, respectfully.

was slaughtered after the initial adjustment period and a sub-maintenance group, expected to lose about 0.5 kg body weight/day, was fed prairie hay for 28 days and slaughtered. Additionally, eight animals were assigned to one of 12 treatments consisting of low (0.77 Mcal NEp/kg feed), medium (1.0 Mcal NEp/kg feed), and high (1.3 Mcal NEp/kg feed) energy rations. These rations were designed to produce gains of about 0.5, 1.0, and 1.5 kg/day, respectively, for low-, medium-, and high-energy rations. Cattle in each energy level were group fed, and were preassigned for slaughter after 56, 91, 119, 147, or 175 days on feed.

Cattle were withheld from feed 18 to 24 hrs. before slaughter in a commercial packing plant. Wholesale ribs from the right sides of all animals were transported to the Kansas State University Meat Laboratory for fabrication.

Treatments and Sample Locations

The longissimus dorsi (LD) muscle was removed from each rib 7 days postmortum and immediately fabricated into steaks. Three 2.5 cm thick steaks were removed: (1) a histological steak from the 12th rib area; (2) a taste panel steak; and (3) an objective textural analysis steak, both removed alongside the 10th rib area. The remainder of the muscle was mechanically tenderized with one pass through a Ross, Model TC-700, mechanical blade tenderizer which produced 32 punctures/in^2. Two more steaks 2.5 cm thick were removed after tenderization from the 9th rib area for taste panel and objective textural analyses. All steaks were wrapped in freezer paper, frozen, and stored at -26°C until analyzed.

Taste Panel

Steaks for taste panel analysis were thawed at 2°C overnight, and modified oven broiled (Harrison, 1975) in a rotary gas oven at 177°C to an internal temperature of 66°C. Endpoint temperature was monitored using a glass thermometer in the geometric center of each steak.

Connective tissue amount, myofibrillar tenderness, overall tenderness, juiciness, and flavor intensity were evaluated by a six-member laboratory panel using an eight point scale (1 = abundant connective tissue, extremely tough, dry, or bland flavor; 8 = no connective tissue residue, extremely tender, juicy, or intense flavor) for each factor. Panelists were screened, trained, and tested using recommendations of AMSA (1978).

Six cores 1.27 cm in diameter were removed from each cooked steak with a drill press unit. Panelists, seated at random in individual booths, were served one core, and instructed to chew, but not swallow, the evaluated samples and rinse their mouths with water between samples. Samples were randomly presented, and no more than two panels were held per day. A "warm-up" LD sample, prepared in the same manner as the test steaks, was served first to each panelist.

Objective Textural Analyses

Steaks for objective measurements were cooked in the same manner as taste panel steaks. Warner-Bratzler and adhesion measurements were done on all steaks and compression measurements were done only on steaks from the control, submaintenance, and high-energy groups fed 56, 119, and 175 days.

Three cores 1.27 cm in diameter were removed near the subcutaneous edge of each steak (Figure 1) with a drill press unit. Steaks were squared-up by removing the rounded edges of the LD muscle. Three serial adhesion samples, 0.67 cm thick and 1.00 cm wide, were cut using a plexiglass jig so that the muscle fibers were aligned essentially perpendicular to the sample length. Compression samples, 1.0 cm wide, were removed with the muscle fibers aligned perpendicularly to the sample length. All samples were kept warm in small, covered beakers placed in a 45°C water bath.

All objective measurements were made using an Instron, Model 1123, equipped with a 500 kg load cell, strip chart recorder, and an integrator.

Warner-Bratzler Measurements: Textural measurements for the 1.27 cm diameter cores were made using an Instron Warner-Bratzler attachment (tension mode). A blade, with a blunt edged triangular hole containing the sample, was pulled past a blade guide at the rate of 250 mm/min. Force-deformation curves were recorded with a load scale setting of 0-5 kg and a strip chart recorder speed of 1250 mm/min. Integrator

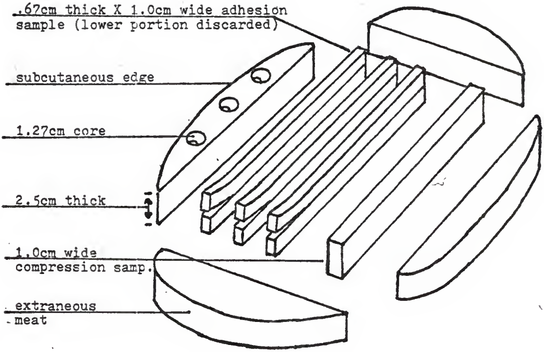

Figure 1 - Sample locations of longissimus dorsi muscle strips and cores used for objective measurements

values were recorded following each test for calculation of total work done. Distance measurements were made from the end of the test. Each core was cut twice resulting in six repetitions per steak.

<u>Compression Measurements</u>: Compression measurements were performed on samples cut 1.0 X 2.5 cm. A 0.67 cm diameter flat ended rod was driven 0.80 cm into the 1.0 cm thick samples at the rate of 50 mm/min. Fibers were aligned perpendicular to the rod travel. The rod was withdrawn, then driven to the same depth into the damaged area. A force-deformation curve was recorded for both compression cycles with the strip chart recorder operating at 100 mm/min. and a load scale setting of 0-5 kg. Integrator values were recorded for each penetration. Distance measurements were made from the point where the force-deformation curve left the base line. Three compression tests were run per steak.

<u>Adhesion Measurements</u>: Samples 0.67 cm thick X 1.00 cm wide were placed in hand operated grips and pulled apart at the rate of 200 mm/min. The force necessary to pull samples apart with the fibers aligned perpendicular to the strain were recorded with a load scale setting of 0-1 kg and a chart speed of 200 mm/min. Samples rupturing at the grips were disregarded. Two or 3 repetitions were obtained for each steak.

Parameters Measured From Force-Deformation Curves:

Instron-Warner-Bratzler (Figure 2A):

a. Initial Yield Force (IYF)

b. Second Peak Force (2PF)

c. Peak Force (PF)

d. Initial Yield Distance (IYD)

e. Second Yield Distance (2YD)

f. Peak Force Distance (PFD)

g. Initial Yield Angle (IYA)

h. Warner-Bratzler Work Done (WWBS): Area under the curve

i. Peak Force Minus Initial Yield Force (C-A)

Instron Compression (Figure2B):

a. Peak Force First Compression (PH1) - Hardness

b. Peak Force Second Compression (PH2)

c. Peak Force Distance First Compression (DP1)

d. Peak Force Distance Second Compression (DP2)

e. Work Done First Compression (WC1): Area under the 1st curve

f. Work Done Second Compression (WC2): Area under the 2nd curve

g. Cohesiveness (COHES): WC2/WC1

h. Chewiness (CHEWY): PH1 X WC2/WC1

Instron Adhesion (Figure 2C):

a. Peak Force (ADH)

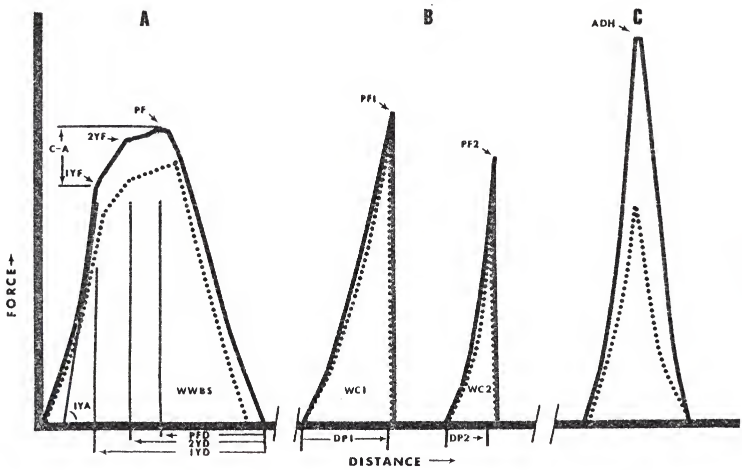

Figure 2 - Typical Instron force-deformation curves for: A. Warner-Bratzler; B. Compression; and C. Adhesion. Illustrates various parameters measured and relationships between non-tenderized (▬▬) and blade tenderized (••••••) steaks.

Cooking Loss: Steaks used for textural measurements were blotted, and weighed before cooking. After cooking, steaks were reweighed, and total cooking loss percentages were calculated.

Statistical Analysis

Experimental design was completely random in assigning animals to treatments. Data were analyzed using analysis of variance and resultant F-test (Snedecor and Cochran, 1973). Duncan's Multiple Range tests were used to separate treatment effects, and simple correlation coefficients were computed to compare textural measurements.

RESULTS AND DISCUSSION

Many sensory and objective measures were affected by blade tenderization (Table 2). Two tenderization by treatment interactions (sensory connective tissue scores and sample cross-sectional areas at second yield force) were significant ($P<0.05$). There were only two interactions for tenderization by ration, tenderization by time, or tenderization by ration by time on sensory or objective measures.

Effect of Tenderization

Sensory Measurements: Blade tenderized steaks were more tender ($P<0.0001$) and had less detectable connective tissue than non-tenderized steaks (Table 3). The interaction (Table 2) for detectable connective tissue indicated that non-tenderized

Table 2 - Analysis of variance for sensory and objective measures of longissimus steaks

Testing Method	Tenderization		Tenderization X Treatment		Tenderization X Ration		Tenderization X Time		Tenderization X Ration X Time	
	F Value	PR>F	F Value	PR>F	F Value	PR>F	F Value	PR>F	F Value	PR>F
Sensory[a]:										
Myofibrillar Tenderness, MFT	117.4	.0001	.9	.57	.2	.86	1.3	.28	.9	.48
Connective Tissue, CT	48.8	.0001	2.3	.01	1.4	.25	.4	.81	1.6	.17
Overall Tenderness, OT	143.1	.0001	1.0	.47	.8	.46	.7	.60	.9	.51
Flavor, FL	.2	.66	.8	.69	.4	.70	.8	.54	1.2	.30
Juiciness, JU	2.7	.11	1.3	.21	1.4	.24	1.5	.20	1.2	.31
Objective:										
Warner-Bratzler										
Initial Yield Force, IYF	31.7	.0001	1.2	.32	2.2	.11	1.3	.27	.8	.55
Second Yield Force, 2YF	29.5	.0001	.9	.54	1.6	.22	1.2	.31	.5	.75
Peak Force, PF	25.6	.0001	.8	.66	.9	.43	1.0	.40	.8	.55
Distance to IYF, IYD	4.7	.03	1.2	.27	.1	.96	.9	.45	2.0	.09
Distance to 2YF, 2YD	12.2	.0007	1.8	.06	.9	.41	1.7	.16	2.9	.02
Distance to PF, PFD	11.6	.001	.5	.91	.9	.40	.4	.80	.5	.78
PF minus IYF, C-A	.5	.50	.8	.65	.5	.62	.4	.84	1.3	.27
Initial Yield Angle, IYA	29.4	.0001	.6	.89	.6	.55	.7	.62	.4	.86
Cross-Sectional Area IYF, CSA IYF	4.0	.05	1.3	.25	.1	.96	.8	.50	2.0	.08
Cross-Sectional Area 2YF, CSA 2YF	11.4	.001	1.9	.04	.7	.50	1.5	.22	3.0	.01
Cross-Sectional Area PF, CSA PF	12.5	.0006	.5	.93	.6	.56	.4	.85	.5	.80
Total Work Done, WWBS	18.2	.0001	.9	.57	1.4	.26	1.1	.36	1.1	.34
Compression										
First Peak Height, PH1	2.1	.15	.3	.88			.4	.66		
Second Peak Height, PH2	2.2	.15	.6	.69			.6	.56		
Distance to PH1, DP1	.2	.66	.7	.57			1.0	.38		
Distance to PH2, DP2	3.3	.08	2.5	.06			1.0	.40		
Work First Compression, WC1	.2	.70	.2	.92			.3	.78		
Work Second Compression, WC2	.4	.52	.8	.54			.2	.85		
Chewiness, CHEWY	.1	.77	1.2	.32			.3	.77		
Cohesiveness, COHES	3.2	.08	1.2	.34			.1	.88		
Adhesion										
Peak Force, ADH	87.4	.0001	1.4	.16	1.7	.19	2.9	.03	1.5	.19
Total Cook Loss	25.4	.0001	1.5	.13	.2	.86	.9	.45	2.4	.04

[a]Scores based on 8 point scale (1 = abundant connective tissue, extremely tough, dry, or bland flavor; 8 = no connective tissue residue, extremely tender, juicy, or intense flavor) for each factor.

Table 3 - Sensory and objective means for non-tenderized and blade tenderized longissimus steaks

Testing Method	Non-Tenderized	Tenderized	Significance Level
Sensory[a]:			
Myofibrillar Tenderness, MFT	6.34	7.22	.0001
Connective Tissue, CT	7.00	7.23	.0001
Overall Tenderness, OT	6.78	7.19	.0001
Flavor, FL	6.46	6.48	.66
Juiciness, JU	6.07	6.18	.11
Objective:			
Warner-Bratzler			
Initial Yield Force, IYF (kg)	1.72	1.48	.0001
Second Yield Force, 2YF (kg)	1.96	1.72	.0001
Peak Force, PF (kg)	2.10	1.85	.0001
Distance to IYF, IYD (cm)	3.02	2.93	.03
Distance to 2YF, 2YD (cm)	2.56	2.41	.0007
Distance to PF, PFD (cm)	1.96	1.72	.001
PF minus IYF, C-A (kg)	.38	.37	.50
Initial Yield Angle, IYA (degrees)	78.1	75.8	.0001
Cross-Sectional Area IYF, CSA IYF (cm^2)	.214	.203	.05
Cross-Sectional Area 2YF, CSA 2YF (cm^2)	.155	.138	.001
Cross-Sectional Area PF, CSA PF (cm^2)	.097	.079	.0006
Total Work Done, WWBS (joules)	.16	.14	.0001
Compression			
First Peak Height, PH1 (kg)	2.21	2.10	.15
Second Peak Height, PH2 (kg)	1.89	1.79	.15
Distance to PH1, DP1 (cm)	1.71	1.70	.66
Distance to PH2, DP2 (cm)	1.00	.95	.08
Work First Compression, WC1 (joules)	.50	.49	.70
Work Second Compression, WC2 (joules)	.20	.19	.52
Chewiness, CHEWY	.87	.86	.77
Cohesiveness, COHES	.41	.40	.08
Adhesion			
Peak Force, ADH (kg)	.34	.19	.0001
Total Cook Loss (%)	21.05	23.18	.0001

[a]Scores based on 8 point scale (1 = abundant connective tissue, extremely tough, dry, or bland flavor; 8 = no connective tissue residue, extremely tender, juicy, or intense flavor) for each factor.

steaks from control and submaintenance cattle had more detectable connective tissue than non-tenderized steaks from fed cattle. However, following blade tenderization, detectable connective tissue in tenderized steaks from control and submaintenance cattle was reduced to that in tenderized steaks from fed cattle. This trend was small, but might be more obvious for muscles containing more connective tissue than the LD. Similar improvements in tenderness for blade tenderized meat were reported for initial tenderness (Glover et al., 1977), muscle fiber tenderness (Bowling et al., 1976), residual tenderness (Glover et al., 1977), and detectable connective tissue amounts (Bowling et al., 1976; Savell et al., 1977). Flavor and juiciness scores were not affected by blade tenderization (Table 3). Similar flavor and juiciness results were reported by Davis et al. (1977) and Hinnergardt et al. (1975), respectfully. However, Glover et al. (1977) and Savell et al. (1977) reported decreased juiciness scores for tenderized steaks.

Although few time on feed or ration effects for taste panel traits occurred, blade tenderization reduced the range of myofibrillar tenderness, connective tissue amount, and overall tenderness scores, especially in the control and submaintenance cattle group.

Instron Warner-Bratzler Values: Blade tenderization significantly reduced all Warner-Bratzler parameters except for differences between peak force and initial yield force (C-A)

(Table 3). Two significant ($P<0.01$) tenderization by time on feed by ration interactions occurred for peak force distance and for cross-sectional areas at second yield force (Table 2), but these interactions did not follow any consistent patterns. Ration and time on feed effects on textural assessments of non-tenderized meat will be published elsewhere (Burson et al., 1979).

Bouton et al. (1975a) found the initial yield force resulted from the compression and initiation of shear fracture planes through the myofibrillar structure and that differences between the initial yield force and the peak force (C-A) was an indication of connective tissue strength remaining after initial yield of the myofibrillar structure. Since all force measurements decreased with blade tenderization and C-A differences were nearly equal, a decrease in the structural strength of both the myofibrillar and connective tissue components occurred to the same degree. Taste panel scores (Table 3) for all tenderness traits corresponds with these objective assessments of tenderness.

Reduced distance values to each force inflection point (Figure 2A) and reduced cross-sectional sample areas at each of the rupture points (Table 3) indicate that the Warner-Bratzler blade traveled farther into the tenderized samples than the non-tenderized samples before it met a resistance due to myofibrillar or connective tissue components. Some decrease in the structural integrity of both the myofibrillar and connective tissue components of texture must have occurred with blade tenderization to allow increased blade travel into the sample with a smaller force requirement. Initial yield angles decreased in concert with lower initial yield force values in blade tenderized meat compared with non-tenderized meat. Since all force measurements decreased with blade tenderization, the total work needed to cut the sample also decreased. Typical Instron-Warner-Bratzler force-deformation curves for non-tenderized and tenderized meat are in Figure 2A.

Separate analyses of variance tests were performed on non-tenderized and tenderized data to determine the variation for objective tests for both non-tenderized and tenderized steaks. Standard deviations were reduced by blade tenderization for most of the objective tests, but less variation was especially evident in Instron-Warner-Bratzler peak force values. Hinnergardt et al. (1975) found that mechanical tenderization reduced tenderness variation of rehydrated, grilled, freeze-dried beef steaks when assessed by the Allo-Kramer shear press.

Instron-Compression Values: All compression measures decreased (Table 3) with blade tenderization, but only the distance to the second peak force and cohesiveness values approached significance (P=0.08). The lack of significance may have been due to the smaller sample size of compression measurements, or because only the LD muscle was used. Muscles with higher connective tissue content had greater compression differences

(Hunt, unpublished data). Bouton and Harris (1972a) found compression measurements depended both on fiber strength and adhesive strength between the fibers; but, connective tissue differences affected compression measures the most (Bouton and Harris, 1972b). Our compression data (although non-significant) agree with Warner-Bratzler and adhesion measurements indicating that the structural strength of both myofibrillar and connective tissue components were affected by blade tenderization. Reduced distance values (P=0.08) indicate that the rod penetrated farther into the sample before meeting resistance in tenderized meat. Mechanically tenderized meat had more structural damage and lacked the ability to "spring" back to original shape following initial compression (Figure 2B). Cohesive measurements tended to be lower (P=0.08) for mechanically tenderized meat than for non-tenderized meat. Chewiness values were not affected by blade tenderization and thus do not appear to be as good a compression measure for blade tenderized meat as cohesiveness.

<u>Instron Adhesion Values</u>: Adhesion peak force values were significantly lower for blade tenderized steaks (Table 3, Figure 2C) than non-tenderized steaks. Reduction in adhesion values corresponded with improved taste panel scores of tenderness traits for blade tenderized steaks. Adhesion measurements were more closely related to intramuscular connective tissue strength in non-tenderized meat than were myofibrillar factors (Bouton and Harris, 1972a). However, blade tenderization

appears to reduce connective tissue strength so that adhesion values become more affected by myofibrillar factors.

Total Cooking Loss: Total cooking loss was 2% higher (Table 3) in blade tenderized meat than non-tenderized steaks. Davis et al. (1975) found total cooking losses increased with blade tenderization. However, Goldner et al. (1974); Schwartz and Mandigo (1974); Savell et al. (1977); Davis et al. (1977); Glover et al. (1977); and Tatum et al. (1978) reported non-significant differences for total cooking losses of non-tenderized and tenderized cuts.

Objective and Sensory Correlations

Many parameters can be measured from force-deformation curves because of the Instron's technological flexibility. But, for parameters to be useful as tenderness predictors they should correlate with taste panel scores (Kapsalis, 1976; Larmond, 1976) and be sensitive to meat structural differences (Harris, 1976). Several force-deformation curve parameters do measure different meat structural components (Bouton and Harris, 1972b; Bouton et al., 1972; Bouton et al., 1975a; Bouton et al., 1975b) and correlate with taste panel analyses (Bouton et al., 1971; Bouton et al., 1975c).

Correlations between all objective measures for both non-tenderized and tenderized steaks are in Table 4. In general, correlations between parameters within each objective method (i.e. Warner-Bratzler with other Warner-Bratzler

Table 4 - Correlation coefficients among objective measures for both non-tenderized (NT) and blade tenderized (T) longissimus steaks

			Warner-Bratzler												Compression								
	Measure[d]		1YP	2YP	PP	1YD	2YD	PFD	IYA	CSA PP	CSA 2YP	CSA 1YP	C-A	WWBS	PH1	PH2	DP1	DP2	WC1	WC2	CHEW	COHES
Warner-Bratzler	2YP	NT	.98^c	—																		
		T	.98^c																			
	PP	NT	.90^c	.92^c	—																	
		T	.89^c	.93^c																		
	1YD	NT	-.04	-.00	-.03	—																
		T	.04	.08	.13																	
	2YD	NT	.09	.08	.04	.93^c	—															
		T	.13	.11	.11	.91^c																
	PFD	NT	.37^c	.37^c	.11	.55^c	.61^c	—														
		T	.33^c	.28^b	.00	.42^c	.57^c															
	IYA	NT	.79^c	.80^c	.75^c	.15	.25^b	.42^c	—													
		T	.81^c	.83^c	.77^c	.28^b	.34^b	.33^b														
	CSA PP	NT	.39^c	.40^c	.18	.57^c	.64^c	.97^c	.46^c	—												
		T	.36^c	.33^b	.10	.51^c	.63^c	.97^c	.39^c													
	CSA 2YP	NT	.09	.08	.05	.93^c	.99^c	.59^c	.25^b	.64^c	—											
		T	.14	.12	.13	.91^c	.99^c	.55^c	.35^b	.62^c												
	CSA 1YP	NT	-.03	.00	-.02	.99^c	.93^c	.54^c	.16	.57^c	.94^c	—										
		T	.04	.08	.14	.99^c	.90^c	.39^c	.29^b	.49^c	.91^c											
	C-A	NT	.01	.09	.44^c	.02	-.09	-.51^c	.10	-.41^c	-.08	.03	—									
		T	.00	.12	.46^c	.20^a	-.01	-.63^c	.11	-.50^c	.02	.23^a										
	WWBS	NT	.88^c	.89^c	.90^c	.23^a	.30^b	.29^b	.68^c	.33^b	.30^b	.24^a	.25^b	—								
		T	.85^c	.87^c	.89^c	.38^c	.37^c	.21^a	.74^c	.29^b	.38^c	.38^c	.29^b									
Compression	PH1	NT	.45^b	.39^a	.48^b	.03	.16	.09	.27	.08	.16	.02	.21	.49^b	—							
		T	.28	.26	.25	.07	.05	.12	.26	.11	.02	.05	.03	.31^a								
	PH2	NT	.45^b	.39^a	.50^b	-.01	.12	.06	.29	.06	.12	-.02	.28	.47^b	.98^c	—						
		T	.31^a	.28	.25	.04	.04	.19	.34^a	.16	.01	.02	-.04	.28	.96^c							
	DP1	NT	.04	.00	.09	.13	.21	.01	-.02	.00	.21	.12	.14	.13	.39^a	.33^a	—					
		T	.22	.22	.30	.16	.09	-.14	-.01	-.18	.06	.14	.26	.44^b	.20	.11						
	DP2	NT	-.04	-.00	.05	.29	.22	.08	-.03	.09	.23	.27	.20	.10	.11	.12	.61^c	—				
		T	-.08	-.10	-.01	.24	.22	-.09	-.35^a	-.14	.20	.23	.15	.27	-.15	-.23	.54^b					
	WC1	NT	.40^a	.33^a	.41^b	.20	.34^a	.16	.20	.15	.35^a	.19	.17	.51^b	.89^c	.82^c	.63	.30	—			
		T	.23	.20	.21	.13	.09	.06	.06	.02	.05	.10	.03	.39^a	.85^c	.75^c	.54^b	.21				
	WC2	NT	.35^a	.30	.42^b	.08	.23	.10	.22	.09	.23	.07	.28	.44^b	.83^c	.84^c	.48^b	.42^b	.83^c	—		
		T	.22	.20	.22	.09	.05	.06	.06	.03	.01	.06	.07	.42^b	.85^c	.79^c	.42^b	.31	.90^c			
	CHEWY	NT	.27	.25	.35^a	-.18	-.11	-.03	.26	-.04	-.11	-.20	.29	.23	.63^c	.73^c	-.04	.14	.34^a	.72^c	—	
		T	.22	.21	.21	-.05	-.05	.12	.29	.12	-.07	-.05	.06	.20	.76^c	.81^c	-.16	-.18	.41^b	.69^c		
	COHES	NT	-.16	-.10	-.09	-.24	-.31	-.12	.05	-.12	-.31^a	-.25	.11	-.25	-.37^a	.23	-.52^b	.00	-.58^c	-.08	.48^b	—
		T	-.10	-.07	-.06	-.21	-.19	-.05	.03	-.03	-.17	-.20	.06	-.20	-.49^b	.36^a	-.48^b	-.03	-.71^c	-.35^a	.18	
Adhesion	ADH	NT	.24^a	.21^a	.19^a	-.02	.06	.01	.20^a	.01	.06	-.03	-.04	.19	.52^b	.50^b	.28	.08	.52^b	.34^a	.12	-.45^b
		T	.05	.07	.03	-.00	-.08	.04	-.03	.05	-.07	-.00	-.04	.04	.22	.14	.02	-.06	.24	.21	.14	-.16

[a]$P<0.05$; [b]$P<0.01$; [c]$P<0.001$

[d]Abbreviations in table 2.

parameters) for non-tenderized and tenderized steaks were similar. However, correlations between Warner-Bratzler and adhesion or compression parameters were often different for non-tenderized and tenderized steaks. When significant correlations existed before tenderization between different objective testing methodologies, correlations following blade tenderization were often smaller and their significance level reduced. This may be due to the reduction in the variation of tenderness between the steaks which accompanies blade tenderization.

For non-tenderized steaks, adhesion was more highly correlated with compression measures than with Warner-Bratzler parameters. These correlations agree with results of Bouton and Harris (1972b) that adhesion and compression tests measure similar textural parameters. Highest correlations between adhesion and Warner-Bratzler values were for force measurements (IYF, 2YF, PF) and initial yield angle (IYA). Adhesion values were not highly correlated with Warner-Bratzler C-A values. Both of these parameters supposedly measure connective tissue (Bouton and Harris, 1972a; Bouton et al., 1975a); but, the low correlations may be due to the lack of large amounts of connective tissue in the LD muscle.

Correlations between selected objective measurements with sensory tenderness assessments are in Table 5. Correlations between objective and sensory measures were significant in many cases, but were relatively low. However, since the

Table 5 - Correlation coefficients between subjective and selected objective measures for non-tenderized (NT) and blade tenderized (T) longissimus steaks

Testing method[d]		Myofibrillar tenderness	Connective tissue	Overall tenderness
Warner-Bratzler:				
1YF	NT	-.41[c]	-.16	-.35[b]
	T	-.37[c]	-.35[c]	-.40[c]
2YF	NT	-.40[c]	-.16	-.33[b]
	T	-.37[c]	-.36[c]	-.40[c]
PF	NT	-.37[c]	-.21[a]	-.31[b]
	T	-.33[b]	-.37[c]	-.35[c]
1YA	NT	-.32[b]	-.10	-.30[b]
	T	-.22[a]	-.19[a]	-.22[a]
1YD	NT	.19[a]	.23[a]	.18
	T	.26[b]	.23[a]	.29[b]
2YD	NT	.11	.22[a]	.09
	T	.25[b]	.21[a]	.27[b]
PFD	NT	-.09	.20[a]	-.04
	T	.01	.10	.02
WWBS	NT	-.29[b]	-.13	-.25[b]
	T	-.21[a]	-.25[b]	-.22[b]
C-A	NT	.00	-.16	.00
	T	.00	-.12	.00
Compression:				
PH1	NT	-.21	-.19	-.24
	T	-.40[a]	-.23	-.33[a]
PH2	NT	-.28	-.28	-.33[a]
	T	-.41[b]	-.21	-.35[a]
CHEWY	NT	-.36[a]	-.39[a]	-.43[b]
	T	-.22	-.07	-.18
COHES	NT	-.21	-.26	-.24
	T	.28	.22	.25
Adhesion:				
ADH	NT	-.12	-.17	-.20[a]
	T	-.18	-.07	-.15

[a]$P<0.05$; [b]$P<0.01$; [c]$P<0.001$

[d]Abbreviations in table 2.

LD muscle is low in connective tissue, and since samples used contained a narrow tenderness range, 0.3 and 0.4 correlations between objective and sensory measures may be expected. Generally, Warner-Bratzler, compression, and adhesion force measurements were negatively correlated with sensory myofibrillar tenderness, connective tissue amount, and overall tenderness scores. Conversely, Warner-Bratzler distance measurements were positively correlated with sensory tenderness scores.

All three Warner-Bratzler force measures (IYF, 2YF, PF) correlated similarly with sensory myofibrillar tenderness and overall tenderness scores for both tenderized and non-tenderized samples. IYF and 2YF were more highly correlated with myofibrillar tenderness scores than to connective tissue or overall tenderness scores in non-tenderized samples. Bouton et al. (1975a) indicated that IYF may be a myofibrillar measure. However, following tenderization IYF and 2YF were equally correlated with all three sensory measures. PF was more highly correlated with sensory connective tissue scores for non-tenderized samples than were either IYF or 2YF. This trend was reduced with blade tenderization of the sample. Warner-Bratzler IYA and WWBS were more highly correlated with myofibrillar tenderness and overall tenderness before blade tenderization. However, following tenderization IYA and WWBS values correlated with all three sensory measures. C-A, a prospective connective tissue measure (Bouton et al., 1975a), failed to show any significant correlation with sensory measures.

Compression measures, which failed to show any major correlations with Warner-Bratzler or adhesion measures, also lacked significant correlations with sensory measures with exception of chewiness. Chewiness correlated ($P<0.05$) with all three sensory tenderness measures, but was most highly correlated with overall tenderness scores ($r = -.43$).

Adhesion, a probable connective tissue measure (Bouton and Harris, 1972a), was more correlated with overall tenderness scores than to either muscle fiber tenderness or connective tissue scores. This may have been due to the low connective tissue content of the LD muscle.

CONCLUSIONS

Blade tenderization significantly improved meat tenderness whether assessed by sensory panel or Instron objective textural measurements. Tenderness improvement was due to decreases in the structural strength of both the myofibrillar and connective tissue components. Blade tenderization had no affect on sensory panel juiciness and flavor scores; but, did increase total cooking loss.

Numerous Instron measures were highly correlated suggesting that several parameters could be eliminated. For testing the effects of blade tenderization on muscles low in connective tissue the measurement of Warner-Bratzler peak force, adhesion peak force, compression chewiness, and cohesiveness values may be sufficient for detecting meat textural differences. No interactions between blade tenderization and ration energy level or time on feed occurred except for cattle on very low planes of nutrition. Correlations between sensory panel and Instron textural measures were significant but low. More work is needed with muscles differing in tenderness because of myofibrillar and/or connective tissue factors before definitive conclusions can be extrapolated to other muscles.

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APPENDICES

APPENDIX A
PALATABILITY SCORE SHEET

Panelist's Name: ____________________ Date: ____________

Sample	Muscle Fiber Tenderness	Amount of Connective Tissue	Overall Tenderness	Juiciness	Flavor Intensity
1					
2					
3					
4					
5					
6					
7					

8. Extremely Tender	8. None	8. Extremely Tender	8. Extremely Juicy	8. Extremely Intense
7. Very Tender	7. Practically None	7. Very Tender	7. Very Juicy	7. Very Intense
6. Moderately Tender	6. Traces	6. Moderately Tender	6. Moderately Juicy	6. Moderately Intense
5. Slightly Tender	5. Slight	5. Slightly Tender	5. Slightly Juicy	5. Slightly Intense
4. Slightly Tough	4. Moderate	4. Slightly Tough	4. Slightly Dry	4. Slightly Bland
3. Moderately Tough	3. Slightly Abundant	3. Moderately Tough	3. Moderately Dry	3. Moderately Bland
2. Very Tough	2. Moderately Abundant	2. Very Tough	2. Very Dry	2. Very Bland
1. Extremely Tough	1. Abundant	1. Extremely Tough	1. Extremely Dry	1. Extremely Bland

APPENDIX B

DETERMINATION OF CROSS-SECTIONAL AREA OF SAMPLE IN WARNER-BRATZLER SHEAR AT PEAK RUPTURE FORCE

Reference: P. W. Voisey and E. Larmond. 1974. Examination of factors affecting performance of the Warner-Bratzler Meat Shear Test. J. Inst. Can. Sci. Technol. Aliment. 7:243.

Theory: As the blade is pulled through the slot, the meat core is deformed to the shape of the triangle of the blade. As the blade continues to be pulled through the slot, the meat core changes cross-sectional area because the remaining blade triangle becomes smaller. Area of the meat core at the point of peak force can be determined and used to report values of kg force per cm^2 area which is a more standard measurement than just peak force.

Blade Dimensions: Equilateral triangle, distance from top edge to bottom point is 4.00 cm.

Formula Development:

1. Height (h) of triangle

   Height of triangle is distance from center of top side to bottom point

   a. Triangle height at start of test is 3.00 cm. (See note 1 below for apparatus set-up)

   b. Measure distance traveled by crosshead by the following:

      (1) Measure distance in mm the pen has traveled on the chart from the end of the test to the peak rupture force and convert to cm.

(2) Divide the distance by the magnification ratio (MR).

$$MR = \frac{\text{chart speed}}{\text{crosshead speed}}$$

2. Triangle side length (ℓ)

a. Formula: $h = \frac{\ell}{2 \cot}$

h = triangle height (cm)

ℓ = triangle side length (cm)

α = triangle angle (angle is fixed at 60^{o})

b. $\cot 60^{o} = 0.57735$, $2 \cot 60^{o} = 1.1547$

$h = \ell - 1.1547$

$\ell = h \times 1.1547$

c. Substitute h from formula (1a) in equation (2b) to get triangle side length

3. Area of meat sample at peak rupture force

a. Area of equilateral triangle

$A = 0.43301\ \ell^2$

A = area in cm^2

ℓ = length of triangle side from equation (2c)

4. Short-cut to determine area of meat sample at peak rupture force

a. Height of triangle at peak rupture force from equation 1a

b. Combination of equations (2b) and (3a)

$A = 0.43301\ \ell^2$

$\ell = h \times 1.1547$

gives $A = 0.43301\ (1.1547\ h)^2$

combined gives $A = 0.577346\ h^2$

c. Substitute h from equation 1a in equation (4a). This yields cross-sectional area of meat sample at peak rupture force by using measurement from Instron chart.

5. Rupture force per unit area

Divide peak rupture force (kg) by cross-sectional area (cm^2) of meat sample.

Note 1.

Apparatus Set-up: Set Warner-Bratzler shear apparatus onto Instron. Set top of shear blade (horizontal side) flush with bottom of slot. Move crosshead 10 mm up and set gauge length at 000.0. Blade triangle height should be 3.00 cm from bottom point to the bottom of the slot. This setting must be made carefully and accurately.

APPENDIX C

COMPONENTS OF RATIONS (% ON AS-FED BASIS) USED TO STUDY ENERGY LEVELS AND LENGTH OF TIME ON FEED

Ingredient	Internat'l ref. no.	Energy level[a]		
		Low	Medium	High
Corn	4-02-931	17.9	27.1	38.6
Wheat	4-05-268	17.9	27.1	38.6
Sorghum silage	3-04-468	16.8	16.5	16.3
Prairie hay	1-07-956	42.9	24.2	---
Supplement[b]		4.6	5.0	6.4

[a]Calculated to contain 35, 45, and 58 megacal/100 lbs. on NEp basis.

[b]Included soybean meal, ground limestone, dicalcium phosphate, salt, trace minerals, and vitamins.

BLADE TENDERIZATION EFFECTS ON SUBJECTIVE AND INSTRON OBJECTIVE TEXTURAL MEASUREMENTS ON LONGISSIMUS STEAKS FROM CATTLE FED VARIOUS NUTRITIONAL REGIMES

by

LARRY HARLAND HAYWARD

B.A., Emporia State University
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Mechanical blade tenderization effects on longissimus (LD) ribeye steaks from animals fed rations differing in energy levels and feeding times were studied using Instron objective measurements and sensory evaluations for detecting textural changes. One hundred twelve yearling steers were randomly assigned to 14 nutritional regimes. Steaks were removed before tenderization and after one pass through a blade tenderizer.

Blade tenderization had little effect on textural differences due to ration energy level or time on feed. Sensory panel scores for myofibrillar and overall tenderness significantly increased, and detectable connective tissue amounts decreased with blade tenderization. Juiciness and flavor scores were not significantly affected by tenderization. Cooking loss increases 2% for blade tenderized steaks.

Blade tenderization significantly lowered Instron adhesion peak force and numerous Instron-Warner-Bratzler measurements (eg. initial yield force, peak force, initial yield angle, total work done and others). Instron compression values were reduced but not significantly. Adhesion values were more highly correlated with compression values than with Warner-Bratzler measures. Correlations between different parameters of the same objective test were high indicating that several parameters would not have to be measured. For testing the effects of blade tenderization on muscles low in connective tissue the measurement of Warner-Bratzler peak force, adhesion peak force, compression chewiness and cohesiveness may be sufficient. Correlations between objective and sensory measures of meat texture were significant but were relatively low.