EFFECTS OF AGE AT SLAUGHTER AND CARCASS TRAITS ON BEEF TENDERNESS VARIATION

By

BRANDON JOE BURTON

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Thesis Approved:

H Glen Dolezal Jr

Thesis Advisor

Donald R Gill

Thomas C. Collins

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

The desire of livestock producers and meat industries is to initiate ways of producing beef products that will maximize palatability at a lower cost to the consumer. According to work by Morgan et al. (1991), tenderness or meat texture is the single most important factor affecting palatability or the consumers perception of palatability. This raises questions about the possibility of producing beef through accelerated management programs with the idea of decreasing the variation in tenderness and maintaining maximum quality. The current quality grading standards for maturity assume that increases in maturity have adverse effects on palatability, especially tenderness. Several studies have examined these effects (Dunsing, 1959; Tuma et al., 1962, 1963; Romans et al., 1965; Berry et al., 1974; and Smith et al., 1982) and collectively found that tenderness is negatively associated with increases in maturity.

What in fact are the age related changes and their mode of action on palatability? Differences in tenderness among muscles occur as a result of the collective influence of actomyosin effects, background effects and bulk density or lubrication effects (Smith et al., 1973); of these, background effects are most closely associated with changes in physiological maturity. Berry et al. (1974) reported that decreased collagen content, increased percentages of soluble collagen and lower myofibril fragmentation were the specific background effects which were most closely associated with increases in tenderness of the beef longissimus muscle. Smith and Carpenter (1970) observed a significant, negative relationship between tenderness ratings and total collagen content in lamb; however, soluble collagen percentages were not consistently associated with tenderness. Cross et al. (1973) concluded that total concentrations of connective tissue components (collagen and elastin) were not closely related to scores for muscle fiber tenderness or ratings for amount of connective tissue, but that soluble collagen percentage was significantly related to the contribution of connective tissue to toughness, as assessed by a sensory panel. Moreover, Cross et al. (1973) found that chronological age was significantly related to percentages of soluble collagen in muscle. The present, two part study examined the effect of age at slaughter on beef carcass quality grade and tenderness traits. Of primary concern was the relationship of chronological age to the palatability attributes of beef from animals of widely differing maturities but of essentially the same fatness.

CHAPTER II

REVIEW OF LITERATURE

Factors Influencing USDA Beef Carcass Quality Grades

The purpose of the USDA beef quality grades is to indicate expected acceptability or palatability of meat after cooking and provide to consumers a reliable guide for identifying beef quality levels (Smith, 1980). Quality of lean for beef is evaluated by considering its marbling and firmness in a cut muscle surface in relation to the physiological maturity of the animal from which the carcass was produced (USDA, 1989).

Maturity

The current USDA grading system places the most emphasis on marbling and maturity in determining eventual quality grade. Estimates of physiological maturity are used to classify carcasses into five maturity groups (USDA, 1989). Physiological indicators of maturity include bone characteristics, ossification of cartilage at various carcass locations, and color and texture of the ribeye muscle. Cartilage ossifies (becomes bone) and bone whitens (becomes harder, flinty-like and white) with increasing age. Additionally, color of lean becomes darker due to accumulation of myoglobin and texture becomes coarser (muscle fibers increase in size) with age. The standards assume that increases in maturity have adverse effects on palatability, especially tenderness. The cartilage and bone characteristics receive greater emphasis in determining maturity than color and texture because the latter characteristics are affected to a greater extent by factors other than physiological age.

Beef carcass maturity is generally recognized as an important factor influencing the palatability of meat (Romans et al., 1965). Many researchers have indicated that the tenderness of bovine muscle decreases with increasing chronological age (Romans et al., 1965; Berry et al., 1974; Smith et al., 1982). Tuma and others (1962, 1963) found that tenderness and juiciness decrease with advancing maturity of beef cattle.

Smith et al., (1973) reported that differences in tenderness among muscles were the result of a collective influence of actomyosin effects, background effects and bulk density or lubrication effects; of these, background effects are most closely associated with changes in physiological maturity. Berry et al. (1974) reported that decreased collagen content, increased percentages of soluble collagen and lower myofibril fragmentation were the specific background effects which were most closely associated with increases in tenderness of the beef longissimus muscle. Cross et al. (1973) found that chronological age was significantly related to percentages of soluble collagen in muscle. McClain (1977) reported that the type and extent of cross-linking in intramuscular collagen are influenced by animal age.

Limited work has shown that increased time-on-feed is associated with increased carcass maturity; Tatum et al. (1980) found that carcasses from cattle fed 160 days had significantly higher ($P < .05$) values for maturity than did carcasses from cattle fed 100 or 130 days.

Dunsing (1959) reported that consumer preference panels consistently favored steaks from carcasses of younger cattle. Within carcasses from cattle greater than 30 months of age, federal grade standards compensate for the adverse effect of maturity on palatability by requiring a higher degree of marbling with advancing maturity for a given grade.

Marbling

Marbling, or intramuscular fat, is evaluated in terms of its appearance in the ribeye (longissimus dorsi) muscle as exposed between the 12th and 13th ribs; the degrees of marbling, (USDA, 1989), in order of descending quantity, are: abundant (AB), moderately abundant (MA), slightly abundant (SA), moderate (MD), modest (MT), small (SM), slight (SL), traces (TR), practically devoid (PD), and devoid (D). Currently, marbling score is the trait with the greatest effect on the USDA quality grades of youthful (< 42 mo at slaughter) beef carcasses. May et al. (1992) found that marbling score was the carcass grade trait most highly correlated with the palatability attributes. Smith et al. (1984) found small, but statistically significant differences in palatability (juiciness, tenderness, and flavor) as marbling was decreased from moderately abundant to practically devoid. Some researchers (Tuma et al., 1962; Breidenstein et al., 1968; Parrish et al., 1973a) have reported that marbling scores provide little assurance that beef will be palatable. Briskey and Bray (1964) concluded that marbling, at best, has only a low correlation with beef palatability. Smith and Carpenter (1974) concluded that marbling had low to moderate relationships with flavor, juiciness and tenderness of beef. Jeremiah et al. (1970) concluded that marbling was associated with 2 to 16% of the variability in flavor, juiciness, tenderness and overall palatability.

Blumer (1963) found that marbling explained about 5% of the variability in tenderness and about 16% of the variation in juiciness.

Muscle Firmness

For steer, heifer, and cow beef, quality of the lean is evaluated by considering a third aspect, lean firmness, as observed in a cut surface in relation to carcass evidences of maturity (USDA, 1989). For each grade, the firmness requirements are different for each maturity group, but, within each maturity group, the firmness requirements do not increase progressively with evidences of advancing maturity. Also, regardless of the extent to which marbling may exceed the minimum of a grade, a carcass must meet the minimum firmness requirements for its maturity to qualify for that grade. The minimum lean firmness requirement for U.S. Choice beef is slightly firm (USDA, 1989).

Quality Grade Trends

Wise (1992) constructed a quality grade consist of the graded steer and heifer slaughter by percentages (Table 1) over a five year period from fiscal year 1987 to fiscal year 1991. Wise (1992) also stated that the percent of graded beef which is Prime or Choice has decreased, while the amount of Select has increased. This is not surprising since the Good grade was renamed Select in November 1987 with the hope of increasing consumer perceptions for this type of beef.

Table 1. Quality Grade Consist (%) of USDA Graded Steer and Heifer Slaughter.

	Fiscal Year				
Grade	1987	1988	1989	1990	1991
Pr	3.1	3.1	2.7	2.2	2.1
Ch	94.6	93.2	87.9	83.0	79.6
Se	2.3	3.7	9.3	14.7	18.3
St	0.0	0.0	0.0	0.0	0.0

Factors Further Associated with Beef Tenderness Variation

Time on Feed

It has been suggested that time-on-feed, the period of time that an animal has been fed a high-energy diet prior to slaughter, is related to the tenderness of beef (Tatum et al., 1980; Burson et al., 1980; Aberle et al., 1981; Dolezal et al., 1982b). Collectively, data from those studies indicate that, for cattle fed a conventional high-energy finishing diet, a feeding period of a determinate length (about 100 days in several studies) is sufficient to assure the production of beef with desirable tenderness and overall palatability; in most of those studies the time-on-feed necessary to achieve "acceptable" palatability is shorter than that currently employed by most cattle feeders (130-200 days, depending on age and size of cattle). Early studies showed that increasing the time on feed improved taste panel tenderness (Kropf et al., 1975; Shinn et al., 1976; Harrison et al., 1978; Leander et al., 1978) and juiciness scores (Judge et al., 1978). Dolezal et al., (1982b) proposed that the length of time that cattle have been fed a high-energy diet ("time-on-feed") be used as an adjunct to or substitute for marbling (intramuscular fatness) for predicting cooked beef palatability. Adams et al. (1977) and Harrison et al. (1978) suggested that beef from cattle that have been fed a high-energy diet for a specified period of time will be acceptable in palatability regardless of marbling amounts or quality grades. Other researchers have reported that once cattle have been fed for a certain period of time on a high-concentrate diet, little additional benefit in ultimate cooked beef palatability is attained by extending the feeding period (Epley et al., 1968; Zinn et al., 1970; Campion et al., 1975; Tatum et al., 1980).

Plane of Nutrition

Jacobsen and Fenton (1956), Cover et al., (1957) and Smith et al. (1977) reported that beef palatability improved as diet energy density increased. The feeding of high energy diets generally increases both carcass weight and fatness (Bowling et al., 1977, 1978; Bidner et al., 1981,1986; Dolezal et al., 1982a,b; Tatum et al., 1982). Fatness has long been thought to be related to beef palatability. The mechanism by which fattening improved tenderness was partially clarified when Smith et al. (1976) found that increased thickness of subcutaneous fat on lamb caused carcasses to chill more slowly, increased enzyme activity, lessened sarcomere shortening and improved meat tenderness. Subsequent investigations have substantiated and partially characterized the relationship between tenderness and subcutaneous fat thickness in beef (Dutson et al., 1975; Bowling et al., 1977, 1978; Meyer et al., 1977; Lochner et al., 1980; Marsh and Lochner, 1981; Tatum et al., 1982). Research has generally shown that 6-10 mm of subcutaneous fat thickness is sufficient to retard the postmortem chilling process to assure that beef from young cattle will be tender.

Grass-finished cattle have less marbling and subcutaneous fat than do grain-fed cattle (Godbey et al., 1959; Klosterman et al., 1965; Kropf et al., 1975). Smith et al. (1974) suggested that increasing quantities of either subcutaneous fat or marbling may insulate muscle fibers and decrease cold shortening during postmortem chilling, and thus improve tenderness. Oltjen et al. (1971) also compared palatability traits of beef from forage-fed versus grain-fed steers slaughtered at similar weights. The forage-fed beef was superior in palatability to the grain-fed beef. Bowling et al. (1977) investigated the effects of preslaughter nutritional regimen (forage vs grain) on beef carcass traits and cooked beef palatability. In that study, cattle finished on grain produced the heaviest, fattest, most massive carcasses and the most tender steaks. In addition, grain-finished beef sustained less myofibrillar shortening during postmortem chilling (28.4% vs 17.2% sarcomere shortening for forage-finished and grain-finished beef, respectively). The authors attributed these differences in myofibrillar shortening and toughening to differences in postmortem temperature decline, resulting from differences in carcass weight and fatness, and demonstrated reduced sarcomere shortening and improved tenderness among the leaner, lighter forage-finished carcasses by exposing one side of each carcass to a higher temperature (27^{o}C) during the first few hours postmortem. Subsequent research (Schroeder, 1978) has documented the existence of relationships among preslaughter feeding regimen, rate of postmortem temperature decline and meat tenderness.

Dolezal et al. (1982a) and Riley et al. (1983) determined that subcutaneous fat thickness has a higher association with tenderness and juiciness than marbling. Furthermore, Dolezal et al. (1982a) stated that palatability improved as the 12th rib subcutaneous fat thickness increased from 2.5 mm to 7.6 mm. Dikeman et al. (1979) demonstrated that carcasses with less than .64 cm of fat thickness had significantly higher shear values and lower tenderness and flavor scores than carcasses with .64 to 2.54 cm of fat thickness. Little improvement in palatability has been observed once carcasses attain a minimum of 7.6 mm of fat (Dolezal et al., 1982a; Tatum et al., 1982; Riley et al., 1983). Subcutaneous fat thickness of at least 7.6 mm (Bowling et al., 1977; Dolezal et al., 1982a; Tatum et al., 1982; Crouse et al., 1984) and carcass weights in excess of 227 kg (Schupp et al., 1979) appear to sufficiently insulate the carcass thus preventing the rapid decline of postmortem muscle temperature and cold-induced toughening.

There is a limited amount of data to support a relationship between preslaughter feeding and the solubility of collagen in postmortem muscle. Wu et al. (1980) reported that beef from steers fed a high concentrate ration for 120 days prior to slaughter contained a higher percentage of soluble collagen than did beef from steers slaughtered directly off of pasture. Similar findings were reported by Aberle et al. (1981).

It has been shown that "accelerated" or "tailored" production systems (cattle fed high-energy diets beginning shortly after weaning and slaughtered younger than 15 mo) result in excellent meat palatability even though faster-growing, more muscular cattle types will not attain a high percentage of Choice carcasses at this young age (Dikeman et al., 1985a; 1985b). Cattle on the "accelerated" system had mostly high-slight marbling but were somewhat more tender than conventionally-fed Choice cattle.

Sex

Results from studies on the influence of sex and carcass quality grade on tenderness have disagreed. Some authors observed no significant difference in tenderness between steaks from bull and steer carcasses (Bailey et al., 1966; Champagne et al., 1969; Wierbicki et al., 1955), but Adams and Arthaud (1963) found that steaks from steers were significantly more tender than those from bulls. Field et al., (1966) reported no significant difference in the tenderness of beef produced by bulls and steers that were 300 to 399 days of age, but they found lower tenderness in bulls than steers at 500 to 699 days of age. Reagan et al. (1971) showed no significant difference in tenderness between steaks from bulls and steers slaughtered at 484 days of age, but observed lower tenderness of steaks from bulls than of those from steers at 385 days.

Tenderness differences between muscles from bulls and steers seem to be related to connective-tissue characteristics. Muscles from bulls have more total collagen than muscles from steers (Boccard et al., 1979; Griffin, 1983; Cross et al., 1984; Klastrup et al., 1984); but, no differences in total collagen have been reported (Prost et al., 1975b). The amount of heat soluble collagen was greater in bull than steer muscle in some studies (Cross et al., 1984; Klastrup et al., 1984), but it was not different or was dependent upon animal age in other studies (Boccard et al., 1979; Griffin, 1983). Burson et al. (1986) reported that the proportion of type I and III collagen does not relate well to tenderness differences between bull and steer longissimus muscles. Collagen characteristics, such as the extent and type of crosslinking and the fiber size (Light et al., 1985) for each collagen type, may play a role in tenderness differences between muscles from bulls and steers.

No difference in tenderness between bulls and heifers was found by Koger et al. (1960) and Zinn et al. (1970). Field et al. (1966) also found no difference for animals 300 to 399 days of age, but found that bulls were less tender at 500 to 699 days than steers or heifers. No difference between steaks from steers and those from heifers was found by Field et al. (1966) and Garcia et al. (1970). Kropf and Graf (1959) indicated, however, that steers were significantly tougher than heifers.

Breed Differences

In the early 1970's several breeds of cattle were introduced into North America. These germ plasm resources were used to increase growth rate and proportion of muscle to fat when compared with traditional British beef breeds. A few studies that have examined the effect of breed-type on the tenderness of beef (McKeith et al., 1985; Ramsey et al., 1963; Luckett et al., 1975) reveal that Zebu and Zebu X European breed-types have higher Warner-Bratzler shear values and/or lower sensory panel tenderness ratings than steaks from European breed-types. Kincaid (1962) showed that tenderness as measured by shear force decreased as the percent of Brahman blood increased in British-Brahman crosses. Klosterman et al. (1961) compared a limited number of Charolais, Herefords and their crosses and found little difference in tenderness. In a study by Totusek (1971) comparing Hereford and Angus calves, Angus carcasses graded less than one-third of a grade higher than the Herefords, which is a smaller difference than often reported by feedlot operators. The cattle represented by these data were young (12-14 months); perhaps with older cattle often fed in feedlots the Angus are fed longer than necessary.

As reported by Algeo and McLean (1993) data clearly demonstrates that carcass traits such as marbling, fat thickness, muscle score and carcass weight are all at least moderately heritable and differences exist both between and within breeds. Furthermore, Algeo and McLean (1993) reported that genetic strains within breeds known to produce less tender beef should be eliminated by rigorous selection as soon as possible.

Amount and Solubility of Collagen

Early work suggested that structural alterations in collagen may cause differences in meat tenderness (Goll et al., 1963). Berry et al. (1974) reported that decreased collagen content and increased percentages of soluble collagen were two specific background effects which were most closely associated with increases in tenderness of the beef longissimus muscle. Smith and Carpenter (1970) observed a significant, negative relationship between tenderness ratings and total collagen content in lamb; however, soluble collagen percentages were not consistently associated with tenderness. Cross et al. (1973) concluded that total concentrations of connective tissue components (collagen and elastin) were not closely related to scores for muscle fiber tenderness or ratings for amount of connective tissue, but that soluble collagen percentage was significantly related to the contribution of connective tissue to toughness, as assessed by a sensory panel. Moreover, Cross et al. (1973) found that chronological age was significantly related to percentages of soluble collagen in muscle. Reagan et al. (1976) reported that increased quantities of total collagen were associated with higher ($P < .05$) sensory panel ratings for juiciness and lower ($P < .05$) ratings for tenderness and amount of connective tissue; but total collagen content was not related to actual age of the animal. Furthermore, Reagan et al. (1976) noted that percentages of soluble collagen and shear force values were positively associated with chronological age of the animal.

Work by McClain (1977) reported that the type and extent of cross-linking in intramuscular collagen are influenced by animal age, and possibly by nutritional status of the animals. Corte (1977) reported an increase in salt- and acid-soluble collagen with increasing plane of nutrition and increased length of feeding. Salt-soluble collagen contains recently synthesized collagen, while the acid-soluble collagen fraction contains some of the younger collagen of the fibers, which are metabolically older than salt-soluble collagen (Bodwell and McClain, 1971). Wu et al. (1981) showed an increase in collagen solubility of the longissimus dorsi muscle from cattle fed a high energy diet. Furthermore, Wu et al. (1981) attributed this increase to an increase in the rate of collagen biosynthesis or a decrease in the rate of collagen cross-link formation after the animals were placed on the higher nutritional plane. Cross et al. (1982) found collagen content of muscle differed between bulls and steers at 12 months of age. Davis et al. (1979) studied the tenderness of beef quality grades and found that collagen amount and solubility were not very important in A-maturity beef.

The different genetic types of collagen may also play a role in tenderness. Types I and III are the predominate collagen types in skeletal muscle (Light and Champion, 1984), and more tender muscles may have a lower percentage of type III collagen than less-tender muscles (Bailey et al., 1979). However, Light et al. (1984, 1985) reported that the percentage of type III collagen in either the endomysium or perimysium of six different muscles was not related to tenderness.

<u>Muscle Variation</u>

Many studies have been made in order to determine the factors that are responsible for the tenderness or toughness of beef. According to very early work by Lehmann (1907) the mechanical strength of a muscle is directly proportional to the amount of connective tissue present; the muscles that are most active and therefore subject to the greatest strains have the largest amounts of connective tissue and are least tender. In today's market more steaks are being cut from the round and chuck. The steaks cut from the round and chuck suffer a setback in marketability when compared to steaks from the rib and loin due to variation in the palatability characteristics of the muscles. Work by Morgan et al. (1991) found shear force values indicated a high percentage of retail cuts from the chuck and round would have received overall tenderness rating scores of less than "slightly tender." Prost et al. (1975a) found the psoas major muscle was the most tender and the biceps femoris the least tender in a study of seven muscles from 180 bovine carcasses.

Individual muscles were shown to differ in content of connective tissue by Bendall, 1967; Doty and Pierce, 1961; and Ritchey and Hostetler, 1964. In findings of Prost et al. (1975b) the level of connective tissue was lowest in the psoas major and highest in the infraspinatus muscles. Furthermore, the muscles of the forequarter of the carcasses contained more connective tissue than those of the hindquarter.

Muscle Fiber Characteristics

The structure of striated muscle can be considered as a two component system: muscle fibers and intramuscular connective tissue. The muscle fibers are responsible for the contraction of the muscle, while the connective tissue network performs the function of both holding the muscle fibers together and attaching the muscle to the skeletal framework. It was once thought that the quantity and strength of the connective tissue determined the toughness of meat (Lehmann, 1907; Mitchell et al., 1926; Mackintosh et al., 1936). More recently, it has been demonstrated (Locker 1960; Locker and Hagyard, 1963; Marsh and Leet, 1966) that changes in myofibrillar structure in the period between slaughter and the full development of rigor mortis can greatly affect the tenderness of the resultant meat. This work has tended to focus most attention on the myofibrillar component as the main factor affecting tenderness and to relegate the role of connective tissue to that of background toughness. However, dimensional changes in the myofibrillar structure also produce concomitant changes in a connective tissue network as it accommodates these dimensional changes. It has been shown (Rowe, 1974) that as the muscle fiber contracts along its length, there is a concomitant increase in the angle between the collagen fibers of the network and the main axis of the muscle fiber. Consequently, Harris (1976) stated that any consideration of the mechanical behavior of such a two-component system must include the effect of strain on both and not just on one component.

A relationship between muscle fiber type and meat quality was proposed by Ashmore (1974), but, delineation of this supposed association has not yet been achieved. Early histological work on muscle fibers concentrated on factors influencing fiber diameter (Romans et al., 1965) and the relationship of fiber diameter to tenderness (Herring et al., 1965; Locker, 1960; Hiner et al., 1953; Tuma et al., 1962). Hunt and Hedrick (1977) stated that the purpose of histological characterization of muscle fibers is to evaluate metabolic potential; fiber type data presented as areas and ratios of one fiber type as compared to another could accomplish this goal.

May et al. (1977) were unable to find a strong relationship between fiber type and meat quality when evaluating Simmental, Limousin, and Hereford crossbred steers. However, Reddy (1970), as reported by May et al. (1977), found significant correlations between marbling, final quality grade and percent "white" fibers. Melton et al. (1974) reported correlation coefficients between red muscle fiber area and hot carcass weight, fat thickness, cutability grade and marbling score to be 0.64, 0.75, 0.67 and 0.49, respectively. Calkins et al. (1981) reported that white muscle fibers were negatively correlated to marbling and tenderness ratings while intermediate and red muscle fibers were positively correlated to these quality attributes.

Postmortem Aging

Bratzler (1971) and Korten (1972) reported that the tenderness of beef is influenced by a number of antemortem and postmortem factors; included among the postmortem factors they identified was the length of time and temperature of storage following slaughter. Smith et al. (1978) reported that aging of U.S. Choice beef carcasses for 11 days will optimize tenderness, flavor and overall palatability of the majority of the muscles in steaks and/or roasts from the major cuts of the carcass. A high muscle temperature postmortem accelerates the rate of pH decline in muscle (Busch et al., 1967), presumably because such physiological temperature conditions permit enzymatic activity to continue (Dutson, 1983). The increased meat tenderness of carcasses with thicker fat cover has been attributed to the delayed cooling of the insulated muscles (Lochner et al., 1980), which may increase proteolysis of muscle proteins (Yates et al., 1983). High-temperature (30 to 40°C) conditioning of muscles and carcasses also has been found to affect meat tenderness adversely (Koh et al., 1987). The extractability of muscle proteins appears to decrease with high postmortem muscle temperature (Babiker, 1985). Better understanding of the aging process would increase our ability to deal with meat of undesirable tenderness.

The increase in tenderness associated with postmortem aging of meat has been attributed to endogenous enzymes in muscle (Wilson, 1957), a loss of tensile strength of the myofibrillar component of the muscle cell (Davey and Gilbert, 1969) and to shortening of muscle fibers during slow vs rapid phases of rigor mortis (Davey et al., 1967).

Calkins and Seideman (1988) noted that there are several protease systems within muscle that could contribute to tenderness. Furthermore, the Ca-dependent proteases (CDP) require Ca and have a neutral pH optimum for activity. The calcium is made available during rigor mortis by its release from the sarcoplasmic reticulum. The lysosomal enzymes (primarily cathepsins) also may influence tenderness. These enzymes have acidic pH optima for activity. There has been disagreement about which of these systems is most important in determining the ultimate tenderness of meat (Marsh, 1983). The CDP system has been shown to have specific action on a variety of muscle proteins (Olson et al., 1977; Koohmaraie et al., 1986) and could function early postmortem when the pH is still high. The calpain proteolytic system consists of at least three components: 1) the form of the proteinase that is fully active at micromolar concentration of calcium (μ-calpain, also called CDP-I or calpain-I), 2) the form of the proteinase that is fully active at millimolar concentration of calcium (m-calpain, also called CDP-II or calpain-II), and 3) calpastatin, which inhibits the activity of both μ- and m-calpain at their respective calcium requirement (Koohmaraie, 1992). Koohmaraie (1988, 1992) has demonstrated that the calcium-dependent proteolytic system (calpain) is probably the major proteolytic system involved in postmortem proteolysis . By comparison, the cathepsins also have some activity toward muscle proteins but could function best when the pH has dropped closer to their optima for activity (Dutson and Lawrie, 1974).

Research suggests that factors affecting tenderness are influenced by breed type (Peacock et al., 1982; Williams et al., 1988). The lysosomal enzymes B + L showed an increase in activity as percentage of Angus breeding increased in a comparison between Angus and Angus x Brahman crossbred steers (Johnson et al., 1990). Furthermore, Johnson et al. (1990) stated that Angus steers appear to have factors that result in greater levels of endogenous enzyme activity than Angus x Brahman crossbred steers.

It has been clearly demonstrated that Z-disk degradation, which occurs in myofibrils during postmortem aging, results in myofibrils fragmenting into smaller segments (Takahashi et al., 1967; Davey and Gilbert, 1969; Henderson et al., 1970; Olson et al., 1976) and that fragmentation of myofibrils is related to increased tenderness (Moller et al., 1973; Parrish et al., 1973b; Olson et al., 1976). Hay et al. (1973) have shown that a 30,000-dalton component occurs during the postmortem storage of chicken muscle.

A study by Locker (1960) showed a close association between muscle shortening (or contraction) and meat tenderness. Marsh and Leet (1966) determined that decreasing muscle length up to 20 percent of the muscle's original excised length did not affect tenderness; however, muscle toughness increased rapidly with continued shortening up to 40 percent. Furthermore, shortening beyond 40 percent caused decreased toughening. Through the use of cow sternomandibularis muscle, Locker and Hagyard (1963) demonstrated the effect of temperature on muscle shortening. Minimal muscle shortening (less than 10 percent) occurred in the temperature range of 14-19°C while muscles exposed to 0°C shortened to 47.7 percent of their original length. Research has indicated that if muscle pH is not below approximately 6.0 before muscle temperature reaches 10 to 12°C (or lower), cold-induced shortening may result (Lochner et al., 1980). Furthermore, Lochner (1980) found that early postmortem temperature (2 hr) was most highly correlated with tenderness values. Within well finished beef carcasses, cold-induced toughening does not appear to be the major factor in determining cooked beef tenderness.

CHAPTER III

EFFECT OF AGE AT SLAUGHTER ON CARCASS QUALITY GRADE AND SHEAR FORCE TRAITS

Abstract

Steers (n = 140) of predominantly Angus heritage were randomly allocated among five chronological age treatment groups: EW = early weaned directly to the feedlot at 3.5 mo of age, NW = normally weaned and placed in the feedlot at 7.9 mo, WP = backgrounded on wheat pasture for 112 d then placed in the feedlot at 11.6 mo, SG = dry wintered and then grazed on early, intensively managed native range for 68 d prior to feedlot placement at 15.4 mo, LG = dry wintered and season long grazed on native range for 122 d prior to feedlot placement at 17.4 mo of age. Steers were slaughtered after reaching a pen mean of 1.4 cm of s.c. fat thickness. No ($P > .05$) differences were noted in skeletal maturity between carcasses from steers placed directly in the feedlot vs backgrounded steers. Percentages of U.S. Choice carcasses were 78.6, 67.9, 71.4, 82.1, and 64.3% for EW, NW, WP, SG, and LG, respectively. Steers placed directly in the feedlot (EW and NW) tended to have higher ribeye and shoulder clod shear force values than backgrounded age groups (WP, SG, LG). Greater than 89% of the ribeye, 78% of the top round, 78% of the shoulder clod, and 64% of the top sirloin butt steaks could be classified as tender (Shear Force < 4.54 kg) regardless of age group.

Variability in shear force tended to decrease with increasing chronological age at slaughter for the ribeye, top round, and clod steaks; however top sirloin butt steaks failed to show any consistent changes in variation with increasing age.

(Key Words: Beef, Tenderness, Age.)

Introduction

Results from the National Tenderness Survey (Morgan et al., 1991) indicated considerable variation in tenderness among retail beef steaks, especially steaks from locomotive regions of the carcass. Furthermore, the Oklahoma Market Basket Study (Nick et al., 1992) has indicated similar results in that approximately one out of every two steaks surveyed from the beef round could be perceived as tough by consumers. Consequently, the beef industry is considering recommendations to improve the current quality grading system to increase consistency in tenderness of beef retail steaks.

Previous research has shown that the period of time an animal has been fed a high-energy diet prior to slaughter is related to the tenderness of beef (Tatum et al., 1980; Burson et al., 1980; Aberle et al., 1981; Dolezal et al., 1982a). Collectively, data from those studies indicate that for yearling cattle fed a conventional high-energy finishing diet, a feeding period of a approximately 100 d is sufficient to assure the production of beef with desirable tenderness and overall palatability, substantially shorter than that currently employed by most cattle feeders.

Many researchers have indicated that the tenderness of bovine muscle decreases with increasing chronological age (Tuma et al., 1962, 1963; Romans et al., 1965; Berry et al., 1974; Smith et al., 1982). Consequently, the USDA grading system includes estimates of physiological maturity which are used to classify carcasses into five maturity groups (USDA, 1989). These standards assume that increases in maturity have adverse effects on palatability, especially tenderness. Smith et al. (1973) reported that differences in tenderness among muscles were the result of a collective influence of actomyosin effects, background effects and bulk density or lubrication effects; of these, background effects are most closely associated with changes in physiological maturity. Berry et al., (1974) found no differences ($P > .05$) in tenderness of beef slaughtered less than 30 mo of age. More recently, some producers have questioned whether or not calf-feds or baby beef require less marbling to be equivalent to yearling fed steers in tenderness. Hence, the objective of this study was to evaluate the effect of age at slaughter on carcass grade traits and shear force of steaks from four different anatomical locations.

Materials and Methods

One hundred and forty steers of predominantly Angus heritage were obtained from two herds and randomly allocated among five chronological age treatment groups: EW = early weaned directly to the feedlot at 3.5 mo of age, NW = normally weaned and placed in the feedlot at 7.9 mo, WP = backgrounded on wheat pasture for 112 d then placed in the feedlot at 11.6 mo, SG = dry wintered and then grazed on early, intensively managed native range for 68 d prior to feedlot placement at 15.4 mo, and LG = dry wintered and season long grazed on native range for 122 d prior to feedlot placement at 17.4 mo of age.

Each treatment (n = 28, 7 head per pen) was fed a standardized feedlot diet containing 12.4% protein (Table 1) with the exception of the early weaned calves (EW) which were started on an 18% all natural protein diet (3 to 5 mo of age) , switched to a 16% all natural protein diet (5 to 6 mo of age), adjusted to a 13.4% protein diet (6 to 7 mo of age), and finally placed on the standardized 12.4% protein diet at about 8 mo of age. Cattle were adapted over 14 d through a series of four diets to a 91% concentrate diet. In the workup diets, alfalfa hay and cottonseed hulls (2 to 1 ratio) replaced corn to achieve 50, 60, 70, and 80% concentrate levels, except for the early weaned steers (EW) which were initiated on 50% concentrate and then elevated to 80% concentrate. Days on feed and age at slaughter are listed in Table 2.

All steers were routinely processed at weaning as follows: vaccinated with IBR-PI3 (modified live virus; i.m.) and seven way clostridial bacterin and injected with ivermectin. EW steers received a shot of Nasalgen one week after arrival at the feedlot. All steers were implanted with Synovex-S (20 mg estradiol benzoate + 200 mg progesterone). EW steers received their first implant at approximately 101 d on feed and then again every 84 d there after. NW steers received their first implant at approximately 8 mo of age and then every 84 d there after. The remaining three treatments received their first implants before going to wheat or grass and were then reimplanted approximately every 84 d there after, except for the LG steers which received implants before grass but were never reimplanted.

Steers were slaughtered upon reaching a subjectively evaluated pen mean of 1.3 cm of s.c. fat thickness. Pens of steers that were identified for slaughter were weighed, and transported to slaughter. All EW steers were slaughtered at the Oklahoma State University Meat Laboratory; however, all remaining steers were commercially slaughtered.

Following slaughter, carcasses were chilled for 48 h at which time data were collected for quality grade determinations (USDA, 1989). Steaks (2.5 cm thick) were removed from the left side ribeye, top sirloin butt, top round, and shoulder clod subprimals. Steaks were then vacuum packaged, aged for 14 d (2°C), and subsequently frozen at -30°C until the entire feeding trial was completed. Steaks were then removed by type and thawed at 2°C for a period of 18 h. Steaks were cooked to a medium degree of doneness (70°C) using open hearth broilers. Upon cooling to room temperature, an average of six cores 1.3 cm in diameter were removed for Warner-Bratzler shear force determinations.

The statistical model included ranch (n=2), age treatment (n=5), and the ranch x age treatment interaction. All individual carcass and shear force variables were adjusted to the mean s.c. fat thickness (1.4 cm) within each ranch x age treatment subclass. Using Levene's procedure to test equality of variances, non-homogeneity of variances was observed among age treatments for ribeye, top round, and clod shear forces, as well as lean and skeletal maturities. Pairwise comparisons were performed on treatment variances of the steak shear force variables using a simple F-test (similar to an LSD). Values for all variables were transformed to base-10 logarithms and subjected to Levene's analysis which resulted in variance differences only for skeletal maturity. Orthogonal contrasts were partitioned on appropriate dependent variables (logarithmic when necessary) to examine the following effects: DB = directly weaned to the feedlot (EW, NW) vs backgrounded (WP, SG, LG); EN = early (EW) vs normal weaned (NW); WG = wheat (WP) vs native range backgrounding (SG, LG); and SL = short (SG) vs long (LG) backgrounding on native range. The observed significance level was set at $P < .05$.

Results and Discussion

Maturity and marbling scores as well as shear force values are reported in Table 2. All maturity scores were well within the "A" maturity classification (USDA, 1989). Skeletal, lean, and overall maturity scores differed ($P < .05$) for the short vs long grazed contrast, where carcasses from the SG steers exhibited more youthful scores coinciding with younger chronological ages than carcasses from LG steers. Furthermore, lean maturity differed ($P < .05$) for directly placed steers vs backgrounded steers in that carcasses from steers placed directly in the feedlot were observed to have the most youthful lean scores. Interestingly, despite the 7.6 mo range in actual chronological age at slaughter, no ($P > .05$) differences were noted using the current visual methodology for assessing skeletal maturity between carcasses from directly placed (EW and NW) steers vs those from backgrounded steers. Perhaps the end point used in this study (constant s.c. fat thickness) was effective for comparison at a similar physiological stage of development as observed by Dolezal et al. (1993). Kempster (1978) reported that use of s.c. fat percentage as a covariate would, to some extent, shift comparisons toward an equal degree of maturity.

Lusby and Neumann (1986) reported that among cattle slaughtered at a constant end point fat thickness, carcass quality grade may be slightly lower with calf-feds than yearlings if the calves are slaughtered too young, typically less than 14 to 15 mo. In this study, marbling scores were similar ($P > .05$)

for all age groups with all groups attaining a "small" degree of marbling, the minimum requirement for the U.S. Choice quality grade. Figure 1 shows the percentage of U.S. Choice carcasses by age treatment. High percentages of U.S. Choice carcasses were observed regardless of age group. Percentages ranged from 64.3% for the long grazed group to 82.1% for the short grazed group. The unexpected lower percentage for the long grazed group is thought to be due to the fact the cattle did not reach the desired endpoint of finish before being evaluated as ready for slaughter. Interestingly, even the early weaned treatment group exhibited 78.6% U.S. Choice. The observed high percentages of U.S. Choice carcasses from the directly placed (EW and NW) steers may be related to increased time-on-feed as these treatments were fed for longer periods than all remaining treatments. Zinn et al. (1970) and Campion et al. (1975) observed an increased quality grade with increased time-on-feed.

No ($P > .05$) differences were noted in shear force values for top round or top sirloin butt steaks between age groups. However, there were significant differences between ribeye and clod steaks; steaks from directly placed steers (EW and NW) had higher shear force values than those from backgrounded (WP, SG, and LG) steers. Shackelford et al. (1991) recommended categorizing steak shear force values into tender (4.54 kg or less) and very tender (3.86 kg or less) levels. Percentage tender steaks by age treatment are reported in Figure 2. Greater than 89% of the ribeye, 78% of the top round, 78% of the shoulder clod, and 64% of the top sirloin butt steaks could be classified as tender regardless of age group. These percentages are higher than those observed by Morgan et al. (1991) and Nick et al. (1992), in retail surveys, especially for the top round steaks. Our study differs in that the round steaks were cut 2.5 cm thick instead of the historical 1.3 cm thickness at retail. Upon cooking it is theorized that thicker steaks could yield more tender cores due to less moisture loss and increased core length associated with a slower cooking time than with thinner steaks. Furthermore, the steers used in this study were similar in breed type and were fed a high concentrate diet to a constant s.c. fat thickness endpoint. Relative to steak types, a similar pattern in tenderness was observed within each age group in a declining fashion ranging from the ribeye (most tender) to the top sirloin butt (least tender). As noted in very early work by Lehmann (1907) the mechanical strength of a muscle is directly proportional to the amount of connective tissue present; the muscles that are most active and therefore subject to the greatest strains have the largest amounts of connective tissue and are least tender. In findings of Prost et al. (1975b) the level of connective tissue was lowest in the psoas major and highest in the infraspinatus muscles. Further work by Prost et al. (1975a) found the psoas major muscle was the most tender and the biceps femoris the least tender in a study of seven muscles from 180 bovine carcasses. A noticeable decline in tenderness was observed for all steaks within the normally-weaned age group; however these percentages are still considered to be high relative to retail tenderness surveys which may represent a much more diverse population of cattle.

Very tender ratings across age treatment groups (Figure 3) tended to be highest for ribeye steaks except among directly placed (EW and NW) steers where the top round steaks exhibited the highest percentages. Percentage very tender steaks increased with increasing age at slaughter for ribeye and clod steaks; top round steaks, normally higher in connective tissue tended to decrease with advancing animal age. Top sirloin butt steaks showed the lowest percentage of very tender steaks and showed very little change regardless of age group. As noted by previous researchers (Berry et al., 1974; Reagan et al., 1976; Davis et al., 1979; Smith et al., 1982), maturity appears to have a minimal effect on tenderness of longissimus muscle within the youthful maturity group (A).

Variation (reported as plus or minus two standard deviations) is shown for shear force values of each steak type stratified by age treatment (Figures 4 through 7). Shear force variance was the highest numerically within the normal weaned group for all steaks with significant differences among ribeye, top round, and clod steaks. Variation tended to decrease as age at slaughter increased, especially among ribeye and top round steaks. Perhaps the increased variance associated with the normal weaned group can be attributed to unknown endocrine changes within cattle 14 to 15 mo of age. A similar trend was observed for clod, ribeye, and top round steaks in that shear force values became more consistent (less variable) with increasing chronological age at slaughter beyond the normally weaned treatment group. Top sirloin butt steaks did not change in shear force variation regardless of age group. Consequently, the belief that baby-fed beef, or calves placed directly in the feedlot will produce carcasses with more consistent tenderness compared to yearling or long yearling fed beef is unfounded in this study.

The ranch main effect was shown to be a significant ($P < .05$) source of variation only for ribeye shear force (data not presented in tabular form). Ribeyes from Angus steers exhibited lower shear force values than ribeyes from Angus x Hereford steers (3.19 vs 3.56 kg, respectively).

Implications

In this study, similar skeletal maturity characteristics were noted despite known differences in chronological age. Furthermore, considering the breed types used, steers slaughtered at a constant s.c. fat thickness end point (1.4 cm) may achieve high percentages of U.S. Choice carcasses, even when slaughtered at less than 15 mo of age. High percentages of tender steaks were observed regardless of steak type or age class supporting the theory that maturity does not exert a large influence on palatability among youthful (13 to 21 mo) beef carcasses. Therefore, accelerated beef management programs may be utilized for the production of tender beef. However, more extensive research is needed to address tenderness variation within certain steak types, namely the top sirloin butt.

Table 1. Feedlot diet composition

	Diet % of DM			
Item	18% Starter diet	16% Starter diet	13.4% Starter diet	Final diet
Corn, dry rolled	52.97	59.25	73.79	79.61
Alfalfa hay, ground	7.80	6.58	4.65	5.02
Cottonseed hulls	10.0	10.0	7.0	3.90
Molasses, cane	3.75	3.75	3.75	4.38
Soybean meal 44	23.02	18.22	8.32	-
Cottonseed meal	-	-	-	3.55
Meat and bone meal	-	-	-	1.42
Distillers grains, corn	-	-	-	.87
Salt	.30	.30	.30	.35
Calcium carbonate	1.25	1.50	1.34	.35
Dicalcium phos.	.83	.33	.29	-
Urea, 46% N	-	-	.50	.30
Ammonium sulfate	-	-	-	.21
Vitamin A-30	.02[a]	.02[a]	.02[a]	-
Rumensin, 60 g/lb	.02[a]	.02[a]	.02[a]	.018
Tylan 40	.01[a]	.01[a]	.01[a]	-
Vitamin A and D_3	-	-	-	.00375[b]
Vitamin E 226800	.02[c]	.002[d]	-	-
Trace mineral premix	.01	.01	.01	.014
Calculated analysis				
NEm	87.14	88.67	92.35	94.63
NEg	55.00	56.00	59.00	60.39
Crude Protein	18.00	16.00	13.40	12.40

[a] Additive package formulated to provide 30,000 IU vitamin A per day, 26.4 grams per ton of Rumensin, and 10 grams per ton of Tylan.

[b] Contained 88,000 IU vitamin A and 88 IU vitamin D_3 per gram.

[c] Formulated to provide 600 IU vitamin E per day.

[d] Formulated to provide 50 IU vitamin E per day.

Table 2. Days on feed, age at slaughter, maturity, marbling, and shear force values stratified by age treatment

Item	Early weaned	Normal weaned	Wheat pasture	Short grazed	Long grazed	Effect[c]	RSD
Days on feed	287	198	134	124	100	-	-
Slaughter age, mo	13.1	14.5	16.1	19.6	20.7	-	-
Maturity score[a]							
Skeletal	149	159	151	138	161	SL	14.9
Lean	133	134	145	137	145	DB, SL	10.5
Overall	141	146	148	138	153	SL	9.8
Marbling score[b]	436	419	421	447	427	-	56.2
Shear force, kg							
Ribeye	3.61	3.88	3.31	3.00	3.06	DB	.55
Clod	3.76	4.10	3.67	3.42	3.56	DB	.46
Top round	3.57	3.84	3.79	3.76	3.85	-	.65
Top butt	3.95	4.24	4.20	4.04	4.10	-	.64

[a] Maturity scores of 100 to 199 = approximately 9 to 30 months of chronological age at slaughter (USDA, 1989).

[b] Marbling score of 400 to 499 = small degree, the minimum required for U.S. Choice quality (USDA, 1989).

[c] SL = Significant difference (*P*<.05) for short grazed (SG) vs long grazed (LG) steers; DB = Significant difference (*P*<.05) for steers sent directly to the feedlot (EW, NW) vs backgrounded steers (WP, SG, LG).

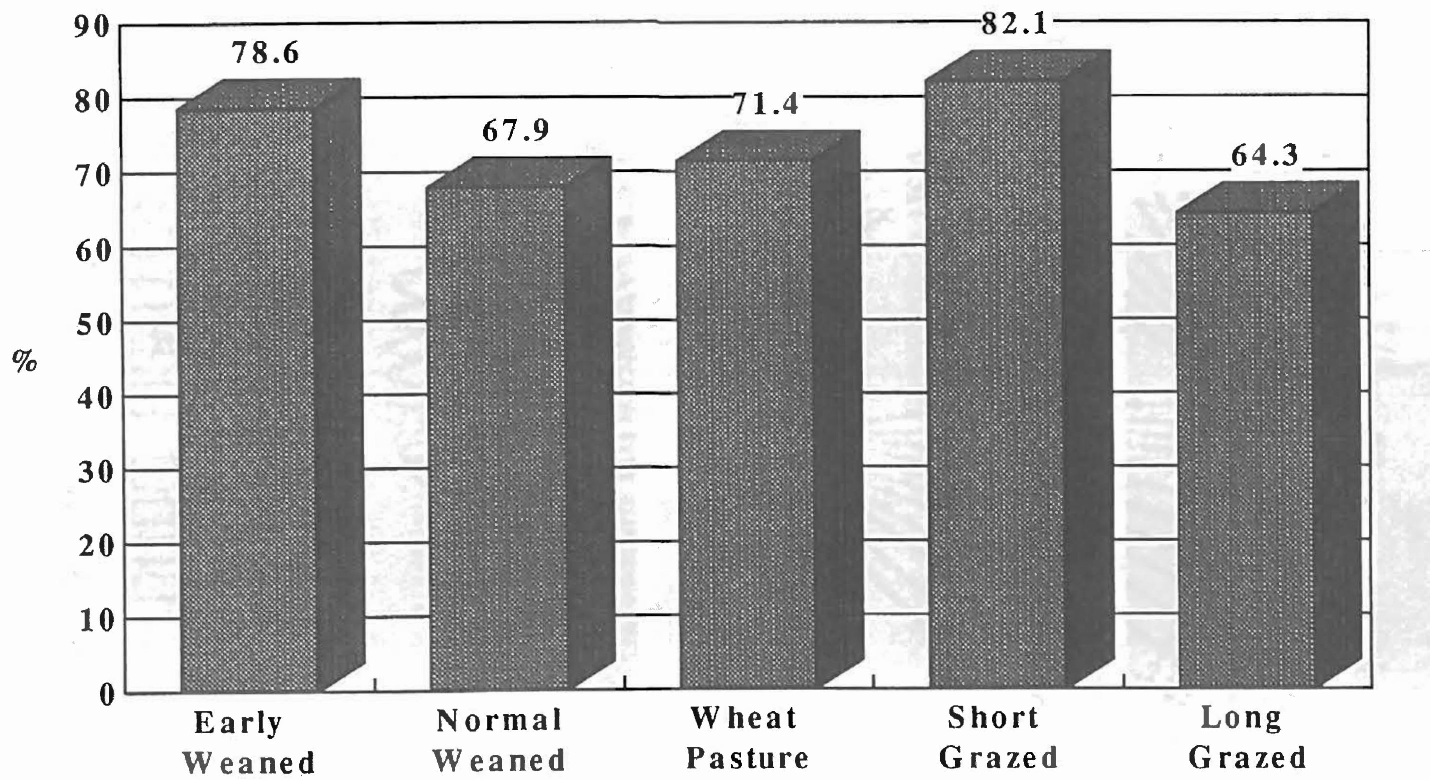

Figure 1. Percentage U.S. Choice by age treatment

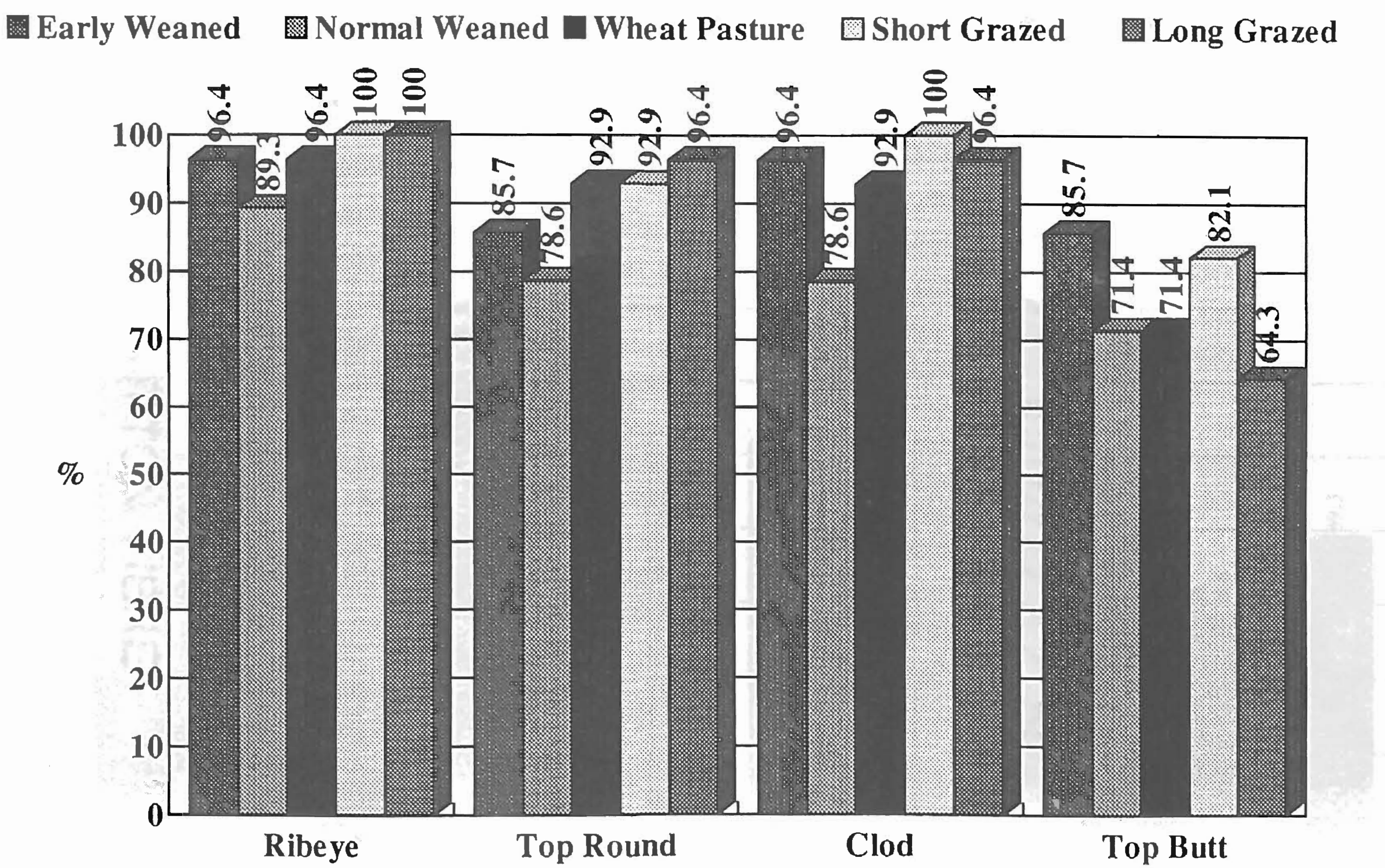

Figure 2. Percentage tender steaks (Shear force < 4.54 kg) within age treatment

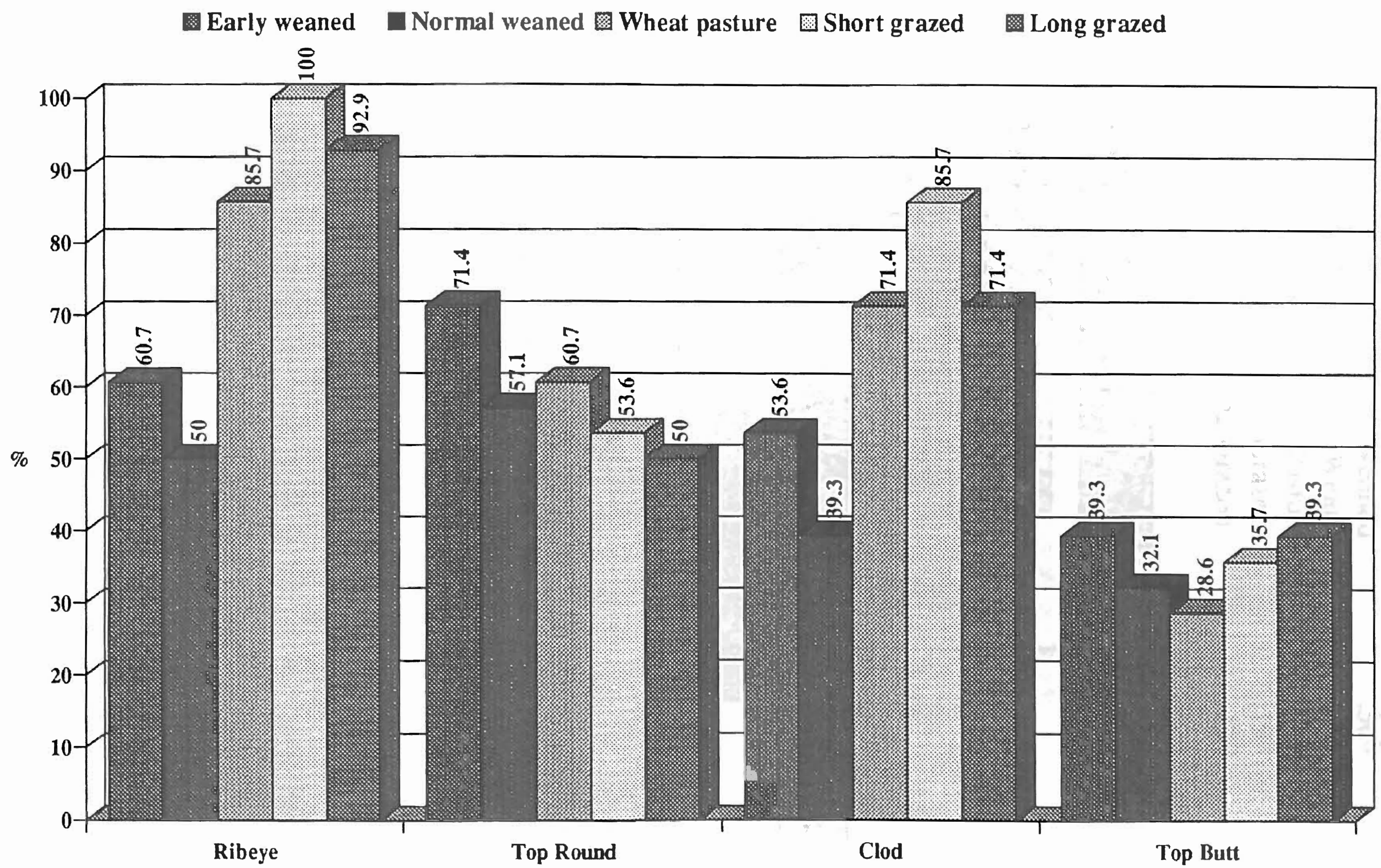

Figure 3. Percentage of very tender steaks (Shear force < 3.86 kg) within age treatment

Age Treatment	s^2
EW = Early Weaned	$.36^b$
NW = Normal Weaned	$.78^a$
WP = Wheat Pasture	$.26^b$
SG = Short Grazed	$.19^b$
LG = Long Grazed	$.22^b$

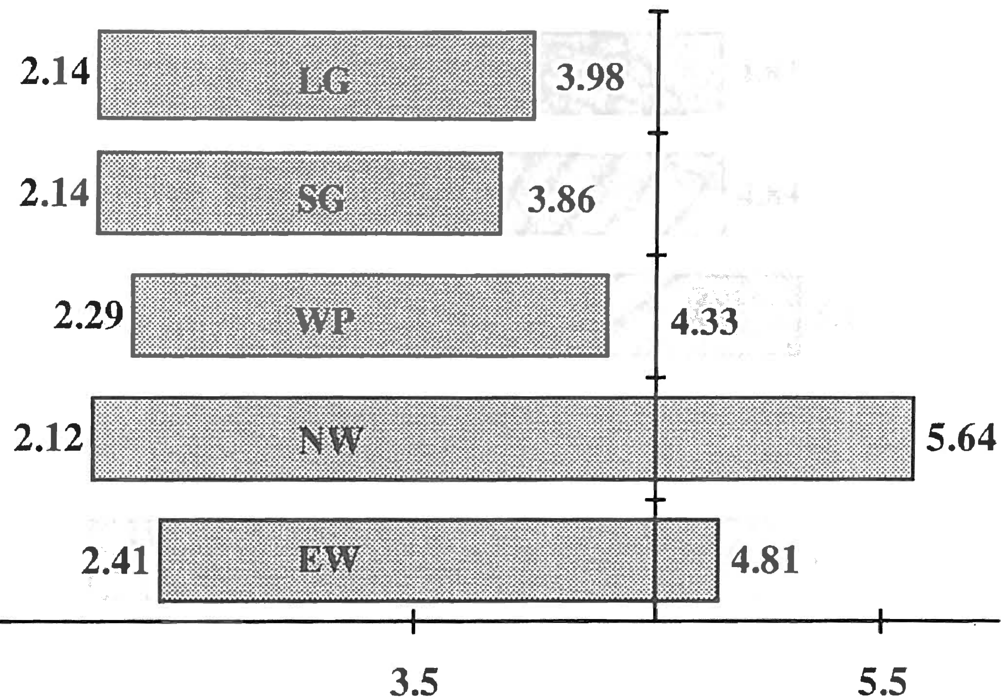

Figure 4. Variation (reported as the mean ± two standard deviations) in shear force within age treatment for the ribeye steak. Variances that do not have a common superscript letter are different ($P < .05$).

Age Treatment	s^2
EW = Early Weaned	$.55^{a}$
NW = Normal Weaned	$.55^{a}$
WP = Wheat Pasture	$.47^{ab}$
SG = Short Grazed	$.29^{ab}$
LG = Long Grazed	$.24^{b}$

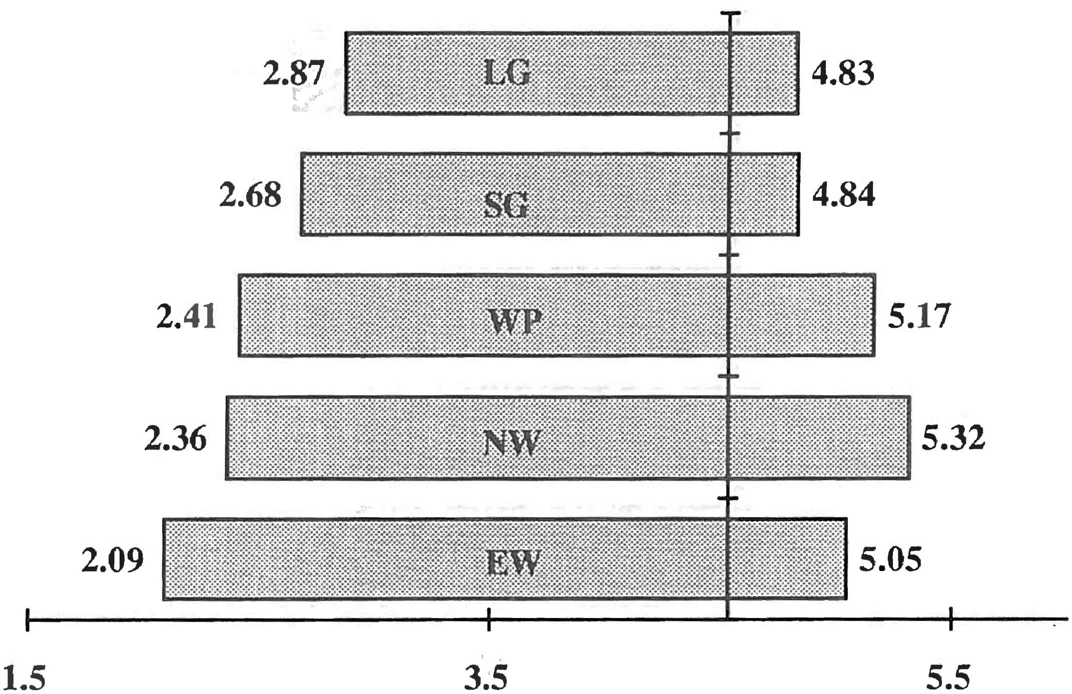

Figure 5. Variation (reported as the mean ± two standard deviations) in shear force within age treatment for the top round steak. Variances that do not have a common superscript letter are different ($P < .05$).

Age Treatment	s^2
EW = Early Weaned	$.18^{ab}$
NW = Normal Weaned	$.36^{a}$
WP = Wheat Pasture	$.22^{ab}$
SG = Short Grazed	$.15^{b}$
LG = Long Grazed	$.22^{ab}$

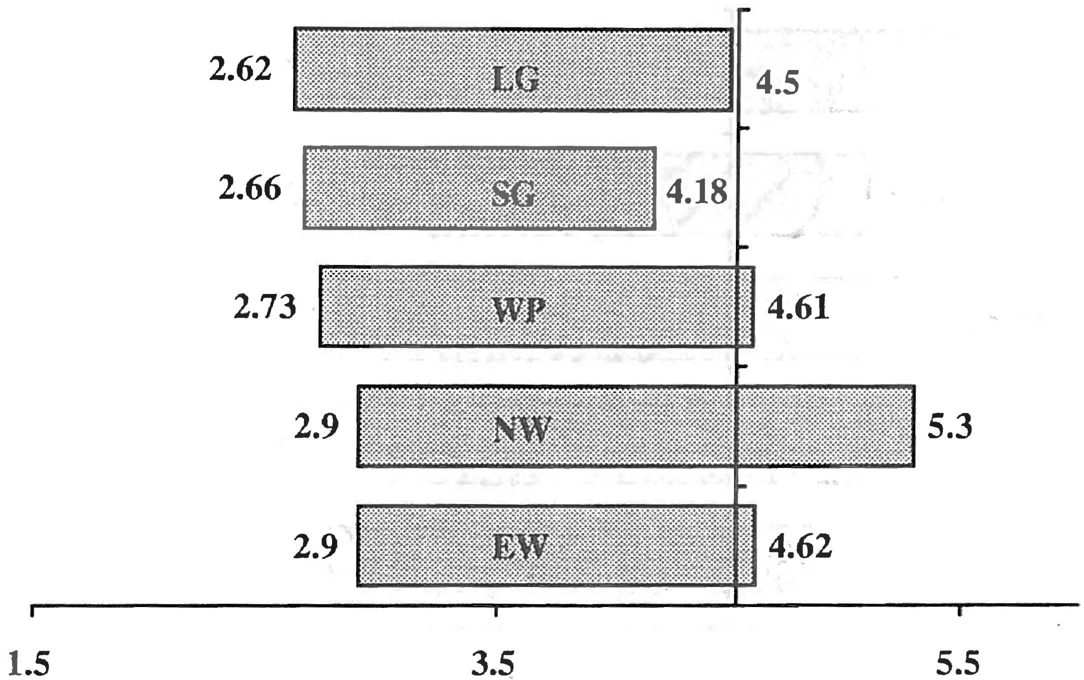

Figure 6. Variation (reported as the mean ± two standard deviations) in shear force within age treatment for the clod steak. Variances that do not have a common superscript letter are different (*P* < .05).

Age Treatment	s^2
EW = Early Weaned	.33
NW = Normal Weaned	.52
WP = Wheat Pasture	.48
SG = Short Grazed	.30
LG = Long Grazed	.49

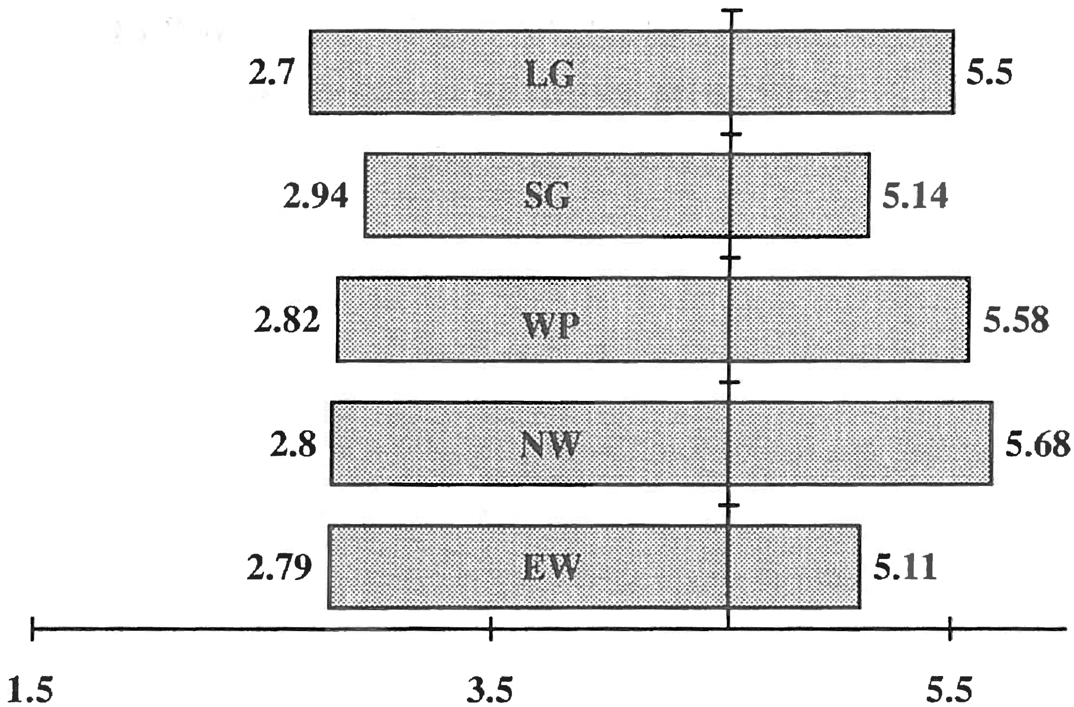

Figure 7. Variation (reported as the mean ± two standard deviations) in shear force within age treatment for the top butt steak.

CHAPTER IV

TENDERNESS VARIABILITY AMONG STEER CARCASSES DIFFERING IN FATNESS, MUSCLING AND QUALITY GRADE

Abstract

Beef sides (n =120) were selected from Choice (50%) and Select (50%) steer carcasses ranging between 318 and 362 kg to represent adjusted s.c. fat thicknesses of .7, 1.0, 1.3 and 1.6 cm and three levels of muscling (thin, average and thick). Carcasses were selected in a "mill run" fashion without knowledge of breed and prior management history. Upon fabrication, steaks (2.5 cm thick) were removed from the ribeye, top sirloin butt, and eye of round subprimals. Steaks were aged for 14 d and subsequently broiled for Instron Warner-Bratzler shear force determinations. Quality grade, fat thickness, and muscle score did not affect mean shear force of steak types ($P > .05$). However, steak types differed in that mean shear force values were highest ($P < .05$) for eye of round steaks with similar ($P > .05$) values for ribeye and top butt steaks. Lean maturity differed ($P < .05$) between muscling groups in that thick muscled carcasses exhibited more youthful lean than thin muscled carcasses. Variability in shear force within the Select grade remained rather constant for all three steak types while the Choice grade variability is inconsistent being highly variable, although more towards the

tender side for the ribeye and somewhat less variable for the top butt and eye of round. A similar trend is observed for each steak in that variability in shear force increases as muscle score advances from thin to thick.

(Key Words: Beef, Tenderness, Variability.)

Introduction

To date, most research supports the early belief that tenderness of grain-fed beef is superior to that of grass-fed beef (Smith et al., 1977; Bowling et al., 1978; Schroeder et al., 1980; Dolezal et al., 1982a, 1982b; May et al., 1992). At question, however, is whether or not our present system of beef quality grading adequately segments grain-fed cattle into similar palatability groups. Most research has failed to consistently document the marbling-tenderness hypothesis employed in our grading system. In fact, numerous researchers have reported low to moderate relationships between marbling and meat tenderness (Carpenter, 1974; Campion et al., 1975; Bowling et al., 1977; Tatum et al., 1980). Furthermore, several studies indicate that steaks from cattle fed grain for a similar period of time differ little in tenderness despite sizable variation in marbling amount (Campion et al., 1975; Adams et al., 1977; Harrison et al., 1978; Tatum et al., 1980, 1982; Dolezal et al., 1982b; May et al., 1992). May et al. (1992) reported that tender beef may be obtained with any one or a combination of the following singular effects: 1) 84 d of high concentrate feeding, 2) s.c. fat thickness of 1.0 cm, 3) hot carcass weight of 293 kg, 4) marbling score of "slight 93" (high Select) or 5) postmortem ribeye temperature of 33°C. Therefore, the objective of this study was to ascertain the effectiveness of quality grade at four levels of carcass s.c. fat thickness and three levels of carcass muscling for predicting tenderness of three retail cuts of beef among mill-run carcasses.

Materials and Methods

Beef sides (n=120) from Choice (50%) and Select (50%) steer carcasses ranging from 318 to 362 kg were selected without knowledge of breed or management history to represent four preliminary yield grades: 2.7, 3.0, 3.3, and 3.6 corresponding to adjusted s.c. fat thicknesses of .7, 1.0, 1.3, and 1.6 cm, respectively and three levels of muscling: thin, average and thick based on approximate ribeye areas of 69.7, 82.6 and 95.5 cm^2, respectively.

Carcasses had been chilled 48 h when data was collected for quality and yield grade determinations (USDA, 1989). Upon fabrication, steaks (2.5 cm thick) were removed from the ribeye, top sirloin butt, and eye of round subprimals. Steaks were then vacuum packaged, aged for 14 d (2^{o}C), and subsequently frozen at -30^{o}C. Steaks were then removed by type and thawed at 2^{o}C for a period of 24 h and subsequently grilled on Farberware® Open-hearth broilers to an internal temperature of 70^{o}C (AMSA, 1978). Upon cooling to room temperature, an average of six cores 1.3 cm in diameter were removed parallel to the fiber orientation for Instron Warner-Bratzler shear force determinations.

Data were analyzed using a 2 x 3 x 4 factorial arrangement of treatments as a split plot. Using Levene's procedure to test equality of variances, non-homogeneity of variances was observed for top butt shear force within the fat thickness main effect. Pairwise comparisons were performed on variances of the top butt shear force variable among fat thickness levels using a simple F-test (similar to an LSD). Values for the top butt shear force variable were transformed to base-10 logarithms and subjected to Levene's analysis which resulted in no variance differences ($P > .05$). Means were separated by Tukey's w procedure (Steel and Torrie, 1980). The observed significance level was established at $P < .05$.

Results and Discussion

Population means, standard deviations and respective coefficients of variation for carcass traits are shown in Table 1. Selection was limited to "A" maturity carcasses for skeletal and lean maturities. Marbling scores for the two quality grades selected approximated the mid-point of "small" and "slight" with a ± 30% variation. Kidney, pelvic, and heart fat percentage, yield grade, and shear force were not part of the selection criteria and were the most variable.

Table 2 exhibits mean squares for the various carcass traits evaluated. Despite the design criteria, muscle group differences ($P < .05$) were noted in carcass weight. Thin muscled carcasses were lighter ($P < .05$) than average and thick muscled carcasses (Table 3). Tatum et al. (1986) reported a significant difference in live weight between thick (heaviest) muscled steers vs average and thin muscled steers slaughtered at a comparable fatness (constant % fat). An unexpected, significant source of variation ($P < .05$) was also noted among muscle groups for skeletal and lean maturities. The thick muscled carcasses selected tended to have more mature ($P = .03$) skeletal maturity scores, but more youthful ($P = .04$) lean maturity scores. The latter may be due to visually perceived differences in that larger ribeyes are often evaluated as lighter or more youthful in lean color. Even though analysis of variance revealed a significant muscle group F test for skeletal maturity, the conservative mean separation technique employed (Tukey's w procedure) did not ($P > .05$) partition differences between thick, average, and thin carcasses.

As expected, marbling score differed ($P < .05$) between U. S. Choice and U. S. Select quality grades. Mean marbling scores approximated the mid-point of the "small" and "slight" marbling scores. Quality grade was not significant ($P > .05$) for any of the other carcass traits.

Based on the selection criteria, fat thickness and muscle group were significant sources of variation for carcass s.c. fat thicknesses (actual and adjusted) and ribeye area, respectively. These differences translated to significant changes in yield grade. Numerical yield grade increased ($P < .05$) consistently with increases in carcass s.c. fat thickness and decreases in muscularity. Interestingly, the fat x muscle interaction was highly significant ($P < .01$) for both fat thickness and adjusted fat thickness. This interaction (data not reported in tabular form) revealed that the average muscled carcasses in the .7 cm fat thickness cell tended to be slightly fatter and the average muscled carcasses in the 1.0 cm fat thickness cell tended to be slightly trimmer than either the thick or thin muscled carcasses. No differences were noted among carcasses for kidney, pelvic, and heart fat.

Carcass and steak sources of variation proved to be significant ($P < .01$) for shear force. Eye of round steaks had higher ($P < .05$) shear force values than ribeye and top sirloin butt steaks. Work by Prost et al. (1975) showed similar differences between steaks from posture and locomotive muscles in that the psoas major muscle was the most tender and the biceps femoris the least tender in a study of seven muscles from 180 bovine carcasses. No differences ($P > .05$) were observed for any main effects for shear force (Table 4). However, steak types differed in that mean shear force values were highest ($P < .05$) for eye of round steaks with similar ($P > .05$) values for ribeye and top butt steaks. Shear force variance was shown to be highest ($P < .05$) within the .7 cm fat thickness level and lowest within the 1.3 cm fat thickness level for the top butt. No ($P > .05$) shear force variance differences were observed for ribeye or eye of round steaks within any effect.

Figure 1 reflects variation in the form of the mean plus or minus two SD for shear force of each steak type within quality grade. Quality grade had considerable effect on ribeye and top butt steaks but minimal effect on the eye of round. Variability for Choice ribeye and top butt steaks revealed fewer steaks with greater than 4.54 kg of shear force.

Figure 2 depicts variation in the form of the mean plus or minus two SD for shear force of each steak type within fat thickness levels. Variation tended to increase as fat level decreases for the ribeye and eye of round; however, the top butt exhibits an unexplainable, sharp decrease ($P < .05$) in variation within the 1.3 cm level of fat thickness and then increases in variation for the lower fat thickness levels. For the most part, fat thicknesses ranging from 0.7 to 1.6 cm were unrelated to tenderness.

Shear force variation for steak types stratified by muscle group are presented in Figure 3. A similar trend is observed for each steak type in that variability tended to increase as muscle score advanced from thin to thick. Possible reasoning for this is the fact that later maturing, larger breed types were used within the average and thick muscle groups.

Implications

Quality grade, muscle score and fat thickness did not affect shear force of the ribeye, top butt or eye of round steaks in the 120 carcasses examined in this study. Consequently, quality grade did not segment carcasses into different expected palatability groups using shear force measurements as an indication of tenderness, the major factor affecting palatability according to Morgan et al. (1991). Additionally, the proposed coupling of fat thickness with marbling to improve the current quality grading system by the National Cattlemen's Association is not substantiated by the findings of this study involving a mill run of steer carcasses.

Table 1. Trait characterization

Variable	Mean	SD	CV, %
Carcass weight, kg	338.6	13.6	4.1
Skeletal maturity[a]	150.2	21	14.0
Lean maturity[a]	139.5	10	7.2
Overall maturity[a]	144.8	11	7.6
Marbling[b]	408.5	70	17.1
Fat thickness, cm	1.14	.40	3.5
Adj. fat thickness, cm	1.18	.36	3.1
Ribeye area, cm^2	82.46	12.1	14.7
% KPH	1.94	.49	25.3
Yield grade	2.8	.70	25.0
Shear force, kg	4.19	.94	22.4

[a]100 to 199 = "A" maturity.

[b]400 to 499 = Small degree of marbling.

Table 2. Mean squares for carcass traits and shear force

Source	df	Carcass wt, kg	Maturity: Skeletal	Maturity: Lean	Maturity: Overall	Marbling	Fat thick-ness, cm	Adj. fat thickness, cm	Ribeye area, cm^2	% KPH	Yield grade	Shear force, kg
Quality grade (Q)	1	246.3	270.0	270.0	.0	392,163.3**	.02	.015	29.99	.002	.0002	3.24
Fat thickness (F)	3	246.2	374.4	170.0	242.8	103.3	5.70**	5.016**	1.94	.058	5.37**	.56
Muscle group (M)	2	824.7**	1,300.8*	332.5*	89.0	472.5	.01	.011	8,038.3**	.4	19.47**	2.88
Q x F	3	174.6	512.2	81.1	148.3	418.9	.03	.008	.91	.102	.011	1.14
Q x M	2	51.6	827.5	107.5	349.4	2105.8	.01	.004	1.90	.058	.033	.79
F x M	6	92.2	248.6	169.2	63.4	1125.8	.05**	.015**	15.8	.506	.034	1.07
Q x F x M	6	96.2	686.4	88.6	161.0	814.7	.005	.004	7.34	.158	.035	1.32
Carcass (Q x F x M)	96	184.3	404.2	82.5	128.1	1,281.3	.018	.005	13.4	.244	.0361	1.40**
Steak (S)	2											18.8**
S x Q	2											1.17
S x F	6											.81
S x Q x F	6											.73
S x M	4											.49
S x Q x M	4											.14
S x F x M	12											.75
S x Q x F x M	12											.37
Residual error	192											.44

*$P < .05$

**$P < .01$

Table 3. Carcass traits within each factor

	Carcass	Maturity[a]				Fat thickness,	Adj. fat	Ribeye		Yield
Effect	wt, kg	Skeletal	Lean	Overall	Marbling[b]	cm	thickness, cm	area, cm^2	% KPH	grade
Quality grade										
Choice	340.0	151.7	138.0	144.8	465.7^{c}	1.16	1.20	82.96	1.94	2.80
Select	337.2	148.7	141.0	144.8	351.3^{d}	1.13	1.17	81.96	1.93	2.80
Adj. fat thickness, cm										
.7	335.1	146.0	138.0	142.0	407.7	$.64^{f}$	$.72^{f}$	82.78	2.0	2.31^{f}
1.0	337.5	154.3	142.0	148.2	406.7	$.96^{e}$	1.02^{e}	82.15	1.93	2.64^{e}
1.3	340.3	151.3	141.0	146.2	411.0	1.32^{d}	1.34^{d}	82.45	1.92	2.96^{d}
1.6	341.5	149.0	137.0	143.0	408.7	1.65^{c}	1.67^{c}	82.45	1.90	3.29^{c}
Muscling										
Thin	333.4^{d}	147.0	141.8^{c}	144.4	404.8	1.15	1.20	67.98^{e}	2.04	3.51^{c}
Average	341.0^{c}	146.8	140.5^{cd}	143.6	409.3	1.12	1.18	83.08^{d}	1.94	2.77^{d}
Thick	341.4^{c}	156.8	136.3^{d}	146.5	411.5	1.16	1.17	96.32^{c}	1.84	2.12^{e}
RSD	13.6	20.1	9.1	11.3	35.8	.13	.07	3.7	.49	.19

[a]100 to 199 = "A" maturity.

[b]400 to 499 = Small degree of marbling; 300 to 399 = Slight degree of marbling.

[c,d,e,f]Means in the same column and within the same item bearing a common superscript do not differ ($P > .05$).

Table 4. Shear force means and variances for each factor stratified by steak type

Effect	Ribeye Mean	Ribeye s^2	Top butt Mean	Top butt s^2	Eye of round Mean	Eye of round s^2
Quality grade						
Choice	3.78	1.06	3.85	.57	4.67	.55
Select	4.09	1.09	4.15	.77	4.63	.55
Adj. fat thickness, cm						
.7	3.77	1.48	4.18	.98[a]	4.64	.60
1.0	4.13	1.18	4.12	.88[a]	4.65	.64
1.3	3.87	.84	3.80	.22[b]	4.81	.61
1.6	3.96	.92	3.90	.65[a]	4.49	.33
Muscling						
Thin	3.69	.80	3.95	.56	4.46	.46
Average	3.95	1.25	3.92	.71	4.75	.53
Thick	4.16	1.16	4.13	.80	4.74	.62

[a,b]Variances in the same column and within the same effect bearing a common superscript do not differ ($P > .05$).

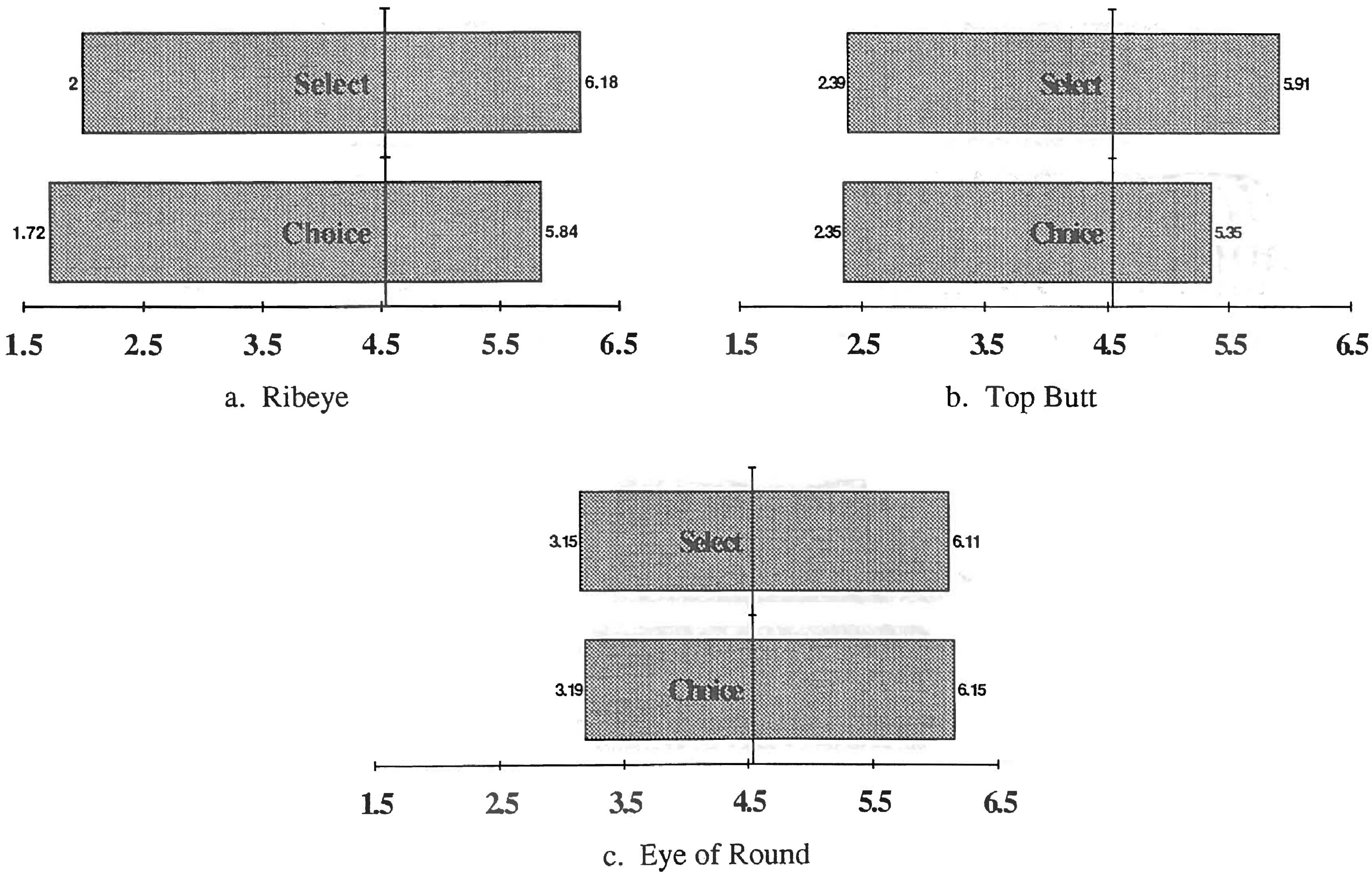

Figure 1. Variation in shear force (kg) for each steak type within quality grade

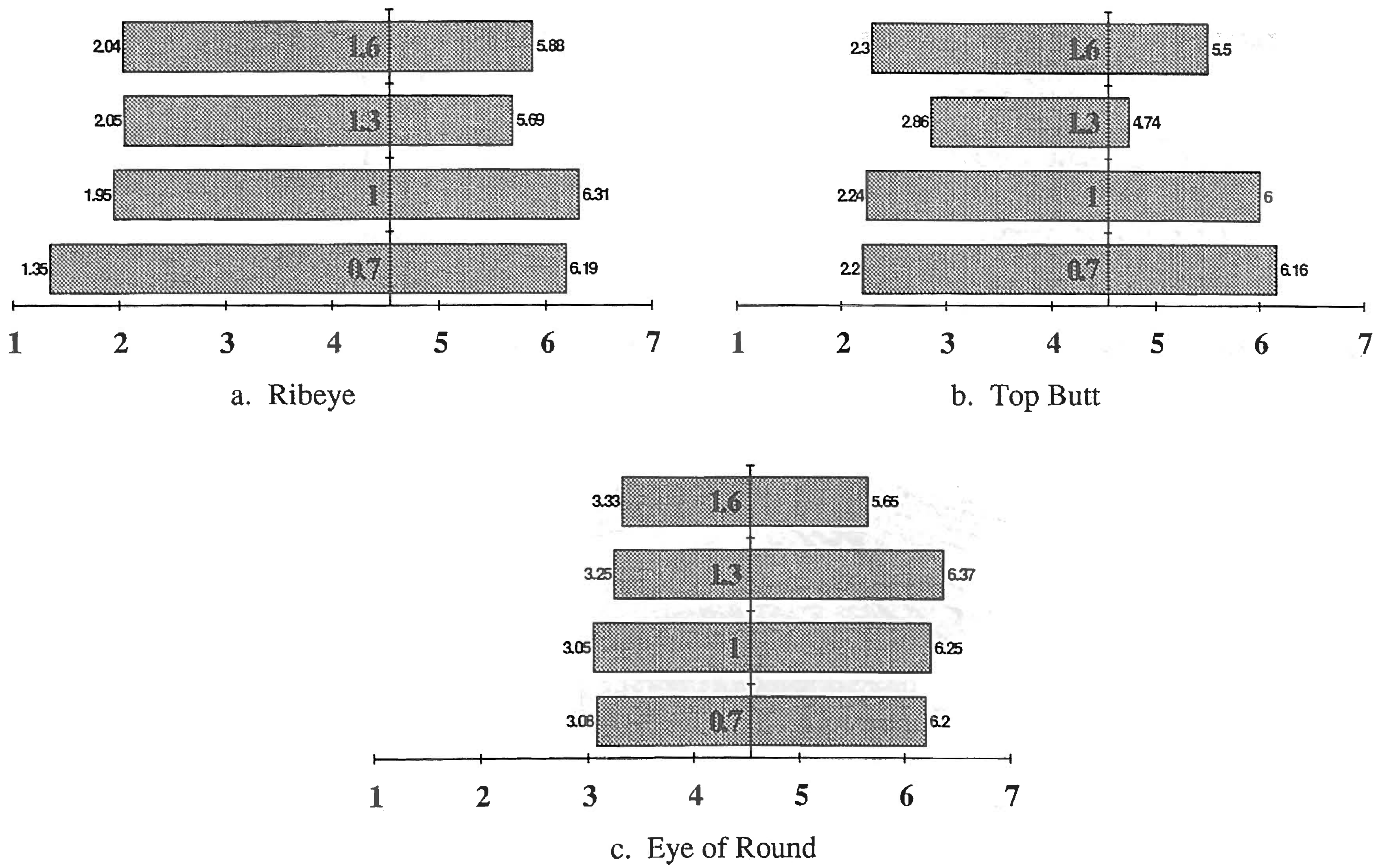

Figure 2. Variation in shear force (kg) for each steak type within fat thickness level (cm)

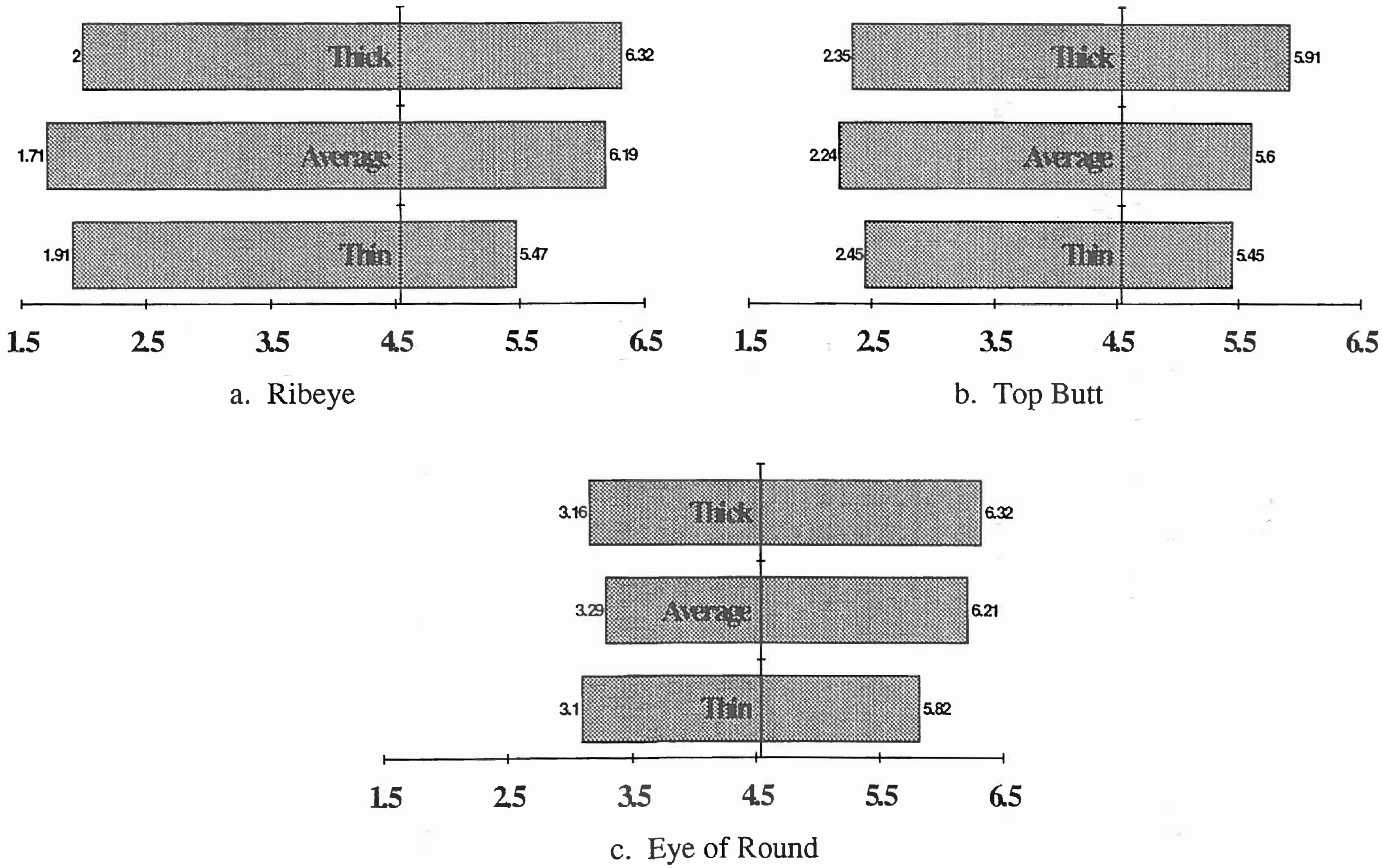

Figure 3. Variation in shear force (kg) for each steak type within muscle group

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APPENDIX

PERCENTAGE TENDER AND VERY TENDER, INTERACTIONS, 28 - DAY RIBEYE VARIATION, CORRELATIONS, AND SHEAR FORCE VARIANCES

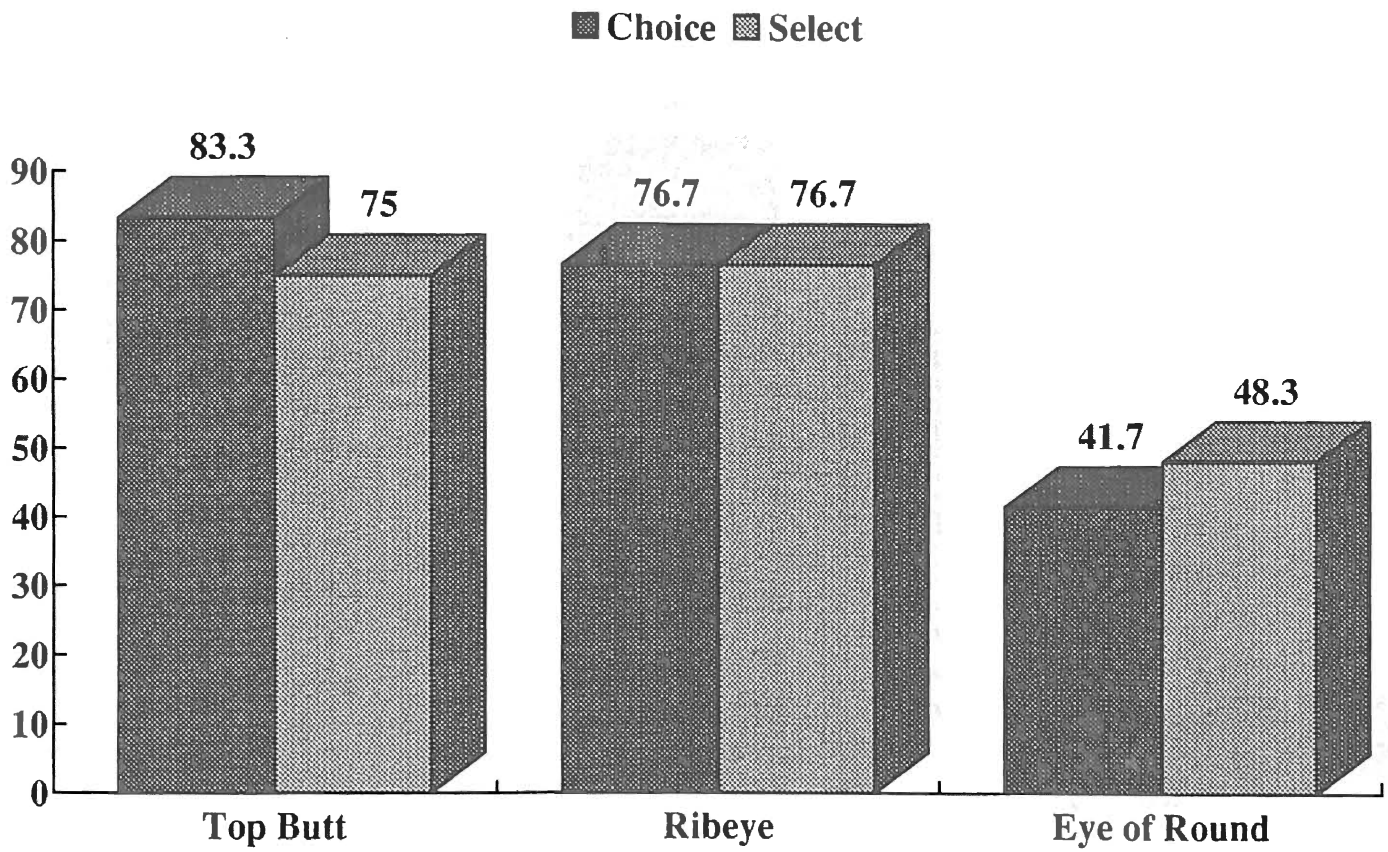


Figure 1. Percentage tender by quality grade

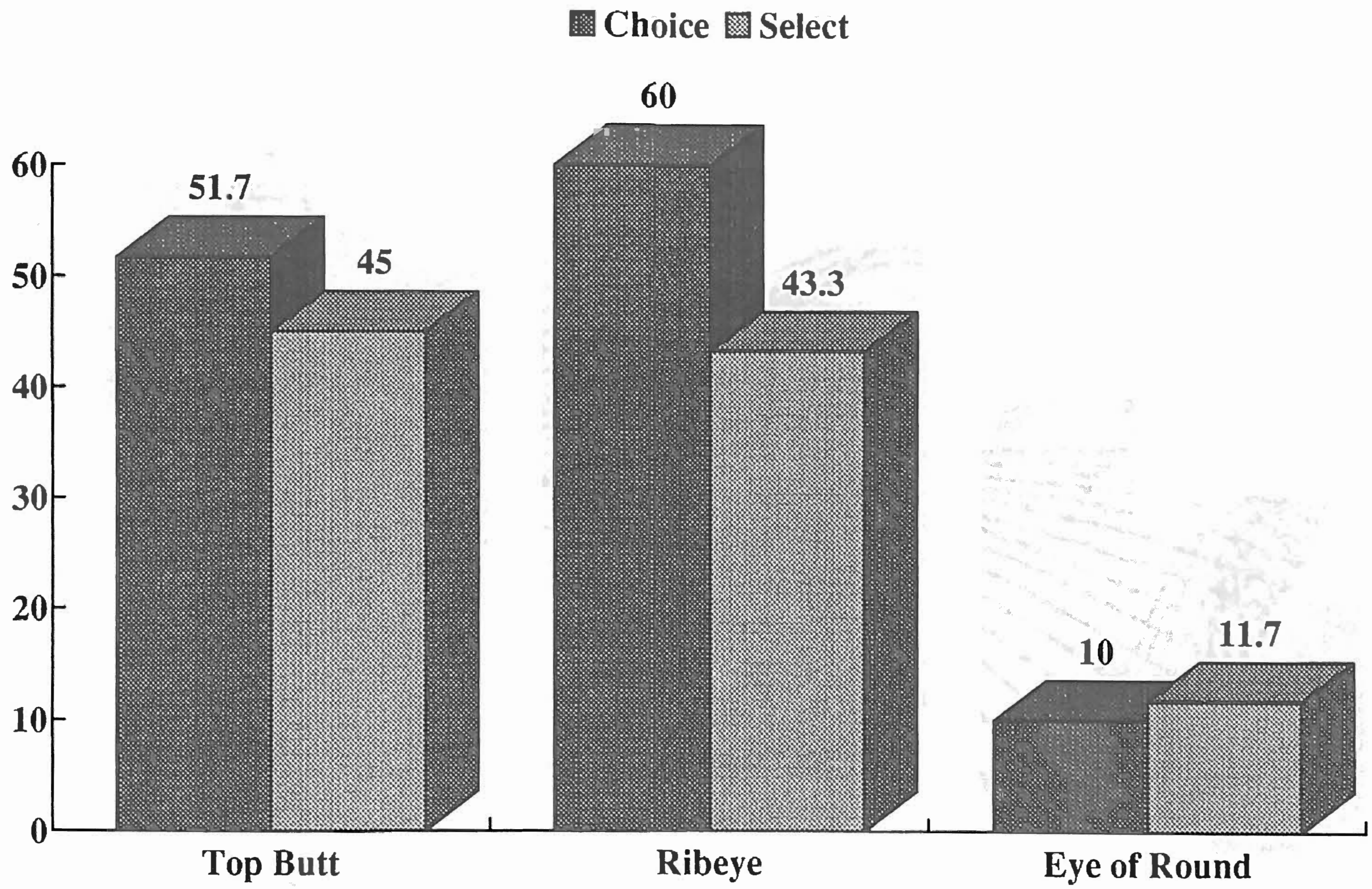


Figure 2. Percentage very tender by quality grade

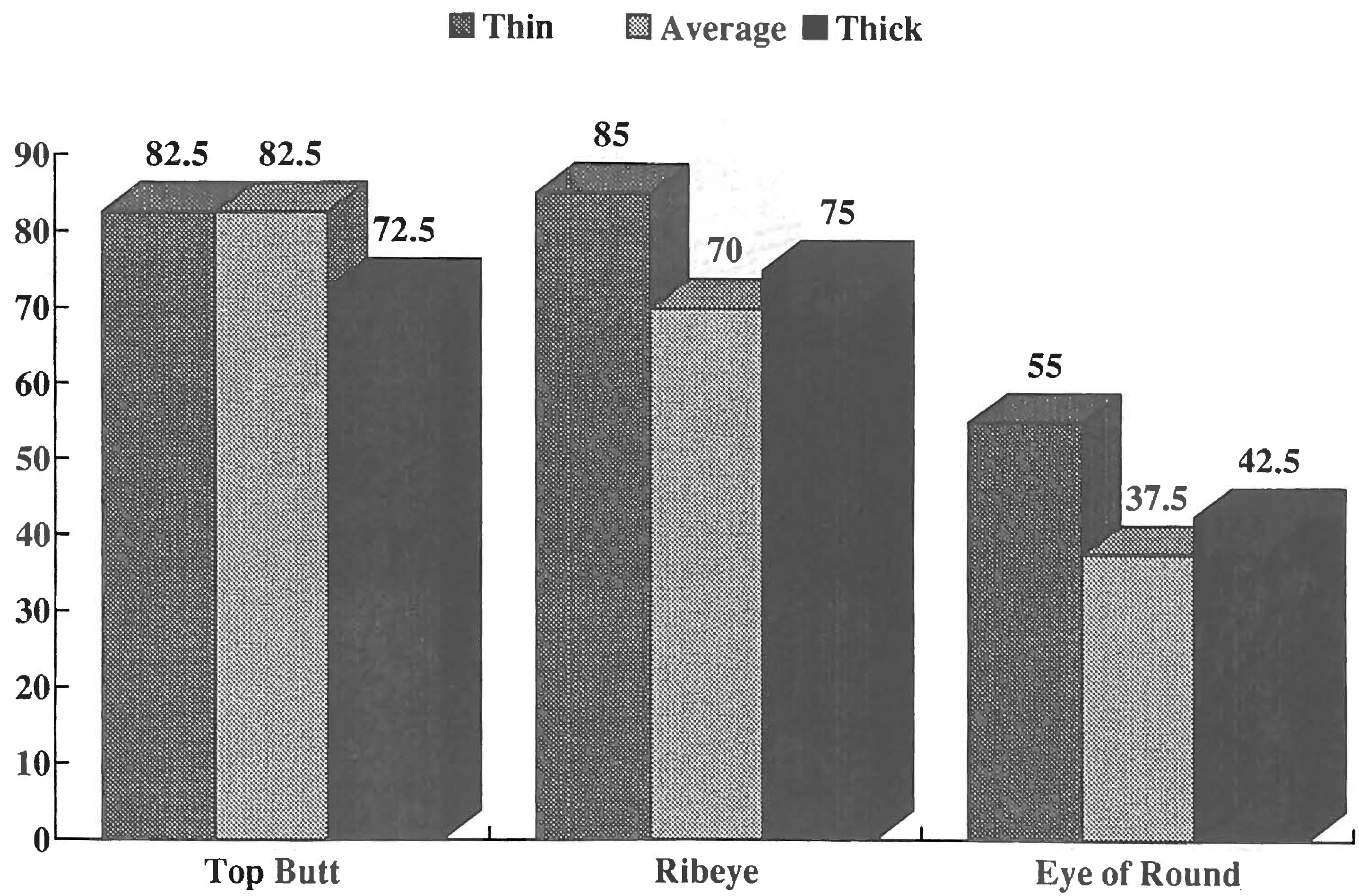


Figure 3. Percentage tender by muscle score

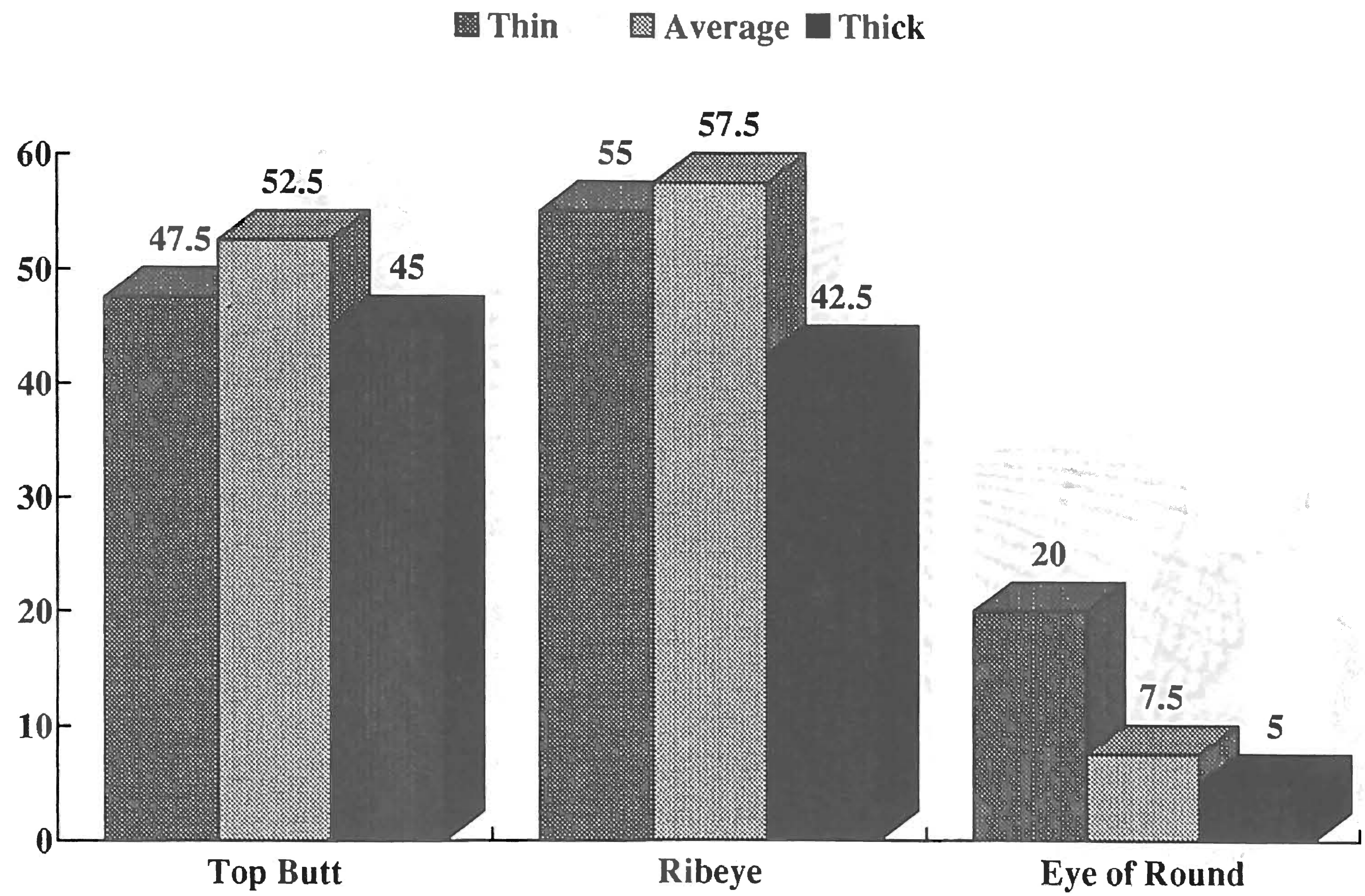


Figure 4. Percentage very tender by muscle score

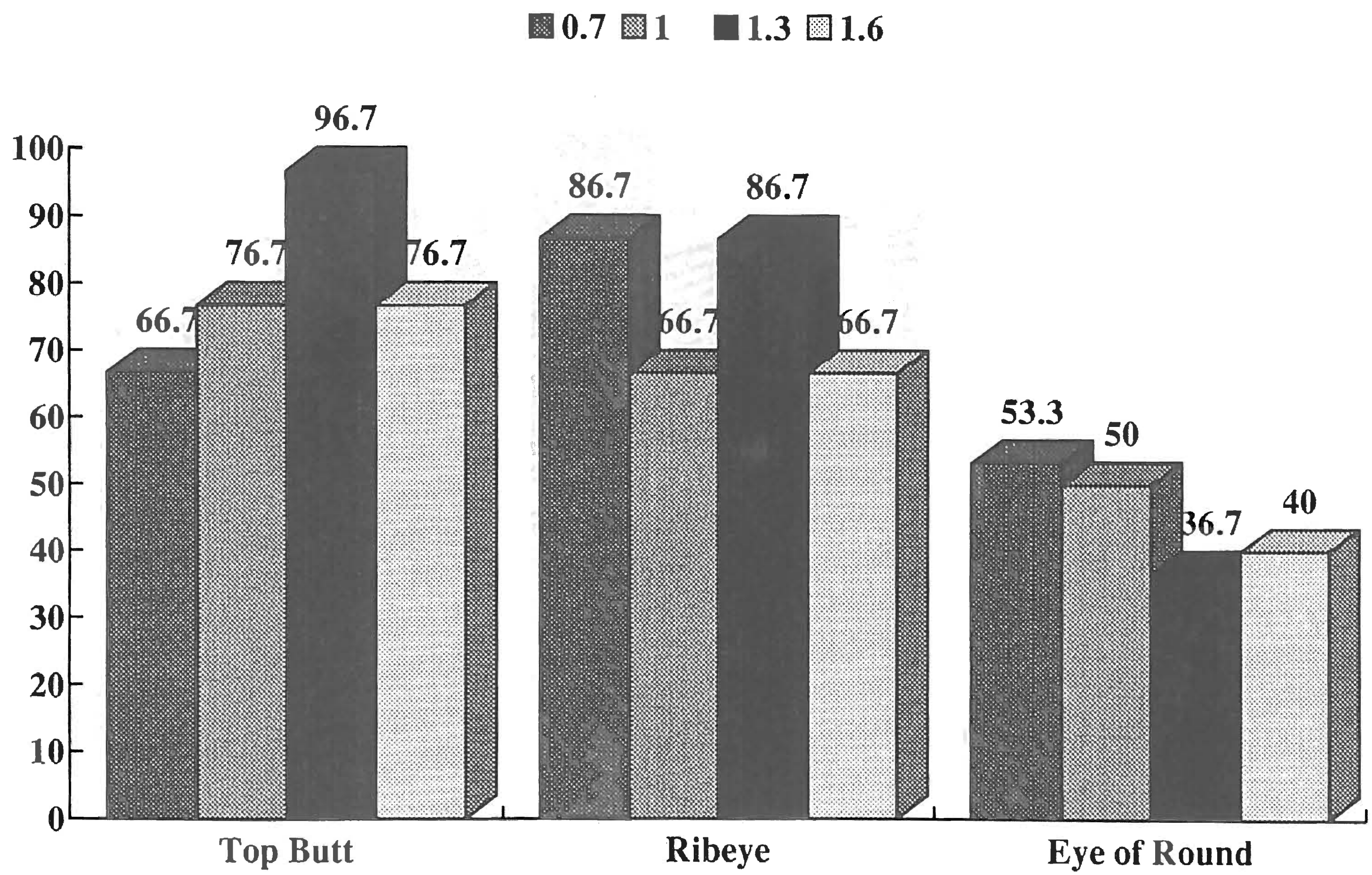


Figure 5. Percentage tender by fat thickness (cm)

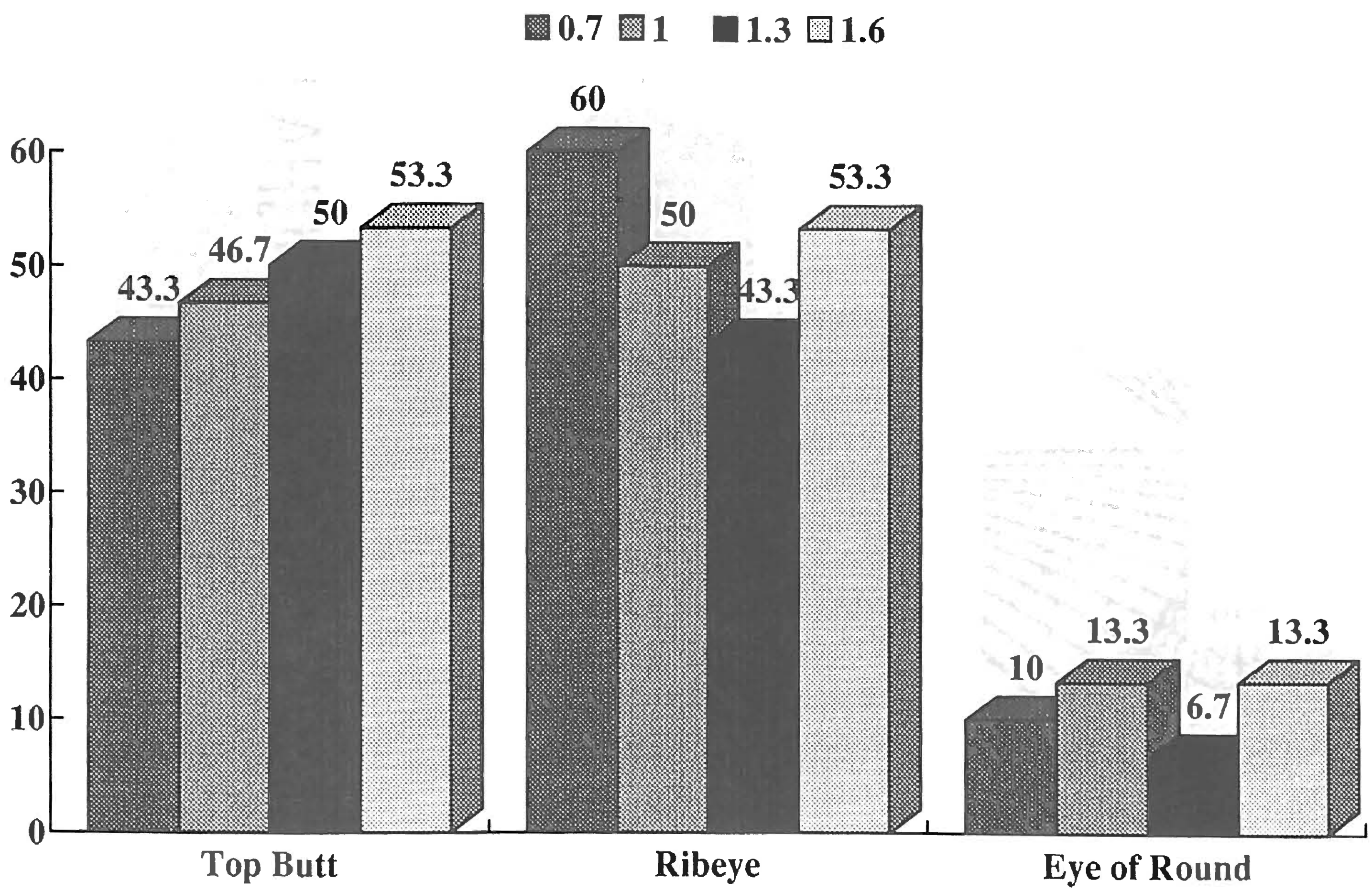


Figure 6. Percentage very tender by fat thickness

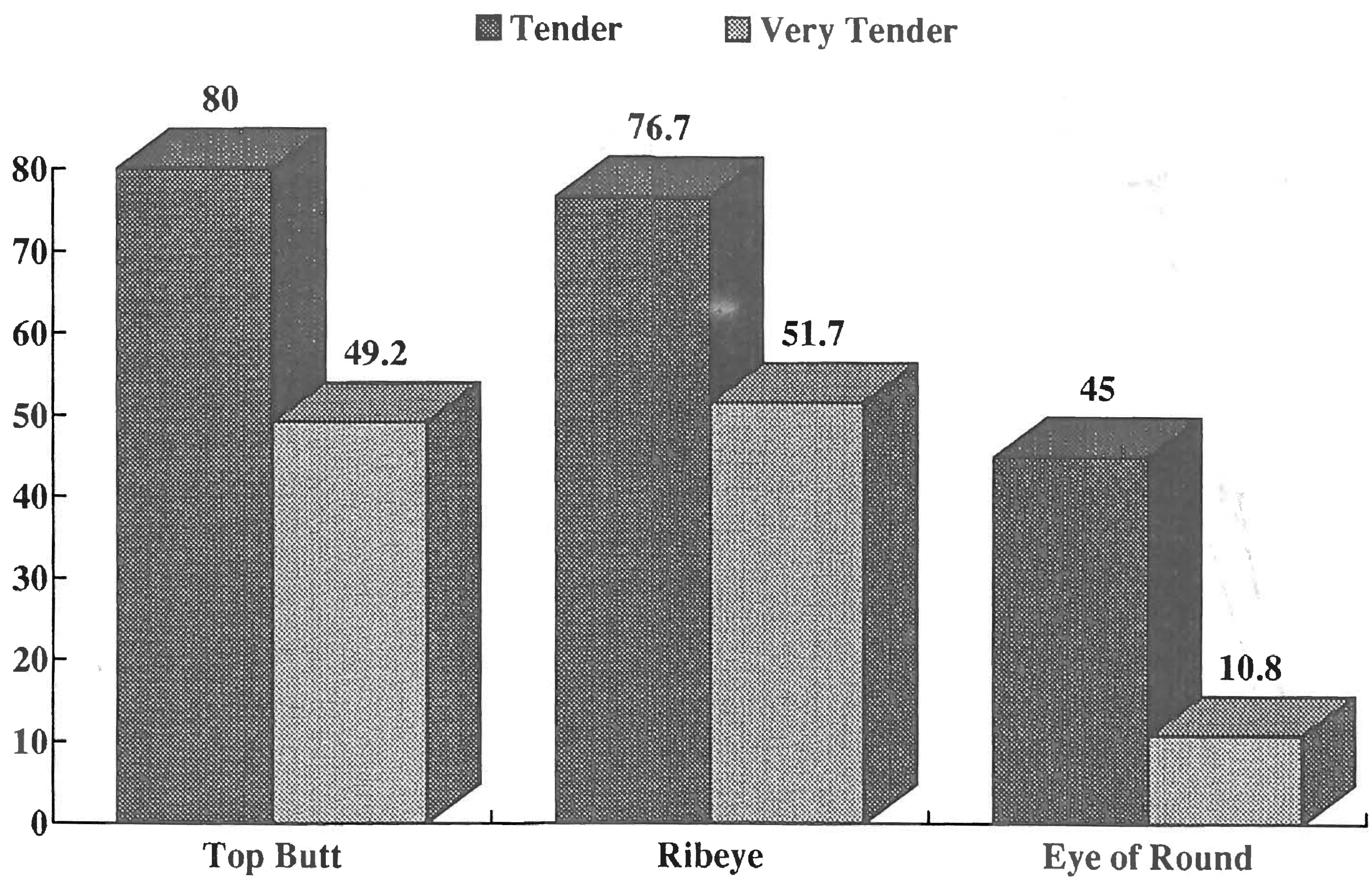
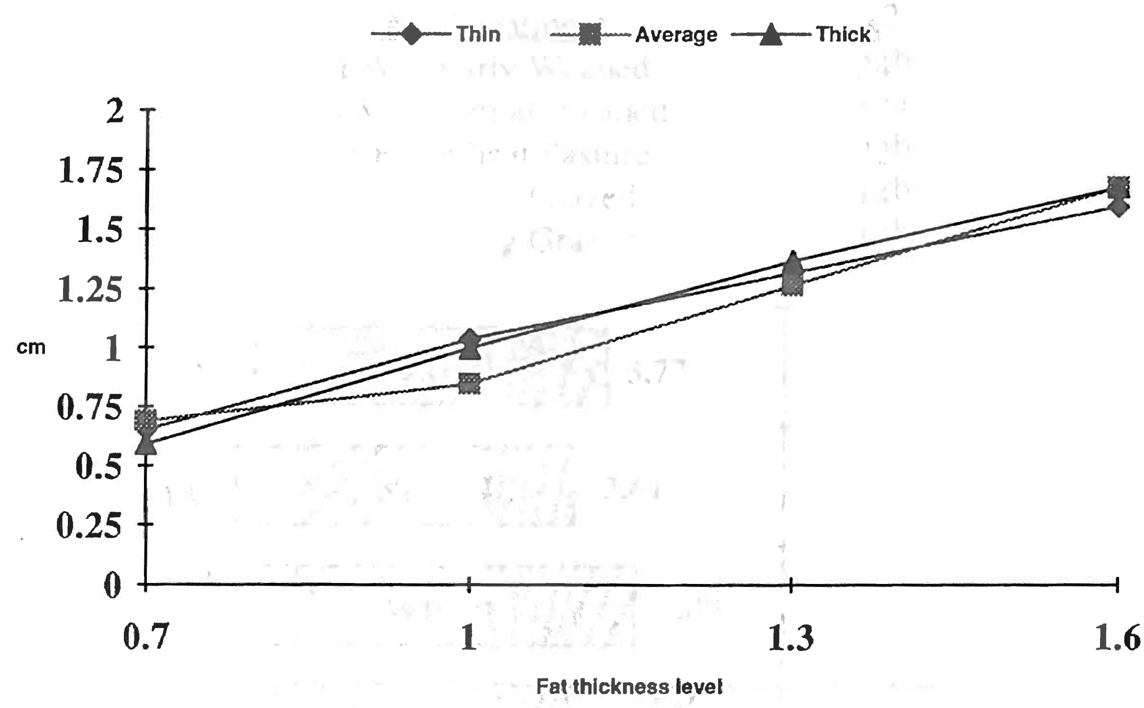
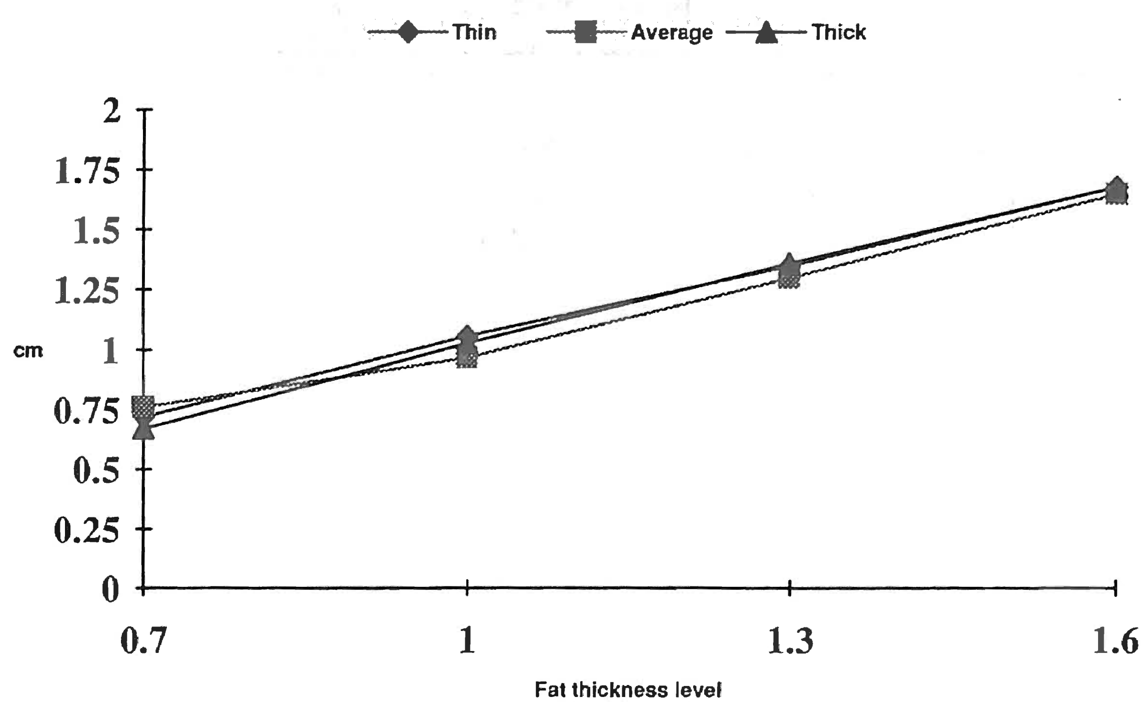


Figure 7. Percentage tender and very tender by steak type



a. Fat thickness



b. Adjusted fat thickness

Figure 8. Fat thickness and adjusted fat thickness response to fat x muscle interaction

Age Treatment	s^2
EW = Early Weaned	$.24^b$
NW = Normal Weaned	$.57^a$
WP = Wheat Pasture	$.22^b$
SG = Short Grazed	$.14^b$
LG = Long Grazed	$.15^b$

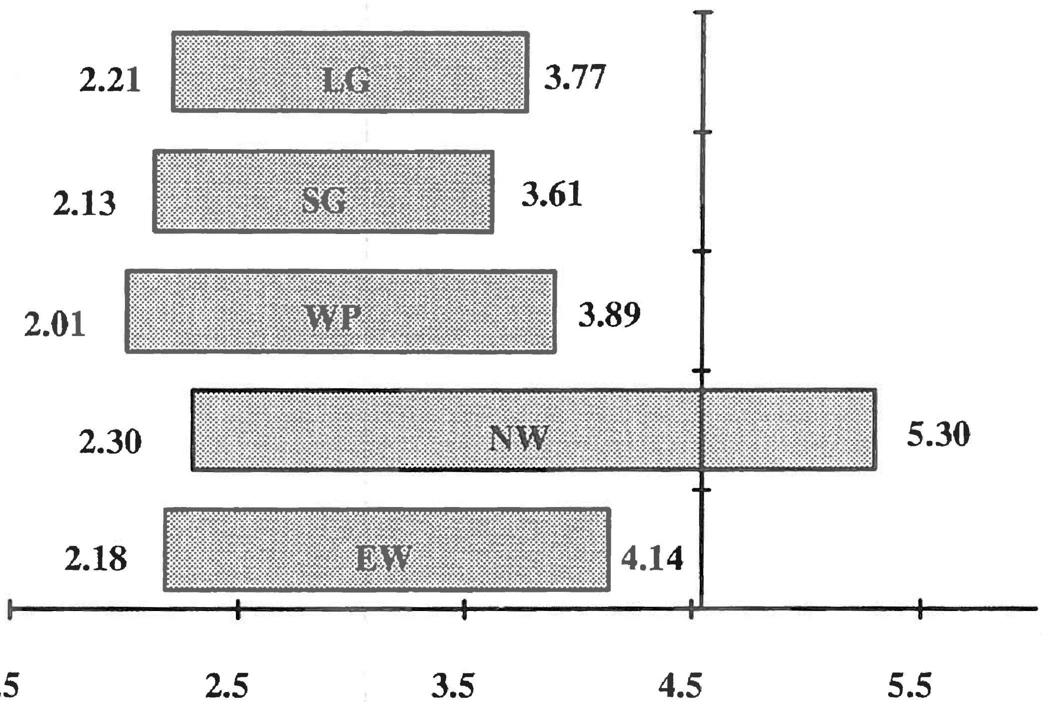


Figure 9. Variation (reported as the mean ± 2 standard deviations) in shear force within treatment for the ribeye steak postmortem aged 28d

Table 1. Simple correlation coefficients

Item	Cook time	KPH, %	Carcass wt, kg	Maturity Overall	Maturity Lean	Maturity Skeletal	Ribeye area, cm^2	Adj. fat thickness, cm	Marbling score	Shear Eye of round	Shear Top butt	Shear Ribeye
Shear force, kg												
Ribeye	.34**	-.13	.25**	.07	-.07	.12	.24**	.02	-.20*	-	-	-
Top butt	.29**	.02	.10	.14	-.01	.16	.12	-.14	-.18*	-	-	-
Eye of round	.09	.05	.10	.19*	-.02	.21*	.18*	-.05	.03	-	-	-
Marbling score	-.06	.04	.10	.01	-.18*	.10	.10	.03	-			
Adj. fat thickess, cm	.04	-.06	.16	-.01	-.09	.03	-.03	-				
Ribeye area, cm^2	.20*	-.12	.39**	.08	-.24**	.21*	-					
Skeletal maturity	.05	-.01	.17	.90**	-.00	-						
Lean maturity	-.11	.05	-.03	.42**	-							
Overall maturity	.00	.02	.14	-								
Carcass wt, kg	.26**	.04	-									
KPH, %	-.02	-										
Cook time	-											

* $P < .05$

** $P < .01$

Table 2. Shear force variances for each steak stratified by treatment group

Steak	Early weaned	Normal weaned	Wheat pasture	Short grazed	Long grazed	Effect[a]
Ribeye	.36	.78	.26	.19	.22	EN, DB
Clod	.18	.36	.22	.15	.22	-
Top round	.55	.55	.47	.29	.24	DB
Top butt	.33	.52	.48	.30	.49	-

[a] EN = Significant difference ($P<.05$) for early weaned (EW) vs normal weaned (NW) steers; DB = Significant difference ($P<.05$) for steers sent directly to the feedlot (EW, NW) vs backgrounded steers (WP, SG, LG).

VITA

Brandon Joe Burton

Candidate for The Degree of

Master of Science

Thesis: EFFECTS OF AGE AT SLAUGTER AND CARCASS TRAITS ON BEEF TENDERNESS VARIATION

Major Field: Animal Science

Biographical:

Personal Data: Born in Wichita Falls, Texas, December 11, 1968, the son of Kenneth J. and Judy A. Burton.

Education: Graduated from Big Pasture High School, Randlett, Oklahoma, May, 1987; received a Bachelor of Science in Animal Science from Oklahoma State University, Stillwater, May 1991; completed the requirements for the Master of Science Degree in Food Science at Oklahoma State University, December, 1993.

Professional Experience: Raised on a small beef cattle farm in Southwestern Oklahoma; employed by Oklahoma State University Animal Science Department: Meat Laboratory, Graduate Research, Teaching Assistantship and Meat Technology Lecturer.

Professional Organizations: American Society of Animal Science, Animal Science Graduate Student Association.