THE EFFECT OF FATNESS, CHILLING RATE AND SEX GROUP ON QUALITATIVE PROPERTIES OF BOVINE CARCASSES

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
HSIANG CHIA LEE
1976

ABSTRACT

THE EFFECT OF FATNESS, CHILLING RATE AND SEX GROUP ON QUALITATIVE PROPERTIES OF BOVINE CARCASSES

By

Hsiang Chia Lee

Ten cows, 10 Holstein steers, 10 bullocks and 20 beef-type steers were included in this study. Each sex group of cattle was divided into two fatness groups. The right sides of each carcass were placed in a -1° to 1°C chilling cooler (fast chilling) immediately following the slaughter. Left sides from each carcass were placed in a 14° to 16°C chilling cooler (slow chilling). After 24 hr both sides were moved to a 0° to 2° cooler for the remainder of a 8 days storage period.

At 2 and 8 days postmortem longissimus muscle samples were removed from the lumbar region for panel tenderness, Warner-Bratzler shear, sarcomere length, myofibrillar fragmentation, collagen, moisture and ether extract determinations.

At 48 hr and 8 days postmortem, steaks from slow chilled carcasses of cows, Holstein steers, bullocks and beef-type steers were more tender than those chilled rapidly. However, the differences in chilling rate from the fat group of cows, bullocks and Holstein steers were not significant. The tenderness of steaks between fat and thin carcasses under the same chilling treatment showed a tendency for fat carcasses to be more tender than those from thin carcasses. This tendency was

significant ($P < .05$), except for the cows, Holstein steers and bullocks chilled slowly and beef-type steers chilled at either rate. All steaks at 8 days postmortem were more tender than 2 days steaks. However, only fat cows, thin Holstein steers and thin bullocks were significant.

The sarcomere lengths of myofibrils from slowly chilled carcasses were greater than those from rapidly chilled carcasses. After 8 days postmortem aging, sarcomeres were shorter than those at 2 days. Irrespective of chilling rate and degree of fatness, sarcomere length was not significantly different in any of the treatments studied. Sarcomere length was not significantly correlated with tenderness.

Myofibrils of longissimus muscles from slow chilled carcasses had more fragments than those from fast chilled carcasses. Significant differences were observed between the carcasses at 2 days and 8 days postmortem. Chilling treatment appeared to have a greater effect on myofibril fragmentation in beef-type steers than did postmortem aging. However, none of these differences was significant ($P < .05$). Fragmentation was highly correlated with tenderness ($P < .01$).

Quantity of intramuscular collagen did not contribute significantly to meat tenderness. Moisture content was negatively correlated with panel tenderness ($P < .05$) but was not correlated with Warner-Bratzler shear value. Moisture content was highly associated with ether extract ($P < .01$). Degree of marbling and 12th rib fat thickness were not significantly correlated with tenderness.

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By

Hsiang Chia Lee

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Animal Husbandry

1976

ACKNOWLEDGEMENT

The author wishes to express sincere appreciation and thanks to his major professor, Dr. R. A. Merkel, for his guidance and support throughout this study and for his help in preparing this manuscript.

Appreciation is also expressed to Dr. A. M. Pearson and Dr. W. G. Bergen for serving as members of the guidance committee. Special thanks are extended to Dr. W. T. Magee and Dr. J. L. Gill for their assistance with the statistical analysis and to Mrs. C. M. Yang for computing all the data.

The author is grateful to Mrs. Dora Spooner for her assistance throughout this study and to Mr. J. R. Anstead for slaughtering all cattle used in this study. The author is appreciative of the guidance and discussions with all the members in the Meat Laboratory.

The author is indebted to his wife, Jane, for her understanding, encouragement and typing of this manuscript.

Lastly, the author expresses his appreciation to his parents, Mr. and Mrs. S. E. Lee, for their continued support throughout his educational pursuits.

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INTRODUCTION

Refrigeration is the most widely used method of meat preservation. Fast and early refrigeration can reduce or limit microbial proliferation and enzyme and chemical reactions that cause deterioration and spoilage, lower the extent of moisture loss or shrink that results in a dry, shriveled, dark and unattractive surface and permits speedier and hence more economical processing. There is little doubt, however, that the rapid chilling treatments for beef, pork, lamb and veal probably cause some toughening as a consequence and shortening among beef and lamb carcasses, particularly. This is recognized as cold shortening.

Cold shortening was first observed by Locker and Hagyard (1963). They observed that excised and unrestrained beef muscle shortened more rapidly at $0^{o}C$ than at any other temperature and the minimum shortening occurred at $14^{o}C$ to $19^{o}C$. The shortening occurred while about 40% of the ATP still remained and the sarcoplasmic reticulum failed in retaining the Ca^{2+} ions and the Ca^{2+} ions are released from the sarcoplasmic reticulum. In the presence of Ca^{2+}, the inhibitory effect that the regulatory complex (troponin and tropomyosin) has to prevent actin from activating the myosin ATPase is removed when calcium is bound to troponin. ATP is then split, actin combines with myosin and muscle contraction occurs.

Cold shortening will decrease the tenderness and shorten the length of muscle. The Warner-Bratzler shear, taste panels, sarcomere length measurement were used in this research to determine the extent

of cold shortening and rigor resolution.

Fat is a relatively good insulator, and is capable of significantly retarding the rate of heat transfer from a carcass. The primary purpose of this research was to investigate whether subcutaneous and intramuscular fat effects the tenderness of muscles by insulating the muscle fibers during postmortem chilling, as well as, the rate of temperature changes and pH reductions and their influence on cold shortening.

Postmortem aging of meat, sometimes called conditioning, ripening, or hanging, is a common practice in meat merchandizing to improve the tenderness of beef. The second purpose of this research was to determine whether aging will nullify the effect of cold shortening.

The third purpose of this research was to study the different effects of cold shortening on bullocks, steers and cows. Hostetler et al. (1975) reported that muscle samples from bullock and steer carcasses did not differ in sarcomere length, and gave similar response in shortening during onset of rigor. However, muscles from steer carcasses were significantly more tender than those from bullock carcasses.

A fourth purpose of this study was to elucidate whether connective tissue, ether extract and moisture content will affect the extent of cold shortening. Since most work with connective tissue has been concerned with tenderness, little information is available concerning chemical components related to the effect of cold shortening.

LITERATURE REVIEW

Postmortem Changes in Meat

The death of an animal does not signal the death of its musculature. Many of the reactions and responses characteristic of the living material are able to continue relatively undiminished into the postmortem phase except as limited by the inability of the tissue to synthesis or to remove certain metabolites.

Chemical Changes. The chemistry of postmortem changes in muscle is essentially anaerobic glycolysis. This is the conversion of glycogen to lactic acid and can be easily estimated by following pH decline (Bate-Smith and Bendall, 1949, 1956; Bendall, 1960 and Cassens, 1966). When adequate glycogen is present, postmortem glycolysis in mammalian muscle frequently results in the pH falling to an ultimate value of 5.4 to 5.5. However, in some muscles the ultimate pH is appreciably higher than this (Lawrie, 1955; Howard and Lawrie, 1957; Lawrie et al., 1959). Excessively low values (below 5.1) have also been noted by Lawrie et al. (1958) in pig muscle. Bate-Smith and Bendall (1949) noted that an ultimate pH value of 5.3 appeared to be a limiting value, below which glycolysis was completely inhibited. They considered that the most probable explanation for this was that one or other of the enzymes involved in glycolysis was increasingly inhibited as the pH fell. Glycolysis ceased in some muscles at appreciably higher values.

Briskey and Lawrie (1961) suggested that in these muscles either the phosphorylase was inactivated more readily or the glycogen is less accessible to attack.

The rate of pH fall postmortem varies considerably in certain skeletal muscles (Ludvigsen, 1954; Wismer-Pedersen, 1959; Briskey and Wismer-Pedersen, 1961; McLoughlin, 1963; Elliot, 1965). The rate of pH and ATP change is significantly influenced by the muscle temperature (Bate-Smith and Bendall. 1949; Bendall, 1951; Marsh, 1954; Marsh and Thompson, 1958; Bendall, 1960; de Fremery and Pool, 1960; Cook and Langsworth, 1966; Cassens and Newbold, 1967). But the effect of temperature is not the same with all muscles and temperature will have very little influence upon the ultimate muscle pH. The greatest drop in pH and loss of ATP occurs during the first 2 to 3 hr postmortem (Kastner et al., 1973). Cassens and Newbold (1967) found that in the range 5°C to 37°C the pH of the ox sternomandibularis (neck) muscle fell more slowly at lower temperatures and there was a period of several hours during which the pH of muscle stored at 1°C fell faster than that of muscle at 5°C. The ultimate pH attained at 1°C or 5°C was significantly higher than that attained at 15°, 25° or 37°C. With rabbit psoas muscle, Bendall (1960) reported that the lower the temperature in the range 0°C to 37°C the more slowly the pH fall. The extent of the pH fall may depend on the amount of glycogen present in the muscle at the time of slaughter. The glycogen content can be reduced by starvation, exhausting exercise, the imposition of pre-slaughter stresses of various sorts, or by struggling at the time of slaughter

(Lawrie, 1966). It can be reduced by the pre-slaughter injection of insulin (Bate-Smith and Bendall, 1947, 1949; Howard and Lawrie, 1956, 1957) or adrenalin (Radoucco-Thomas et al., 1959 de Fremery and Pool, 1963; Klose et al., 1970; Khan and Nakamura, 1970; Bouton et al., 1971). Struggling at death will accelerate the rate of postmortem glycolysis because under such conditions phosphocreatine is depleted and the resynthesis of ATP is primarily dependent on the anaerobic breakdown of glycogen (Bendall, 1960). The release of adrenalin at death will contribute a postmortem biochemical environment conducive to an increased rate of anaerobic glycolysis (Cori, 1956). Adrenalin converts the inactive (β) form of phosphorylase to the active (α) form. McLoughlin (1970) found that anoxia just before or at death and the release of adrenalin probably contributed appreciably less to the effect of the death reaction than did muscular contraction. Muscle contraction at death appreciably influenced the course of postmortem glycolysis.

Bodwell et al. (1965) reported that the average initial pH value of 6.99 declined to 5.46 at 48 hr and was 5.57 at 480 hours. Glycogen appeared to be stoichiometrically degraded to lactic acid and reducing sugars. The sum of these constituents was approximately constant at all times postmortem, if expressed in terms of glucose equivalents.

Physical Changes. At the time of slaughter, muscle is plastic and highly extensible; from the time of death muscle plasma goes through a series of characteristic changes. This is rigor mortis, a condition of rigidity or contracture which develops in a matter of hours after

death (Wierbicki et al., 1954). In full rigor it is firm and relatively inextensible. In addition to losing its extensibility, unrestrained muscle shortens during the development of rigor mortis. Various studies have established that postmortem shortening occurs by a sliding of the thick and thin filaments such as occurs during physiological contraction (Bendall, 1951; Stromer et al., 1967; Stromer and Goll, 1967) and that this shortening is the primary cause of carcass stiffening during the development of rigor (Okubanjo and Stouffer, 1975). Huxley (1964) found that during muscular contraction the interdigitation of myosin with actin filaments drew the Z-band together reducing the sarcomere length and increasing the cross-sectional area in inverse proportion. Buck and Black (1967) studied seven pairs of muscle strips prepared from bovine longissimus muscle in two degrees of stretch-tension during rigor and indicated that the average muscle fiber diameter was significantly smaller in stretched muscle strips. Onset of rigor mortis is defined as the period of increasing isometric tension development (Busch, 1967; Goll, 1968; Goll et al., 1970, 1971; Jungk et al., 1967). Attempted shortening (i.e., isometric tension development) by muscles on opposing sides of the same bone would cause carcass stiffness or rigidity. These physical changes have been quantified during normal rigor development through the measurement of the isometric tension developed by Jungk et al. (1967), Schmidt et al. (1968), Chrystall et al. (1970) and Busch et al. (1972).

The coincidence between the onset of rigor mortis an appreciable increase in the modulus of elasticity was reported by Bate-Smith (1939)

who noted that new crossbonds were formed between the muscle contractile units following the loss of ATP.

The duration of the rigor process depends on three things : the initial level of ATP, the initial glycogen reserve, and the initial reserve of phosphocreatine which acts as an important source of resynthesis of ATP (Lohmann, 1935; Bendall, 1951). Newbold and Harris (1972) reported that shortening could occur only while ATP was present. When all the ATP was lost the rigor process was complete, and the muscle was fixed in whatever state of contraction it happened to be at the time. Kushmerick and Davies (1968) as well as Schmidt and Briskey (1968) have also shown that an appreciable degradation of both ATP and ADP is essential for the development of muscle inextensibility. Conversely, postmortem shortening requires ATP as an energy source.

Goll et al. (1970) have stated that the reason rigor mortis does not occur until just before the complete loss of ATP is that the decline in ATP concentration lowers the ability of the sarcoplasmic reticulum to accumulate calcium ions against a concentration gradient, and this release of calcium ions is required to initiate tension development. Busch et al. (1967) and Jungk et al. (1967) reported separately that after a given period of postmortem storage both rabbit and bovine muscle strips gradually developed tension when suspended isometrically. Jungk et al. (1967) found that the time at which isometric tension development began depended on environmental temperature of the strips and on antemortem condition of the animal. Exhausted muscle containing little or no glycogen will pass more quickly into rigor than rested muscles. Rapid loss of extension has

been reported to begin when the ATP level has fallen to about 30% of its initial level in horse muscle by Lawrie (1953) and in chicken muscle by de Fremery and Pool (1960), to about 25% and 50% in rabbit muscle at 17°C and 37°C, respectively, by Bendall and Davey (1957) and to about 67% in beef muscle by Howard and Lawrie (1957). Two different values 87% (Lawrie, 1960) and 30% (Bendall et al., 1963) have been reported for pig muscle. Busch (1972) reported that tension development in rabbit and porcine longissimus muscle was minimal and similar at 2°, 16° and 25°C but increased greatly if the strips were incubated at 37°C. Bovine semitendinosus muscle strips developed most isometric tension when stored at 2°C, and least isometric tension at 16° to 25°C. Isometric tension development in bovine muscle, like rabbit and porcine muscle, reached a maximum sooner after death at 37°C than it does at 2°, 16° or 25°C. Maximum isometric tension was usually attained within 3 to 16 hr after death. After maximum isometric tension had been reached, ability of the muscle strip to maintain this tension development in the absence of ATP gradually declined and isometric tension therefore also gradually declined. Decline of postmortem isometric tension occurred more slowly than isometric tension development, and 24 to 48 hr of postmortem storage were required for a 50% to 80% decline in isometric tension.

Loss of ability to maintain this tension development would result in dissipation of rigidity, or in carcass softening. The period of isometric tension decline is defined as resolution of rigor mortis (Busch et al., 1967; Goll, 1968; Goll et al., 1970, 1971; Jungk et al., 1967). Busch et al. (1967) and Jungk et al. (1967) stated that

postmortem isometric tension decline was most noticeable at environmental temperatures under 16°C and decline of isometric tension might not occur at environmental temperatures near 37°C. Busch et al. (1972) further examined the postmortem changes in isometric tension and reported that decline of isometric tension was most rapid at 37°C and is somewhat slower at 2°C or 16°C. Bovine muscle strips lost all isometric tension after 30 hr at 37°C and rabbit psoas muscle usually lost all its isometric tension after 12 to 24 hr at 37°C.

Cold Shortening. The shortening of excised muscle during onset of rigor increased with storage temperature from 17°C to 37°C was reported by Bendall (1951) with rabbit muscle and by Marsh (1954) with beef. However, Locker and Hagyard (1963) investigated excised unrestrained beef muscle which was stored at 0°C and found that while undergoing rigor mortis it displayed more rapid shortening than at any other temperature and observed that muscle stored at 14°C to 19°C had minimal shortening. The length change of ox neck muscle placed at 0°C to 2°C within 2 or 3 hr postmortem, usually exceeded 50% and might attain 60% of the initial excised length. This phenomena is known as cold shortening. Cold shortening not only occurred in beef sternomandibularis muscle, but also was found to occur for beef longissimus muscle and to a lesser extent for beef psoas major muscle. Ovine (Cook and Langsworth, 1966; Marsh, 1968), porcine (Galloway and Goll, 1967; Henderson et al., 1970; Hendricks et al., 1971), rabbit red semitendinosus (Henderson et al., 1970) and avian (Smith et al., 1969) muscle have also been shown to cold shorten.

Locker and Hagyard (1963) also pointed out that cold shortening could not be provoked at all in the white muscles of the rabbit. Jungk and Marion (1970) detected no cold shortening in turkey pectoralis held at 4°C, but Smith et al. (1969) reported that excised pectoralis major muscles of chicken and turkey shortened significantly more at 0°C than 12°C to 18°C. Newbold (1966) reviewed the chemical changes involved in cold shortening and indicated that shortening occurred while about 40% of the ATP still remained. This demonstrated the observations of Marsh and Thompson (1958), Locker and Hagyard (1963) and Marsh and Leet (1966) that cold shortening decreases as the period between slaughter and exposure to cold or freezing conditions is extended.

With phase microscopy, Stromer et al. (1967) found that the 16°C-24 hour samples exhibited a marked thickening of the A-band, a shortening of the I-band, and a replacement of the H-zone by a dark line or band. The 2°C-24 hour samples showed only alternating light and dark bands of nearly equal width, which were described as a supercontracted pattern.

In the same year, Stromer et al. (1967) studied the myofibril with an electron microscope and found that myofibrils from muscle sampled 24 hr postmortem at 2°C were supercontracted with thick filaments pushed against or through the Z-line, and no trace of I-bands remained. Myofibrils from muscle sampled 24 hr postmortem at 16°C were contracted, but to a much lesser extent than 2°C-24 hour myofibrils.

Voyle (1969) studied the histology of beef neck muscle shortened

at 2°C using the light and electron microscopes. He found that less than half the fibers had actively shortened with a mean sarcomere length of 1.1 micrometers. The others were crimped, although these also had shortened substantially (mean, 1.6 μm). A control, allowed to go into rigor at 18°C restrained only by its own suspended weight, had only straight fibers (mean, 2.3 μm). Individual fibers among those actively shortened contained both contraction nodes and stretched areas as well as breaks.

Thaw Rigor. Thaw rigor or sometimes called thaw shortening was first observed by Moran (1930) in frog muscle in a strip of pre-rigor muscle which was frozen fairly rapidly and thawed at a later time. Extensive shortening took place within quite a short period which was accompanied by copious " drip ".

Marsh and Thompson (1958) studied thaw rigor in lamb, using excised longissimus muscle and found that if lamb was frozen immediately and thawed at 16°C to 20°C, there was an average shortening of 72%, with a 27% loss in weight as drip. Muscle frozen in rigor and then thawed, shortened by only 5% with 3% drip. If muscle was frozen pre-rigor, the drip increased with ambient thawing temperature, rising rapidly between 5°C and 10°C. Muscle thawed at -3.5°C for four days did not shorten or have any appreciable drip losses.

Bendall (1960) noted that considerable thaw rigor occurred in rabbit muscle before the ATP level had fallen significantly and that after shortening had proceeded rapidly for a few minutes there was a

temporary increase in length of loaded strips followed by further relatively slow shortening. Newbold (1966) showed that the rapid and drastic physical events of thaw rigor precede the accelerated metabolic run down. The onset of thaw rigor occurred while the amount of ATP was relatively high (40%). The pH fall and disappearance of ATP were almost complete within an hour.

Okubanjo *et al.* (1975) reported that the development of thaw tension occurred at all thawing temperatures before the decrease in level of ATP. When thaw rigor occurred, the ability of the sarcoplasmic reticulum to accumulate Ca^{2+} ions was destroyed so that Ca^{2+} ions were released in the presence of ATP and muscle contraction had occurred.

Thaw shortening in excess of 70% has been reported in rabbit *psoas* muscle by Lawrie (1968), ox neck muscle by Marsh and Leet (1966), Scopes and Newbold (1968) and sheep *longissimus* muscle by Marsh and Thompson (1958).

Marsh and Thompson (1958) stated that thaw shortening in muscle frozen pre-rigor could be prevented by keeping the muscle at a temperature just below its freezing point for several days before allowing it to thaw. Under these conditions the chemical changes associated with the development of rigor mortis were completed while there was sufficient ice in the muscle to prevent shortening.

Factors Affecting Tenderness

Tenderness is one of the most important palatability factors in the acceptance of beef and meat from other species. The tenderness of meat is notoriously variable. It varies not only among anatomically different muscles but also among corresponding muscles from animals of the same or different species. Factors that influence tenderness were roughly divided into three time-based groups by Marsh (1972): those which are determined before the birth of the animal (e.g. breed, sex), those modified by management during life (age, acidity, fat content, feed), and those affected by treatment before and after the musculature set in rigor mortis (hot boning, suspension methods, chilling rate, aging, cooking method, etc.). This review lists some of these factors and their relationships to tenderness.

Shortening Effect. In 1960, Locker concluded that there was a relationship between postmortem shortening and tenderness. Recently, McCrae et al. (1971) observed that the same relationship for lamb muscles as that previously found for ox neck muscle.

Pre-rigor excised breast muscle from chicken was considerably tougher than muscle that was left attached to the skeleton as reported by Lowe and Stewart (1946). Ramsbottom and Strandine (1949) removed the longissimus muscle from beef carcasses before chill and reported that these samples were considerably less tender than paired non-excised muscles. Locker and Hagyard (1963) reported that the stimuli of

excision caused a small quantity of the contraction ultimately obtained.

Using ox muscles excised soon after slaughter, Marsh and Leet (1966) and Davey et al. (1967) showed that shortening up to 20% of the excised length produced relatively small changes in tenderness, whereas further shortening from 20% to 40% produced a several-fold increase in shear value. With further shortening there was a progressive decrease in toughness until at 60% shortening shear values were of the same order as those obtained at 20% shortening or less. Herring et al. (1967) and Davey et al. (1967) reported that stretching muscle and allowing it to go into rigor in this condition had little effect on tenderness.

Utilizing isometric tension measurements, Jungk et al. (1967) suggested that the increase and decrease in tension postmortem, probably corresponded to similar phases of decreasing and increasing tenderness. However, Busch et al. (1967) reported that isometric tension measurements are not necessarily a valid method for determination of shear values. They concluded that shortening contributed to muscle tenderness, but probably was not the main contributor.

Aging Effect. Aging of carcass beef at refrigeration temperature for several days is regarded as a necessary procedure to obtain retail beef of satisfactory tenderness. Although research reports on aging effects appeared about 70 years ago (Lehmann, 1907), reasons that cause meat tenderness is still not well understood.

Stanley et al. (1974) suggested that at least four separate mechanisms might be at work during postmortem aging-specific chemical

changes at the Z-line and perhaps actin-myosin interaction site, catheptic activity, degradation of collagen cross-links and general microbial action.

Davey et al. (1967) demonstrated that when the amount of shortening of ox neck muscle increased above 20% the tenderness improvement with aging became smaller. At 40% shortening or greater there was no improvement. However, Herring et al. (1967), using ox semitendinosus muscle, showed that during aging, muscle which had shortened to a sarcomere length of about 1.5 μm improved in tenderness.

Busch et al. (1967) and Sleeth et al. (1957, 1958) reported accelerated tenderization with high aging temperatures. Henderson et al. (1970) found that Z-line degradation occurred more rapidly upon storage at 25°C or 37°C versus storage at 2°C or 16°C.

Goll et al. (1970), Hay et al. (1973) evaluated muscle with transmission electron microscopy and pointed out that postmortem tenderization might be associated with ultrastructural changes in myofibrils including degradation of the Z-line and changes in the actin-myosin interaction. Hegarty et al. (1973) reported structural deterioration in myofibrils from "normally" aged and rigor - stretched turkey and porcine muscle. Z-lines were diffuse and sometimes separated into clumps of Z-line material in samples examined 6 to 9 hr postmortem. Deterioration was more extreme after 24 hr aging and structural changes were more rapid in turkey than in porcine muscle.

The tendency for myofibrils to fragment when mechanical stress is applied has been used to evaluate structural deterioration during aging.

Fragmentation may result from weakening of bonds between the actin filaments and the Z-line material (Johnson and Bowers, 1976). Dutson and Lawrie (1974) studied the effect of postmortem aging on bovine muscle tenderness and observed that as time postmortem increased, the protein content of the supernatant from homogenized muscle tissue increased and the muscle became more tender. Moller et al. (1973) found a correlation coefficient of .78 between the light absorbance of a myofibril suspension and beef tenderness at 7 days postmortem.

Stanley (1974) studied the effect of aging on beef psoas and semitendinosus muscle by scanning electron microscopy and found that myofibrils immediately postmortem were unbroken and crossed by continuous transverse elements at the level of the Z-line. At six days postmortem, breaks were beginning to be seen in myofibrils and transverse elements were less pronounced. At 12 days postmortem these trends had intensified and a general deterioration in structure might be seen.

Eino and Stanley (1973) and Stanley and Eino (1974) found that catheptic activity reached its maximum activity between 4 and 6 days postmortem. Since sarcomere length decreased up to 2 day postmortem and increased thereafter while tenderness generally increased over the first 2 days, it might be other changes in the myofibril such as weakened actin - myosin interactions or Z-line degradation which caused the differences in tenderness.

Connective Tissue Effects. The character and content of connective tissue is one of the major contributors to muscle tenderness.

Lesser quantities of connective tissue result in greater tenderness, and consequently the shank muscles are not as tender as longissimus or psoas major muscles. Cover et al. (1962), Herring et al. (1967) and Field et al. (1970) reported that some muscles had more collagen than others and the amount of collagen in various muscles had a negative relationship to tenderness. Goll et al. (1963) McClain et al. (1965) and Herring et al. (1967) showed that as tenderness decreased due to increased animal age there was essentially no change in the total amount of collagen present in the muscle, and that, although tenderness of muscle increased due to postmortem aging, there was little change in the total amount of collagen over the postmortem aging period. However, Goll et al. (1964) and Carmichael and Lawrie (1967) showed that differences in the character of the connective tissue could be observed in older, tougher muscle compared with more youthful, tender muscle. In addition, Goll et al. (1963, 1964), Hill (1966) and Herring et al. (1967) also reported that the amount of heat labile or percentage soluble collagen decreased with increase in animal age over a wide range of ages. This decrease was associated with the decreased tenderness of aged animals.

Changes in the molecular structure of collagen due to postmortem aging was reported by Kruggel and Field (1971), Pfeiffer et al. (1972) and Stanley and Brown (1973). They found that there was an increase in the amount of smaller molecular weight subunits and a decrease in the amount of larger molecular weight subunits that could be extracted from muscles with increased postmortem aging.

Kruggel and Field (1971) and Pfeiffer et al. (1972) indicated that

the amount of extractable low molecular weight collagen subunits was increased by stretching a muscle. Pfeiffer et al. (1972), Shimokomaki et al. (1972) and Bailey (1972) reported that tenderness might be affected by the degree of cross-linking in intramuscular connective tissue.

Sex Effect. The facts that bulls grow faster than steers or heifers, are leaner, more efficient and have larger longissimus muscles and that steers are leaner than heifers and cows have been reported by many researchers.

Locker and Hagyard (1963) reported that muscles from steer carcasses sustained greater shortening than samples from cow carcasses when stored at 19°C and 31°C. However, when carcasses were refrigerated at 2°C, the samples from cow carcasses shortened to a greater extent than the muscle sample from steer carcasses.

Wierbicki et al. (1956) found that at 3 days the untreated steers were more tender than the diethylstilbestrol treated bulls. At 13 days postmortem the differences between heifers, bulls and steers were not significant.

Hedrick et al. (1969) showed no significant differences in Warner-Bratzler shear values of steaks from bulls less that 16 months of age and steers and heifers of comparable chronological age. However, shear values of steaks from more mature bulls were greater than those from steers of heifers at the same age.

Champagne et al. (1969) and Warwick et al. (1970) reported

nonsignificant differences in tenderness ratings between steaks from bull and steer carcasses. In contrast, Field et al. (1966), Hedrick et al. (1969), Arthaud et al. (1970), Hunsley et al. (1971), Reagan et al. (1971) and Hostetler et al. (1975) reported that muscle samples from bull and bullock carcasses were less tender than those from steer and heifer carcasses. When animals were slaughtered at a reasonably young age there is little consumer discrimination against corresponding muscles of any sex group in tenderness.

Fatness Effect. It is generally believed that fatter animals produce meat that is more tender than that from leaner animals. Fatter animals also tend to deposit greater quantities of marbling and the increased deposition of intramuscular fat is associated, although not very highly, with increased palatability of cooked meat. McBee and Wiles (1967) found significant differences in tenderness, juiciness and flavor among carcass grades of Prime, Choice, Good and Standard. Dryden and Marchello (1970) reported a significant correlation between muscle fat content and taste panel tenderness. However, Henrickson and Moore (1965), Walter et al. (1965), Breidenstein et al. (1968), Norris et al. (1971) and Parrish et al. (1973) emphasized that tenderness was not significantly affected by marbling over a wide range of marbling scores.

Cover et al. (1956) and Campion and Crouse (1975) found that although correlations between ether extract, marbling and tenderness were positive, none was very high. Field et al. (1966) used roasts from the longissimus muscle of bulls, steers and heifers, which contained

marbling degrees ranging from traces to moderate, and found that Warner-Bratzler shear scores were not significantly affected by marbling when age was held constant. Significant correlations were found between marbling and palatability for steers and heifers, but not for bulls.

Cross et al. (1972) and Reagan (1974) reported significant ($P < .01$) correlations between intramuscular fat content and sarcomere length in lamb and beef longissimus muscles, respectively, suggesting that marbling might also be related to tenderness via its insulatory effect in reducing the severity of cold shortening induced by low temperature chilling.

Ultimate pH. Mackey et al. (1952) used pork with a pH range of 5.57 to 6.39 and found no relationship between pH and tenderness. However, Bouton et al. (1957) reported a curvilinear relationship between taste panel scores and the ultimate pH of beef muscles (range 5.4 to 6.4) with a maximum toughness at pH 5.9. Penny et al. (1963) and de Fremery (1963) induced high ultimate pH by pre-slaughter injection of epidephrine and/or iodoacetate and found that meat with a high pH was more tender and juicy than that with a low pH.

Miles and Lawrie (1970) reported that shear force values decreased linearly as the pH of rabbit muscles increased from 5.4 to 7.2.

Investigating changes in the ability of muscle proteins to retain water and in mechanical properties as the pH of sheep muscle varied from 5.4 to 7.0, Bouton et al. (1971, 1972) considered that although

ultimate pH influenced both myofibrillar strength and adhesion between muscle fibers, those measurements reflecting myofibrillar toughness were most affected.

Using 20 Hereford steers, Bouton et al. (1973) reported that the taste panel and shear force measurements are linearly and significantly related to pH for both the normal and stretched samples from longissimus, adductor and rectus femoris muscles and tenderness increased with increasing ultimate pH.

Electrical Stimulation. Electrical stimulation was first used to accelerate aging of beef by Harsham and Deatherage (1951). They observed that stimulation of beef carcasses at 3000 volts produced a fall in the pH of muscle to 6.1 in 1 hour. The meat was as tender after 2 days at 1°C as that from unstimulated controls after 18 days at 1°C. de Fremery and Pool (1960) found that electrical stimulation of chicken breast muscle for 15 min increased the initial rates of fall in pH and ATP content.

Hallund and Bendall (1965), Forrest and Briskey (1967), McLoughlin (1970) and Tarrant et al. (1972) reported that, in pigs with a naturally slow glycolytic rate, 30 sec of stimulation approximately doubled the rate of pH fall.

Carse (1973), Chrystall and Hagyard (1976) reported that glycolysis of freshly slaughtered lambs was accelerated by the high voltage (3600 V) electrical stimulation. Longissimus muscle pH in stimulated carcasses fell to below 6 within 1 hr of slaughter, compared with the 14 hr

required by unstimulated muscle. Shear force values for muscles from leg and loin cuts of stimulated carcasses roasted from the frozen state were about half of those from unstimulated carcasses and there were no deleterious effects due to stimulation.

Davey, Gilbert and Carse (1975) stimulated beef sides for a 1 to 2 min period with high-voltage (3600 V) electric stimulation immediately after carcass dressing and found that the time for rigor development was reduced from 24 hr to about 5 hours. The stimulated carcasses even though chilled rapidly were still warm at rigor entry. Cold shortening and toughening would not develop under these conditions and the meat could be aged to a high degree of uniform tenderness.

MATERIALS AND METHODS

Experimental Animals

This study was divided into two separate experiments. Experiment 1 consisted of a study to observe the effect of cold-shortening on bovine muscle and its relationship to sex, fatness, postmortem aging and rate of postmortem pH decline. Ten cows, ten bullocks and ten Holstein steers were used in the first experiment of this study. Each group of cattle was equally divided into two fatness ranges according to fat thickness at their 12th rib and this breakdown is shown in table 1.

TABLE 1. DISTRIBUTION OF CARCASSES WITHIN SEX AND FAT THICKNESS GROUPS

Experiment	Sex	Fat thickness (12th rib) [a]	
		Fat group	Thin group
1 [b]	Cows	.91 (.76 - 1.27)	.18 (.01 - .25)
	Holstein steers	.69 (.32 - 1.02)	.18 (.13 - .25)
	Bullocks	.48 (.41 - .51)	.18 (.01 - .38)
2 [c]	Beef-type steers	1.65 (.89 - 2.16)	.47 (.25 - .64)

[a]Fat thickness in centimeters measured 3/4 lateral length of longissimus muscle.

[b]Five carcasses per group.

[c]Ten carcasses per group.

Experiment 2 emphasized the effect of cold shortening of beef-type steers with wide differences in fatness. Twenty steers were used in the second experiment of this study and divided into two fatness ranges according to their 12th rib fat thickness (table 1).

Slaughter Procedures

All cattle were slaughtered at the Michigan State University Meat Science Laboratory. They were fasted approximately 17 hr prior to slaughter. Two cattle were slaughtered each slaughter day. The cattle were stunned with a captive bolt pistol, exsanguinated and dressed within 60 min following death. All carcasses were split into right and left side and the right side of each carcass was placed in a -1°C to 1°C chilling-cooler. The left side was placed in a 14°C to 16°C cooler. After 24 hr, both sides were moved to a 0°C to 2°C holding cooler for the remainder of the eight day storage period.

Measurement of pH and Temperature

Internal temperature and pH of the longissimus muscle were monitored during chilling by inserting a thermocouple and a Type 7GR231/100L combination electrode, with a Type 36101 portable pH meter (Kerotest Manafacturing Corp., Pittsburg, Pennsylvania), respectively into the muscle at a point opposite the sixth lumbar vertebra of each side. Temperature and pH measurements were taken on both sides

before the carcasses were moved into the respective chilling coolers, at one, two, three, four, six, eight, 12 and 24 hours. In addition, readings were taken after 48 hr and 8 days postmortem.

Measurement of Body Composition

Fat Thickness. The carcasses were ribbed 48 hr postmortem and single fat thickness measurement of subcutaneous fat was made at the twelfth rib. The measurement was made perpendicular to the outer fat surface at a point 3/4 the lateral length of the longissimus muscle from the vertical process of the twelfth thoracic vertebra (American Meat Science Association, 1967) on the exposed twelfth rib surface of the forequarter.

Marbling. Intramuscular fat was scored in the exposed longissimus muscle at the twelfth rib based on the standard photographs of the Official United States Department of Agriculture Standards for Grades of Carcass Beef (USDA, 1973).

Cutting and Sampling Procedure

In experiment 1, the whole shortloin (13th thoracic through the sixth lumbar vertebra) was removed from each side of the carcass at 48 hr postmortem. One 3.8 cm steak was obtained from the 13th thoracic and first lumbar vertebrae region of each shortloin for moisture, ether

extract, connective tissue, sarcomere length and fragmentation determinations. In addition, two 3.2 cm steaks were removed from the first to third lumbar region for taste panel and Warner-Bratzler shear determinations. The remainder of the shortloin was wrapped in parchment paper and stored at $0^{o}C$ to $2^{o}C$ for an additional six days. After 8 days storage, one 2.5 cm steak was removed from the third lumbar vertebra region of the shortloin and discarded to avoid dessication and any microbial contamination. Then one 3.8 cm and two 3.2 cm steaks were removed from the fourth and fifth lumbar vertebra region of the shortloin for the same determinations as those previously described for the 48 hr samples. In experiment 2, the same procedure for removing steaks from the shortloin was followed, except one 1.6 cm steak was removed for shelf life study posterior to where the first three steaks were taken at 48 hr postmortem and again following the removal of steaks after the 8 days storage period.

A 2.54 cm diameter core was taken from the center of the 3.8 cm thick steak frozen stored at $-30^{o}C$ for sarcomere length and fragmentation study. The remaining portion of each of these steaks was ground (Model T215GA, Hobart MFG. Co., Troy, Ohio) twice with a coarse plate (3.0 mm) and twice with a fine plate (1.5 mm). After grinding it was stored in a freezer at $-30^{o}C$ until moisture, ether extraction, and total hydroxyproline determinations could be performed.

Measurement of Muscle Composition

Moisture - Oven drying. Prior to analysis, the frozen, finely ground samples of the longissimus muscles were thawed in the 0°C cooler for 24 hours. After thawing, samples were mixed by stirring with a spatula. A 5 g sample was weighed into a previously dried and weighed aluminum foil moisture dish. The dishes were placed on a shelf in an electrically heated oven (Model 18, Precision Scientific Co.) at 100°C. At the end of a 24 hr drying period, the dishes were removed to a desiccator to cool at room temperature, weighed and then kept for ether extraction. The moisture was determined on duplicate samples to insure a difference within .25%.

Ether Extraction. The A.O.A.C. (1970) ether extraction method (Goldfisch Method) of the dried sample was used. The dried samples were transfered from the moisture determination dishes to alundum extraction thimbles and placed on ether extraction apparatus and extracted for 4 hr with anhydrous diethyl ether. Duplicate samples were determined and .5% differences were allowed.

Connective Tissue. The connective tissue was determined using the modified procedures of Parrish et al. (1961). The dried, fat free samples were powdered in a mortar and mixed thoroughly. Five hundred mg samples were weighed and placed in ampules containing 5 ml of distilled water and then 5 ml of 12 N HCl were added. The ampules

were sealed and hydrolyzed for 16 to 24 hr at 110°C for hydroxyproline analysis. Standard gelatin samples were also hydrolyzed with each group of meat samples examined. The samples were cooled and neutralized with 24% NaOH, filtered, and diluted to 50 milliliters. Duplicate aliquots of these samples were analyzed for hydroxyline.

One-tenth ml of .1 M phosphate buffer pH 7.0 and .1 ml of hydrolyzed sample were pipetted into 10 ml volumetric flasks. Two and one half ml of benzene were added, and the flask was placed in a carrier basket. Two-tenths ml of cold (5°C) .3 M ninhydrin in piersolve (ethylene glycol monomethyl ether) was added and the flasks were transfered to the water bath at 71±1°C. The samples were shaken 5 min at 100 strokes per minute and immediately cooled to room temperature in an ice-water bath. The contents of the flasks were diluted to 10 ml with benzene and thoroughly shaken. The organic layer was poured into 20 ml test tubes containing 200 mg of anhydrous sodium sulfate and the mixture was shaken vigorously. The dried solutions were transfered to cuvettes and their absorbancies read in a Spectrophotometer (Model 24, Beckman Instruments Inc. Fullerton, California) at 570 nm and 550 nanometers. The equation derived by Wierbicki and Deatherage (1954) was applied to convert hydroxyproline content to connective tissue content of the samples.

Cooking Method

Two 3.2 cm thick steaks cut from the longissimus muscle were cooked for the tenderness determination. A thermometer was inserted

into the geometric center of steaks and then cooked in a 138°C deep fat fryer (lard) to an internal temperature of 62°C. The cooked steaks were stored over night at 4°C and used for the panel taste and Warner-Bratzler shear value determinations the following day.

Measurement of Tenderness

A nine-point hedonic scale was used by the twelve taste-panel members consisting of Meat Laboratory faculty, staff and graduate students at Michigan State University to evaluate tenderness of cores (2.5 cm) taken from the steaks. Three 2.5 cm cores were removed from each steak, their browned surfaces removed and each core was cut into two pieces perpendicular to the myofiber axes for tasting.

Shear measurements were determined on the same steaks used as those used for taste panels. Twelve to 15 - 1.25 cm cores were removed from one steak and shear force (kg) determined with a Warner-Bratzler shear device.

Measurement of Sarcomere Length

The frozen longissimus muscle 2.5 cm core was thawed at 0°C to 4°C. Approximately 1 g of muscle was placed in 14 ml of .25 M sucrose and blended at low speed in a Virtis homogenizer (Type Super 30 Virtis, New York) for one minute.

Sarcomere length was measured by use of a phase-contrast

photomicroscope III (Carl Zeiss, Oberkochen, West Germany) equipped with a filar micrometer at a magnification of X2000. The mean length of 10 sarcomeres from each of 25 myofibrils per sample was determined.

Fragmentation Determinations

Homogenization for Fragmentation. Moller (1973) developed the homogenization procedure for myofibril fragmentation as used in this study. A 2 g sample of the 2.5 cm core of the longissimus muscle used for sarcomere length was homogenized by a Virtis homogenizer (a blade homogenizer) for 30 sec at medium speed in 12.5 ml KCl-phosphate buffer consisting of .06 M KCl and .05 M potassium phosphate (pH 7.0). The homogenate was poured through a stainless steel mesh to remove connective tissue and other gross material.

The suspension was centrifuged in a Sorvall centrifuge (Model RC 2-B, Sorvall, Inc.) for 3 min at 1800 rpm using a SS-34 rotor. The sediment was washed with three cycles of 12.5 ml KCl-phosphate buffer solution followed by centrifugation for 30 min at 4000 rpm in the same rotor and centrifuge.

Measurement of Turbidity. Partical size of suspended homogenized myofibril fragments was determined essentially as described by Davey and Gilbert (1969). The myofibril sediment was dispersed in 25 ml KCl-phosphate buffer solution under standard conditions. The suspension solution was stirred for 5 min at $0^{o}C$ to $4^{o}C$ using a multiple magnetic

stirring apparatus (Lab-Line Instruments, Inc. Melrose Park, Ill.). One ml of homogenized myofibril suspension was pipetted to a cuvette containing approximately .1 mg protein / milliliter. Turbidity readings (colorimeter transmittance units) were made with the Spectronic 20 colorimeter (Bausch and Lomb) at 520 nm immediately after gentle inversion of the cuvettes containing the suspensions.

The measurements were adjusted to equivalent nitrogen concentration from a standard curve. A linear relationship between turbidity reading and nitrogen concentration was obtained for suspensions containing approximately .08, .10, .15, .20 and .25 mg (figure 1). Total nitrogen concentration of the myofibril suspensions was determined by the Kjeldahl method.

Kjeldahl Protein Analysis. The American Instrument Company (1961) Micro-Kjeldahl method was used with modifications. The myofibril suspension was transferred to a Kjeldahl flask with a small amount of distilled water. Glass beads and approximately 1 g of sodium sulfate, 1 ml of 10% copper sulfate, and 7 ml of concentrated sulfuric acid were added to the flask. The mixture was digested over electric coils for 2 to 4 hr with occasional shaking until a light green color developed and then for about 1/2 hr more. The flask and its contents were cooled after digestion and approximately 15 ml of deionized water were added. Nitrogen was distilled into 10 ml of 2% boric acid and three drops of bromocresol-green indicator solution added to the 125 ml Erlenmeyer collection flask. Fifteen ml of 40% cold sodium hydroxide were added

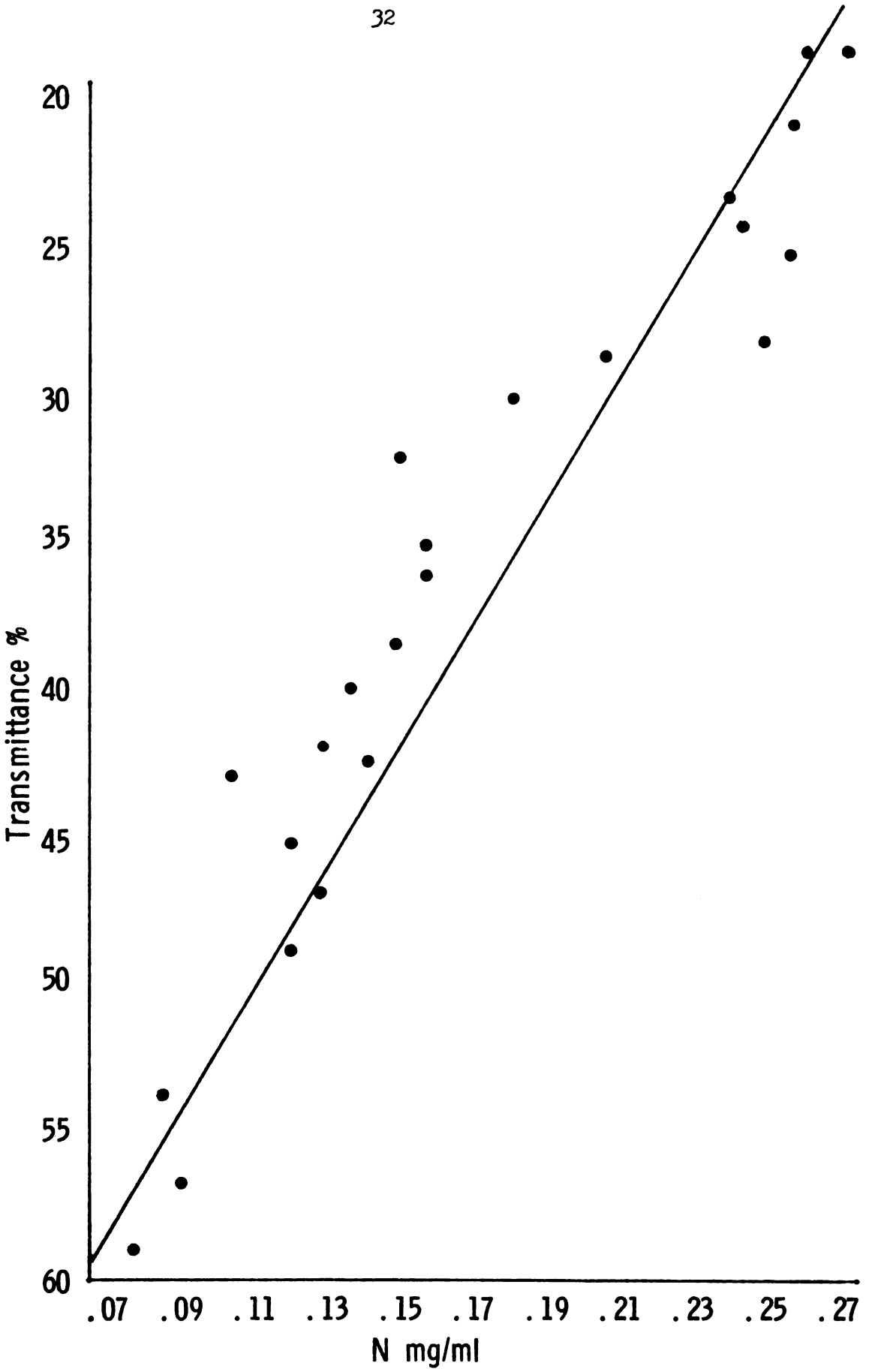

Figure 1. Standard curve for adjusting myofibril fragmentation measurements

to the digestion flask. Steam was directed from the boiling water flask through the closed system so as to enter the sample, the condenser and the Erlenmeyer flask. After 7 min distillation, the collection flask was lowered and the condenser was flushed for 3 minutes. The 2% boric acid solution was titrated to the green end point with .0094 N sulfuric acid. The percentage protein was determined from the nitrogen analysis by using the factor of 6.25 X nitrogen.

Statistical Analysis

The statistical analysis was done by a CDC 6500 computer at the Michigan State University Computer Laboratory. Simple correlation coefficients were determined as described by Snedecor and Cochran (1969). Data were analyzed by three-way double split plot analysis of variance within each sex group. Where significance was indicated, individual comparisons were performed with t-test to determine which means were significantly different in both experiments (Rohlf and Sokal, 1969).

RESULTS AND DISCUSSION

Postmortem Temperature Changes

Internal longissimus muscle temperatures were monitored to determine relative chilling rates (figure 2). The data presented in figure 2 are those from experiment 2. The fat carcasses had higher initial internal temperature than the thin carcasses. The average initial internal temperature of fat carcasses was 39.25°C and that of thin carcasses was 38.15°C. The normal cattle body temperature is approximately 38.3°C to 39.1°C (Hafez, 1968). The internal temperature of fat carcasses exceeded the range of normal live cattle body temperature. Struggling at death as well as the exothermic effect of postmortem metabolism led to an increase in heat production and this heat increment probably caused high carcasses internal temperature. The fat carcasses had thick subcutaneous fat that is a good heat insulator and could keep a high internal temperature for a long time. Consequently, fat carcasses had higher internal temperatures than thin carcasses.

Significant temperature differences could be found after the carcasses were in the chilling cooler for 2 hours. Slow chilling causes slower temperature decline than did fast chilling and temperature decline in fat carcasses was slower than thin carcasses. Muscle temperatures of fat carcasses that were fast chilled were considerably lower than those of thin carcasses that were chilled slowly. Thus, carcass fatness had an effect on chilling rate.

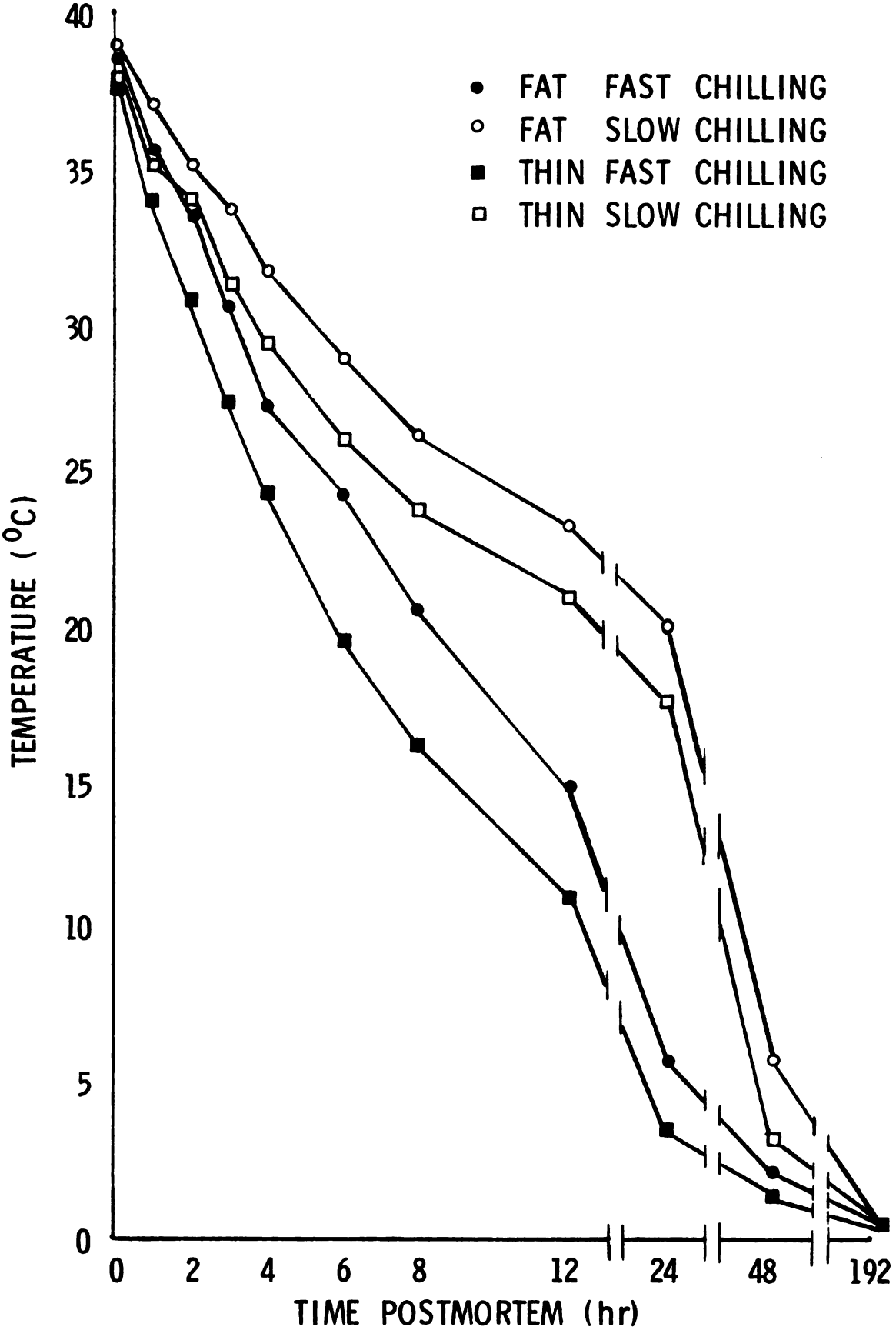

Figure 2. Rate of temperature decline in beef-type steers

Postmortem Changes of pH

The postmortem pH decline is the easiest way to estimate the conversion of glycogen to lactic acid (Bate-Smith and Bendall, 1949; 1956; Bendall, 1960; Cassens, 1966). In experiment 1 the rates of pH decline during the first 4 hr were similar for cows, bullocks and Holstein steers. The fat carcasses had faster pH fall than did the thin carcasses and the fast chilling rate (0°C to 1°C) caused the pH to drop more slowly than did slow chilling (15°C to 16°C) (figures 3 to 10). As indicated in the figures 5 and 6 the fastest mean pH decline of Holstein steers was those in carcasses with the thickest fat and chilled in the 15°C to 16°C cooler. It took only 2 hr to attain a constant pH level. The slowest mean pH decline was found in the carcasses with thin fat and chilled in the 0°C to 1°C cooler. It took almost 12 hr to reach a constant pH level.

After 4 hr postmortem, the slopes of all curves for cows, bullocks, fast chilling, slow chilling, fat and thin groups decreased gradually until they reached their lowest pH values. The patterns for Holstein steers were similiar to those for cows and bullocks, except that no further pH decline was noted in the fat group with slow chilling after 4 hr postmortem. This suggests that the fatter the carcass is and the higher the chilling temperature, the more rapid the glycolytic rate. On the other hand, the thinner the carcass is and the lower the chilling temperature, the slower the glycolytic rate. When all the ATP or glycogen is depleted, the ultimate pH is reached or very closely

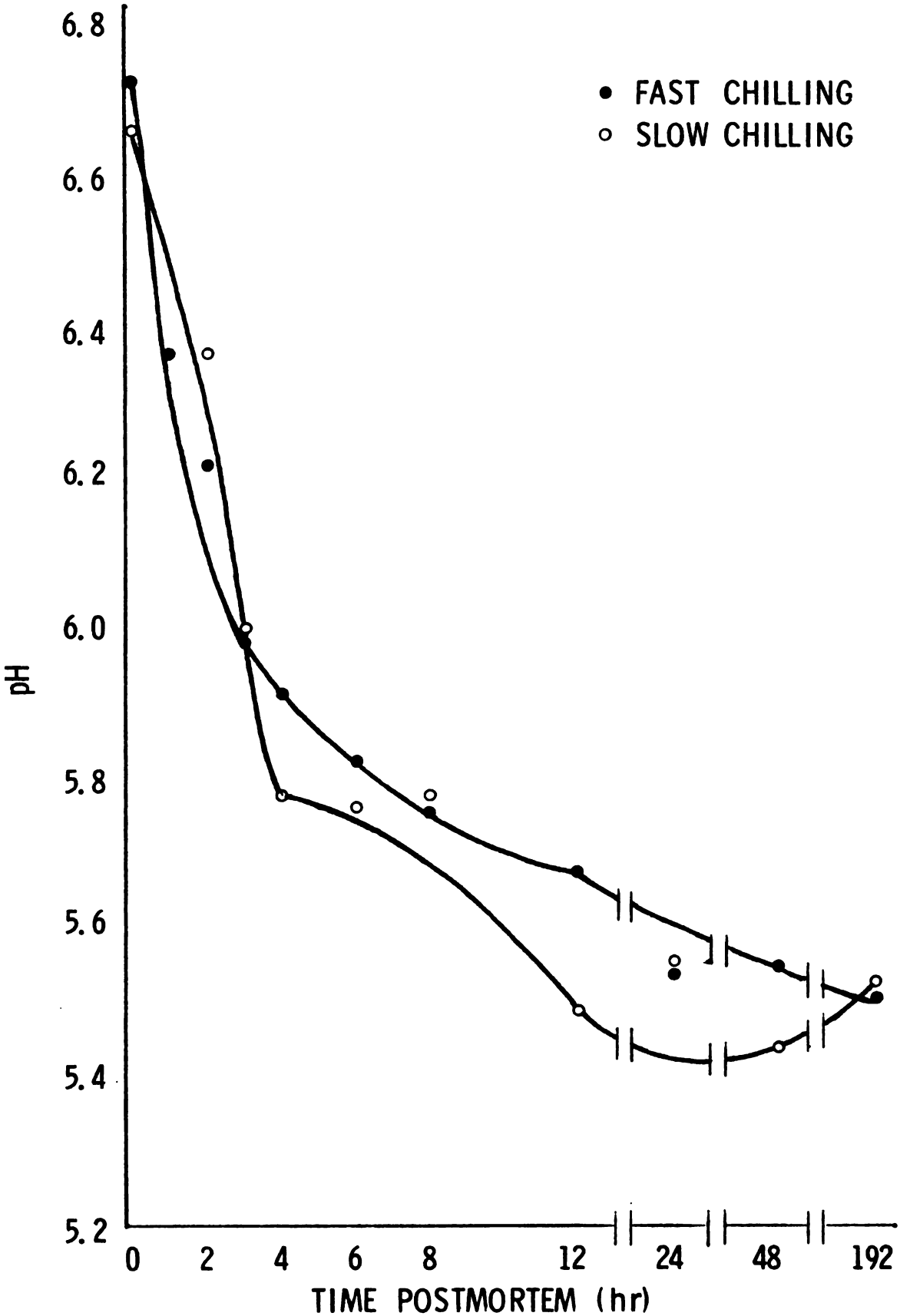

Figure 3. Rate of pH decline in fat cows muscles with fast and slow chilling

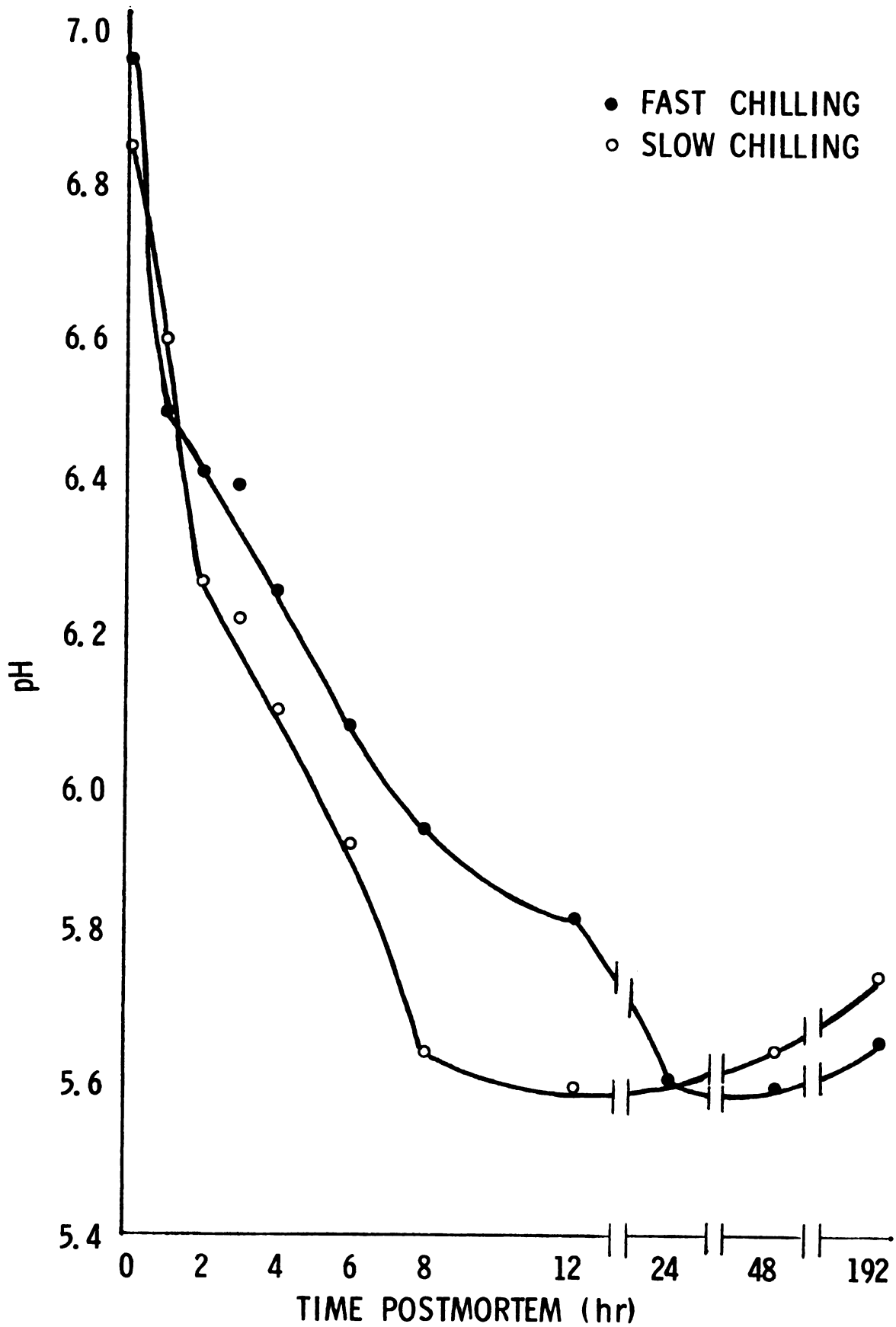

Figure 4. Rate of pH decline in thin cows muscles with fast and slow chilling

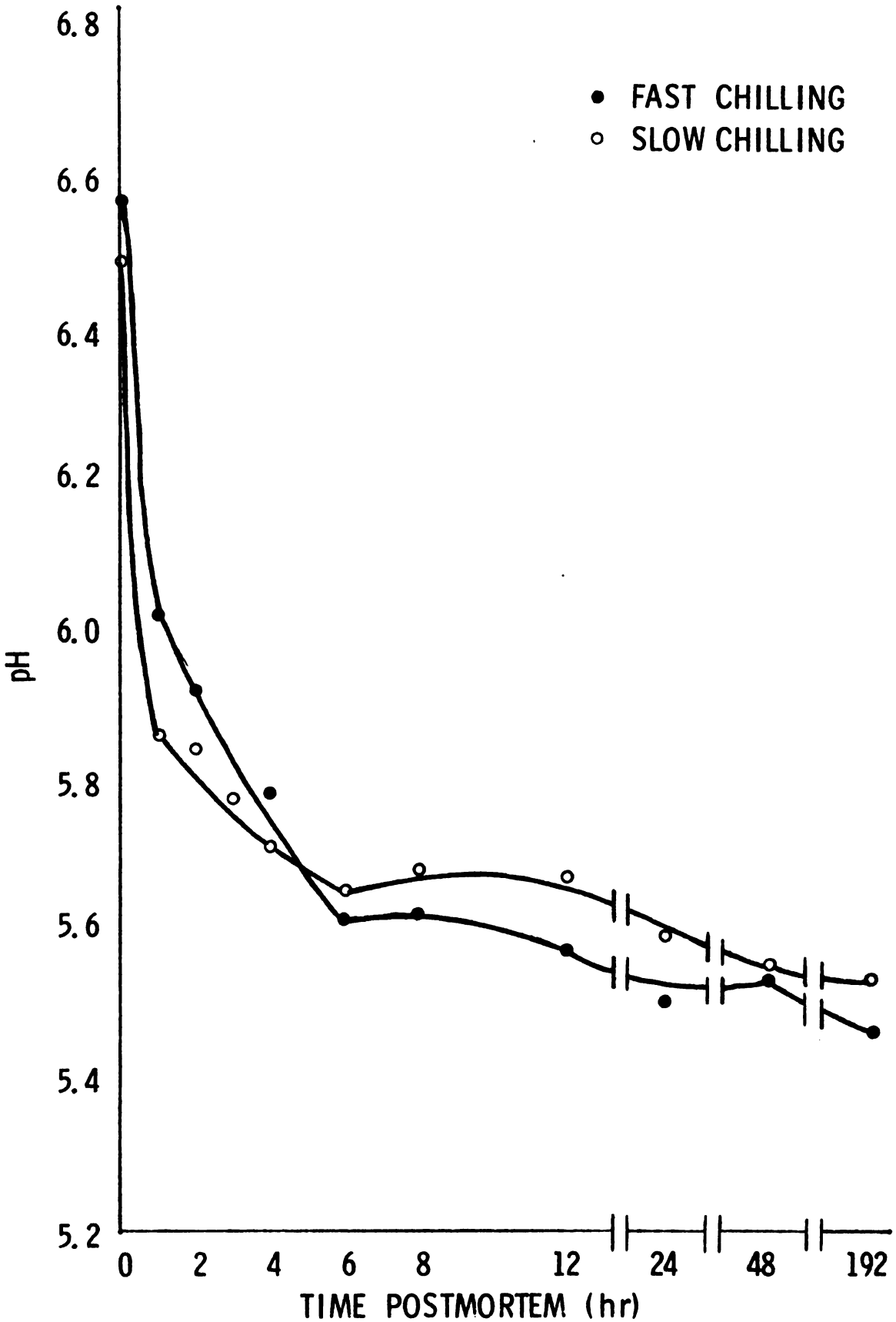

Figure 5. Rate of pH decline in fat Holstein steers muscles with fast and slow chilling

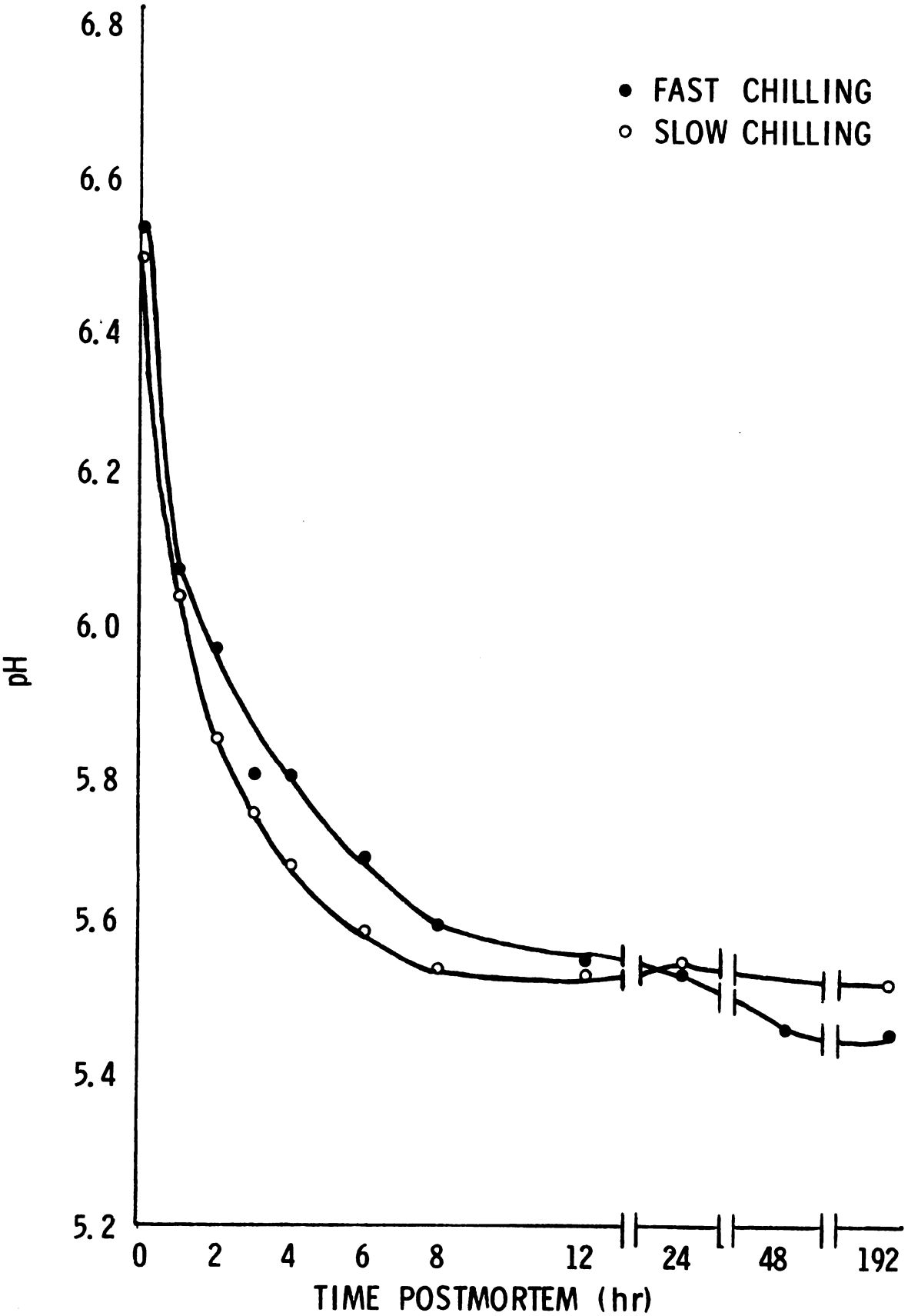

Figure 6. Rate of pH decline in thin Holstein steers muscles with fast and slow chilling

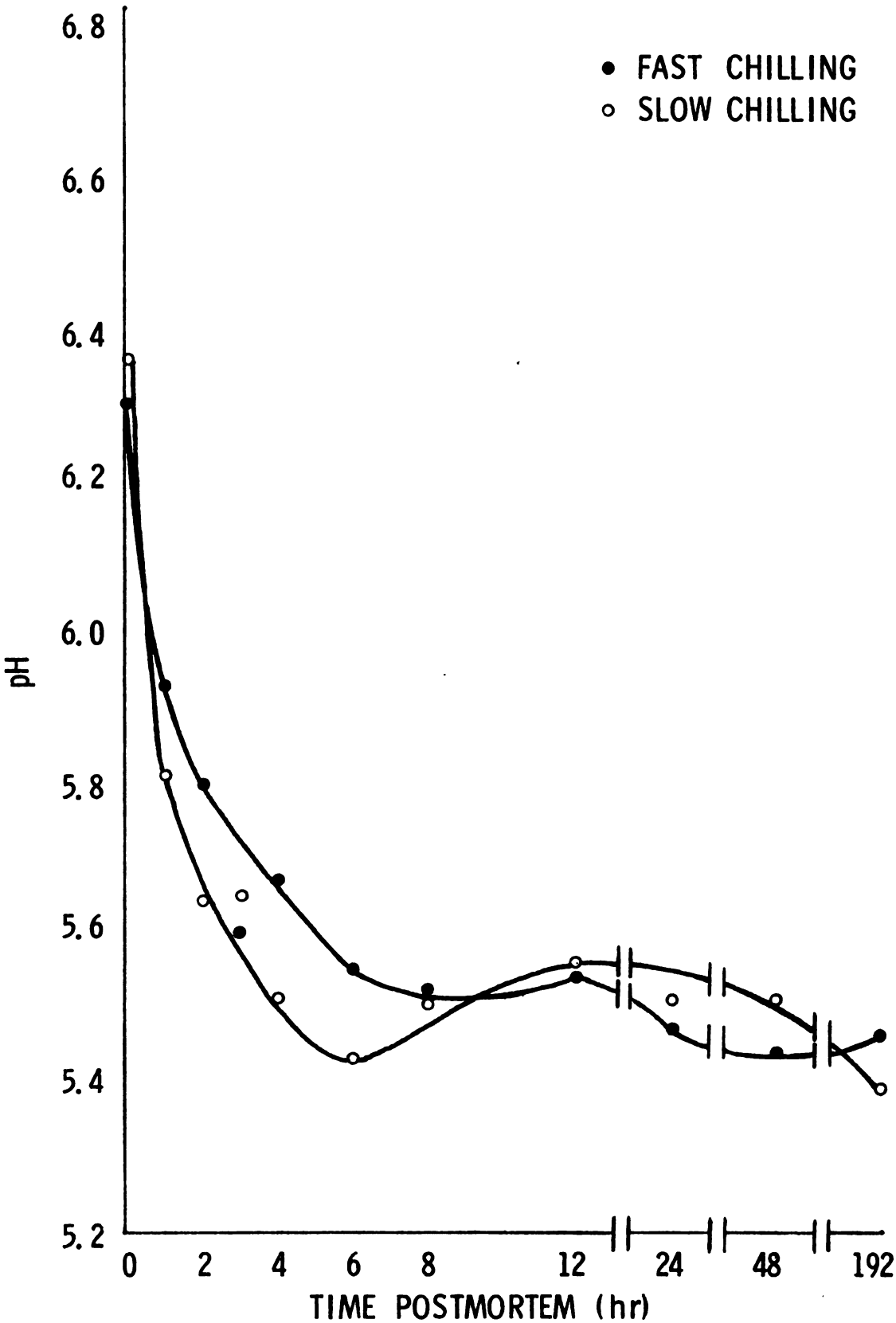

Figure 7. Rate of pH decline in fat bullocks muscles with fast and slow chilling

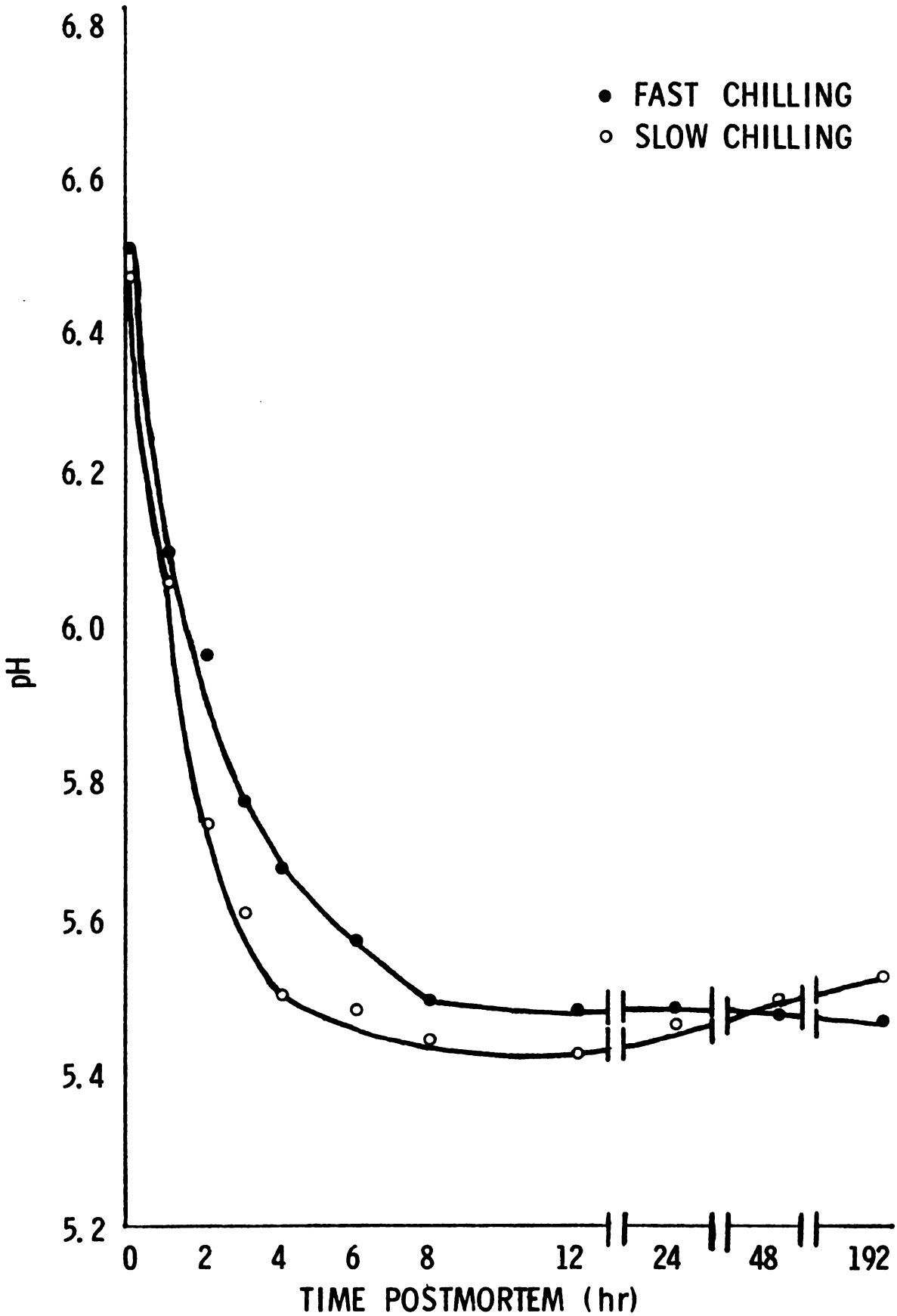

Figure 8. Rate of pH decline in thin bullocks muscles with fast and slow chilling

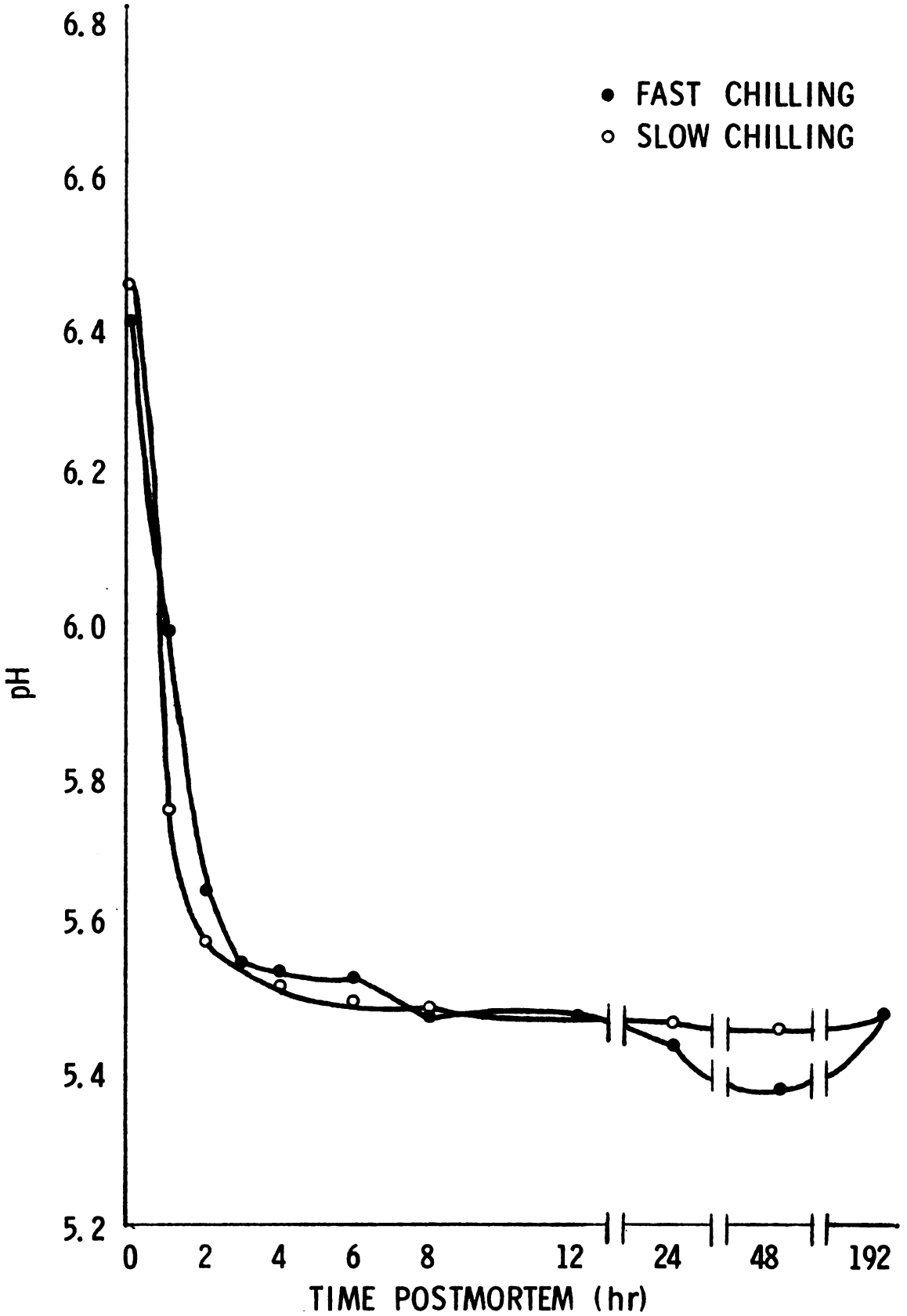

Figure 9. Rate of pH decline in fat beef-type steers muscles with fast and slow chilling

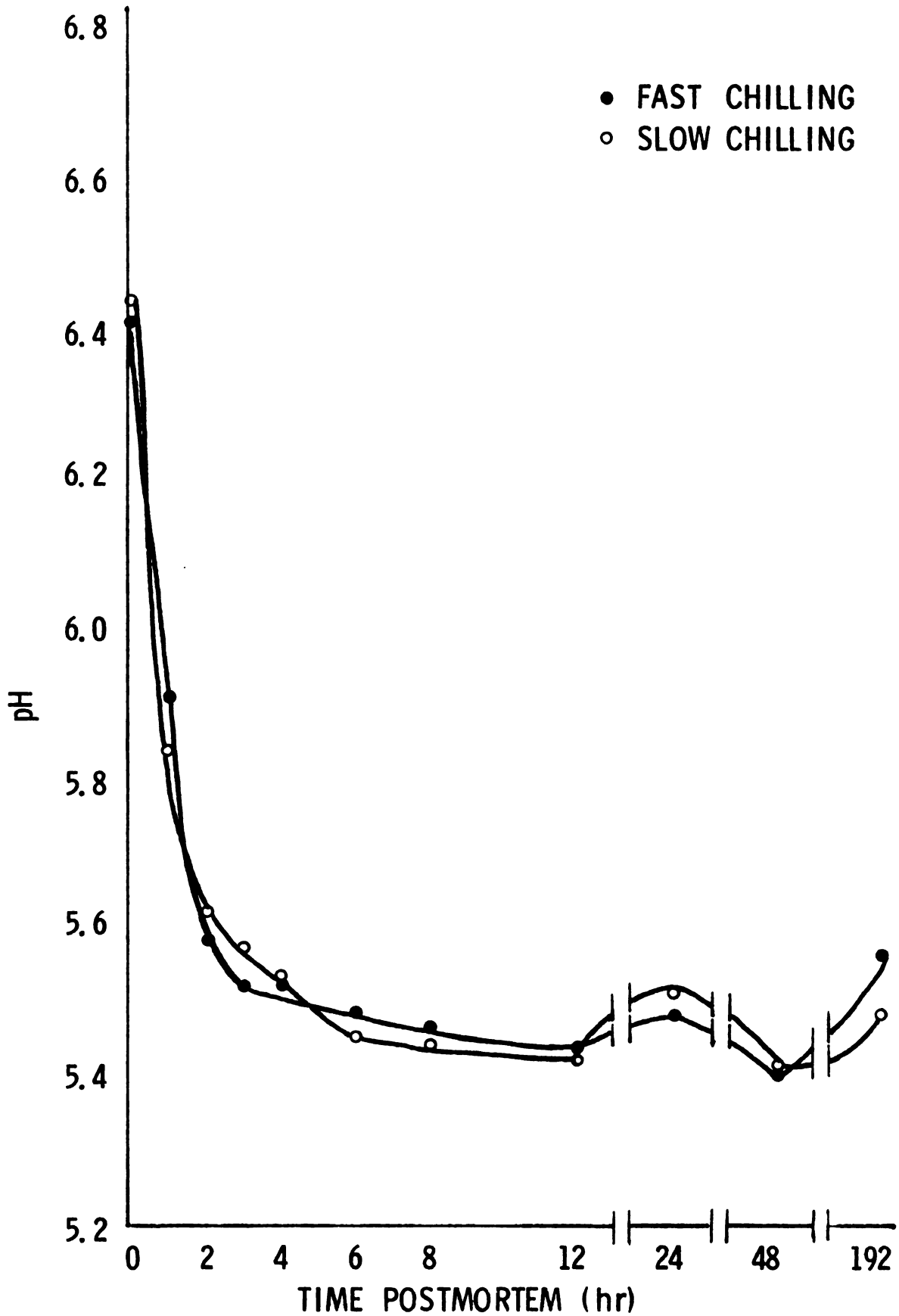

Figure 10. Rate of pH decline in thin beef-type steers muscles with fast and slow chilling

approached. The ultimate pH of the carcasses will be maintained for a period of time. At this point the carcass is considered to be in full rigor. After this period the pH rose slightly.

In the study of Cassens and Newbold (1966) the rate of pH decline postmortem at 1°C was not slower than that at 15°C until several hours postmortem. In their later work, Cassens and Newbold (1967) reported that the rate at 1°C was faster than that at 5°C and close to the rate at 15°C. In the present experiment it appears that fatness provided an insulatory effect by retarding temperature fall and thus it had an important effect on the rate of pH decline.

The mean ultimate pH values of the five fat cows with fast chilling and slow chilling treatments were 5.54 and 5.43, respectively, and those of the five thin cows were 5.60 and 5.59, respectively. For the ten bullocks, the mean ultimate pH of the five fat sides with fast chilling and slow chilling treatments were 5.46 and 5.42 and those of the five thin bullocks were 5.47 and 5.46, respectively. For the ten Holstein steers, the mean ultimate pH of the five fat sides with fast chilling and slow chilling treatments were 5.5 and 5.46, respectively and those of the five thin sides were 5.46 and 5.46, respectively. These data are in agreement with those of Cook and Langsworth (1966) and Cassens and Newbold (1967). They reported that the ultimate pH attained at 1°C or 5°C was significantly higher than that attained at 15°, 25° or 37°C. The rates of pH decline in experiment 2 (figures 9 and 10) had the same pattern as that in experiment 1.

During the first 2 hr postmortem pH dropped very rapidly and then

the rate decreased gradually until 4 hr postmortem. After 4 hr postmortem the pH remained quite constant until 24 hours. Most of the mean pH values at 24 hr postmortem were higher than those at 12 hours.

There was little difference in the rate of pH decline between fat and thin steers, fast chilling and slow chilling in experiment 2. This observation could be due to the beef-type steers that we used in experiment 2 which had thicker muscles than the cattle in experiment 1. The mean ultimate pH in experiment 2 was similar to that in experiment 1. The thicker muscles showed a slower heat transfer rate and probably provided somewhat the same insulatory effect as carcasses with a high fat covering. The fat steers chilled at 15°C to 16°C had the lowest ultimate mean pH values, on the other hand, the thin steers chilled with the low temperature had a highest ultimate mean pH values. The mean ultimate pH values of the lean steers with slow chilling were higher than those of the fat steers with fast chilling. These results indicated that the insulatory effect of fatness caused a higher ultimate pH than the effect of chilling temperature. These data of experiment 1 and 2 once again confirm the statement of Cassens and Newbold (1967) that temperature affects not only the rate but also the extent of glycolysis.

It is interesting to note that the mean pH of the five fat bullocks with fast and slow chilling reached their lowest pH value at 6 and 8 hr, respectively, and rose to a higher level pH respectively, (5.55 and 5.53) at 12 hr postmortem. After 12 hr the mean pH dropped gradually to 5.5 and 5.46, at 24 hours.

Panel Tenderness

In experiment 1, steaks from either fat or thin carcasses treated with slow chilling had higher panel tenderness scores than those treated with fast chilling (tables 2 and 3). The same observation was reported by Locker and Hagyard (1963), Herring et al. (1965), Marsh and Leet (1966), Smith et al. (1971), Goll et al. (1964), Hostetler et al. (1970), Bouton et al. (1973), Hostetler et al. (1975) and Field et al. (1976). However, the differences in panel tenderness between fast and slow chilling of the fat group were not significant. These results indicate that fat carcasses with thick insulatory subcutaneous fat apparently eliminated the cold shortening effect.

The differences of panel scores of steaks between fat and thin carcasses under the same chilling treatment showed a tendency for steaks from fat carcasses to be more tender than those from thin carcasses. These data agree with those of Bell (1939) who reported that leg roasts from fatter lambs were more tender than those from lean lambs. The differences between fat and thin carcasses were not significant except for the Holstein steers with fast chilling ($P < .05$, table 2).

Comparisons of panel tenderness for steaks aged 8 days indicate that all 8 day steaks had higher panel tenderness scores than did the 2 day steaks. Steiner (1939) reported that rate of aging was dependent on sex, age and other factors, rate being faster in younger than in older animals and slower in steers than in cows. However, in experiment 1 only fat cows, thin bullocks and thin Holstein steers showed significant

TABLE 2. MEANS OF PANEL TENDERNESS OF COWS AND HOLSTEIN STEERS [a,b,c]

COWS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	4.37	3.36	5.07	2.45
8	6.99	5.51	6.31	3.77

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .955	2.008	3.204
Fast vs slow	± .603	1.391	2.203
2 vs 8 days	± .669	1.543	2.244

HOLSTEIN STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	6.17	5.14	5.55	2.98
8	6.87	5.60	6.61	4.72

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .690	1.591	2.315
Fast vs slow	± .688	1.588	2.308
2 vs 8 days	± .442	1.018	1.483

[c]A score of 9 = extremely tender, and 1 = extremely tough.

aging differences.

In experiment 1, the simple correlation of tenderness on a pooled cows, bullocks and Holstein steers basis gave a highly negative ($r = -.64$, $P < .01$) correlation between panel tenderness and Warner-Bratzler shear (table 4). Similar correlation ($r = -.68$, $P < .01$) was obtained in experiment 2 (table 5). These results would tend to lead to the conclusion that either the Warner-Bratzler shear or the panel tenderness could be used to estimate the tenderness of cooked samples.

In exepriment 1, the initial pH and 4 hr postmortem pH were significantly correlated with panel tenderness, although the correlation coefficients were low ($r = -.27$ and $-.30$). However, this relationship was not found in experiment 2.

Warner-Bratzler Shear

In experiment 1, steaks from either fat or thin carcasses, 2 or 8 days postmortem aging, that were chilled slowly always had lower Warner-Bratzler shear values than those chilled rapidly (tables 6 and 7). These results indicate that steaks from slow chilled carcasses were more tender than those from fast chilled carcasses. Only the differences between slow and fast chilled thin carcasses were significant ($P < .05$). These data confirm the results of panel tenderness scores in that differences between fast and slow chilled fat carcasses were not significant. However, in experiment 2, the differences in fast vs slow chill of both fatness groups were significant. Thus, fatness did not

TABLE 4. SIMPLE CORRELATION COEFFICIENTS BETWEEN VARIOUS PALATABILITY TRAITS, PHYSICAL AND CHEMICAL ANALYSIS OF POOLED COWS, HOLSTEIN STEERS AND BULLOCKS [a,b]

Variable	Variable								
	Panel tenderness	W-B shear	Sarcomere length	Frag-mentation	Intramuscular collagen	Moisture	Ether extract	Marbling degree	12th rib fat thickness
Panel tenderness	1.00								
W-B shear	- .64	1.00							
Sarcomere length	.19	- .18	1.00						
Fragmentation	- .45	.50	.08	1.00					
Intramuscular collagen	- .01	- .02	- .11	- .18	1.00				
Moisture	- .27	.08	.21	.02	.19	1.00			
Ether extract	.15	- .00	- .25	.07	- .11	- .93	1.00		
Marbling degree	.19	- .08	- .22	- .05	- .09	- .85	.85	1.00	
12th rib fat thickness	.10	- .05	- .16	- .04	- .08	- .76	.75	.82	1.00
pH 0 hr	- .15	.02	- .01	- .09	.33	.29	- .18	- .10	- .10
pH 4 hr	- .30	.07	- .14	- .03	.44	.32	- .18	- .13	- .12
pH 24 hr	- .12	.05	- .21	- .17	.37	.23	- .09	- .00	- .14
pH 48 hr	- .10	.03	- .01	- .03	.17	.26	- .11	- .15	- .25
pH 8 days	- .10	- .07	- .10	- .04	.28	.28	- .14	- .14	- .22

[a] n = 120.

[b] $P \leq .05 = .278$; $P \leq .01 = .326$.

TABLE 5. SIMPLE CORRELATION COEFFICIENTS BETWEEN VARIOUS PALATABILITY TRAITS, PHYSICAL AND CHEMICAL ANALYSIS OF BEEF-TYPE STEERS [a,b]

Variable	Variable								
	Panel tenderness	W-B shear	Sarcomere length	Frag- mentation	Intramuscular collagen	Moisture	Ether extract	Marbling degree	12th rib fat thickness
Panel tenderness	1.00								
W-B shear	- .68	1.00							
Sarcomere length	- .11	.31	1.00						
Fragmentation	- .39	.45	.31	1.00					
Intramuscular collagen	.01	.16	- .08	.14	1.00				
Moisture	- .35	.10	- .01	.23	.18	1.00			
Ether extract	.30	- .12	- .03	- .31	.14	- .95	1.00		
Marbling degree	.28	- .16	- .03	- .26	.15	- .79	.74	1.00	
12th rib fat thickness	.16	- .28	- .10	- .28	- .26	- .16	.11	.45	1.00
pH 0 hr	- .25	.06	.04	.21	- .20	.18	- .18	- .34	- .15
pH 4 hr	- .06	.05	- .03	.09	.17	.34	- .32	- .20	.13
pH 24 hr	- .13	.00	- .13	- .01	- .12	.21	- .23	- .24	- .03
pH 48 hr	- .01	- .05	- .01	- .18	.09	.14	- .12	- .16	.01
pH 8 days	.01	- .03	- .03	.19	- .15	.36	- .41	- .59	- .29

[a] n = 80.

[b] $P \leq .05 = .336$; $P \leq .01 = .394$.

TABLE 6. MEANS OF WARNER-BRATZLER SHEAR (kg/cm^2) OF COWS AND HOLSTEIN STEERS [a,b]

COWS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	3.06	3.54	2.95	4.10
8	2.37	3.34	2.59	3.43

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .418	.965	1.404
Fast vs slow	± .364	.839	1.221
2 vs 8 days	± .336	.774	1.127

HOLSTEIN STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	3.17	3.58	3.18	3.80
8	2.84	3.34	2.48	3.40

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .279	.644	.937
Fast vs slow	± .291	.671	.977
2 vs 8 days	± .200	.462	.671

TABLE 7. MEANS OF WARNER-BRATZLER SHEAR (kg/cm^2) OF BULLOCKS AND BEEF-TYPE STEERS [a,b]

BULLOCKS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	3.18	3.71	3.54	4.13
8	2.92	3.22	2.66	3.10

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .411	.949	1.381
Fast vs slow	± .297	.685	.998
2 vs 8 days	± .382	.881	1.283

BEEF-TYPE STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	2.93	3.46	2.99	3.40
8	2.50	2.85	3.23	3.51

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .245	.514	.705
Fast vs slow	± .122	.256	.351
2 vs 8 days	± .226	.476	.650

have much effect on Warner-Bratzler shear values in the beef-type steers.

Within the same chilling treatment, steaks from the fat carcasses almost always had lower Warner-Bratzler shear values, than those from thin carcasses, but none of the differences was significant. This indicated that fatness has some effects on meat tenderness but the effect is not as great as temperature treatment during postmortem chilling.

Steaks from carcasses aged 8 days postmortem always had lower shear values than those from carcasses with 2 days postmortem aging. In experiment 1, significant postmortem aging effects were observed in steaks from thin cows chilled rapidly, thin Holstein steers and thin bullocks from both the fast and slow chilling treatments (table 6). These data suggest that postmortem aging effectively improved the adverse tenderness effects of cold shortening.

In experiment 2, steaks from carcasses chilled slowly had lower Warner-Bratzler shear values than those from fast chilled carcasses and the differences from both the fat and thin carcasses were significant (table 7). This observation once again demonstrates that fatness did not have a marked effect on cold shortening in beef-type steers. There is one interesting fact that after 8 days postmortem aging, steaks from fat carcasses with either slow or fast chilling, were more tender than those from thin carcasses ($P < .01$). However, at 2 days postmortem, steaks from the same chilling treatment regardless of carcass fatness had almost identical shear values. Postmortem aging did not improve the

tenderness of steaks from thin carcasses, in fact they became tougher. This observation suggests that postmortem aging was more effective on fat beef-type steers than on thin beef-type steers.

Sarcomere Length

Sarcomere length is a measure of the contraction state of the muscle (Herring et al., 1967). In 1960, Locker concluded that there was a relationship between postmortem shortening and tenderness. Using ox muscles excised soon after slaughter, Marsh and Leet (1966) and Davey et al. (1967) reported that shortening by up to 20% of the excised length produced relatively small changes in tenderness, whereas further shortening from 20 to 40% produced a several-fold increase in shear value. With still further shortening there was a progressive decrease in toughness until at 60% shortening shear values were of the same order as those obtained at 20% shortening or less. The sarcomeres of freshly excised ox muscle are about 2.5 μm long (Davey et al., 1967), so that 20% and 40% shortening corresponds to a sarcomere length of about 2.0 μm and 1.5 μm, respectively.

In experiment 1, the sarcomere of the longissimus muscle from the slow chilled carcasses were longer than those chilled rapidly (tables 8 and 9). These results agree with those of Locker and Hagyard (1963). However, the mean sarcomere lengths from the slow chilled carcasses were not significantly different from those of the fast chilled carcasses. These results are contrary to the observation of Welbourn et al. (1968)

and Smith et al. (1969) but confirm the data of Hegarty and Allen (1975). Stromer and Goll (1967) examined the muscles of seven heifers using phase microscopy at various times and temperatures and reported that the myofibrils held at 2°C and sampled 24 hr postmortem were supercontracted and exhibited a pattern of alternating light and dark bands. In contrast, the myofibrils held at 16°C and sampled at 24 hr exhibited a marked thickening of the A-band, a shortening of the I-band, and a replacement of the H-zone by a dark line or band. There were no sarcomere length differences between fat and thin carcasses or among the sex groups (tables 8 and 9). Smith et al. (1976) studied 40 lambs with thick, intermediate and thin finish and reported that increased quantities of fat sustained less shortening of sarcomeres. Perhaps different species of animals may differ in their response to the effect of fatness on sarcomere length. Postmortem aging did not have a significant effect on sarcomere length between fat or thin carcasses or between fast and slow chilling rate. Samples obtained after 8 days postmortem aging did not have as distinctive A-bands and I-bands as those from the 2 day samples and numerous short fragments were observed in the 8 day myofibril suspension. These findings confirm the data of Stromer and Goll (1967) in that variability in appearance was greater in the samples removed 312 hr postmortem and most of the myofibrils isolated after 312 hr postmortem storage at 2°C were supercontracted, thereas those isolated after 312 hr postmortem storage at 16°C were only slightly contracted. No significantly different sarcomere lengths were found between cows, bullocks and Holstein steers (tables 8 and 9).

TABLE 8. MEANS OF SARCOMERE LENGTH (μm) OF COWS AND HOLSTEIN STEERS [a,b]

COWS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	1.97	1.81	2.04	1.78
8	1.87	1.75	1.91	1.77

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .126	.292	.423
Fast vs slow	± .141	.326	.473
2 vs 8 days	± .008	.188	.027

HOLSTEIN STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	1.95	1.86	2.05	1.85
8	1.83	1.75	1.92	1.81

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .050	.130	.168
Fast vs slow	± .050	.130	.168
2 vs 8 days	± .050	.130	.168

TABLE 9. MEANS OF SARCOMERE LENGTH (μm) OF BULLOCKS AND BEEF-TYPE STEERS [a,b]

BULLOCKS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	1.94	2.02	1.92	1.89
8	1.86	1.88	1.84	1.82

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .100	.250	.336
Fast vs slow	± .060	.150	.201
2 vs 8 days	± .090	.210	.302

BEEF-TYPE STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	1.85	1.81	1.84	1.86
8	1.69	1.75	1.75	1.76

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .045	.095	.130
Fast vs slow	± .045	.095	.130
2 vs 8 days	± .055	.116	.158

In experiment 2 chilling treatments did not cause any differences in sarcomere length of myofibrils from either fat or thin carcasses (table 9). Sarcomeres from fat carcasses, irrespective of chilling rate had almost the same length as those from thin carcasses. These data indicate that cold shortening does not have any effect on beef-type steers regardless of fatness. Postmortem aging results in myofibrils shortening similar to that observed in experiment 1 (tables 8 and 9).

In experiment 1, sarcomere length was not significantly correlated with either Warner-Bratzler shear ($r = -.18$, table 4) or the panel tenderness score ($r = .19$). In experiment 2, similar correlation coefficients were obtained except the sign of the coefficients were reversed (table 5).

Fragmentation

Myofibril fragmentation was read spectrophotometrically as percent transmittance thus the more myofibril fragments there are, the lower the percent transmittance reading. Myofibril fragmentation is associated with meat tenderness and as fragmentation increases, tenderness generally increase also. Thus myofibril fragmentation was determined in this study to assess the effect of cold shortening on the extent of fragmentation. In experiment 1, the fragmentation readings obtained from longissimus muscle samples from slow chilled carcasses were almost always lower than those from fast chilled carcasses. Then 8 day postmortem samples were lower than those from the 2 day postmortem samples

(tables 10 and 11). These findings indicate that elevated chilling temperatures and postmortem aging increased myofibril fragmentation. Olson et al. (1976) reported that fragmentation during postmortem aging was muscle and temperature dependent.

In experiment 2, longissimus muscles from slow chilled carcasses had lower transmittance readings (more fragmentation) at 2 days postmortem, but at 8 days postmortem these same samples did not always have lower transmittance readings than fast chilled carcasses. Chilling treatment appeared to have a greater effect on myofibril fragmentation in beef-type steers than postmortem aging, however, none of these differences was statistically significant ($P > .05$).

In experiment 1, fragmentation was highly associated with panel tenderness ($r = -.45$, $P < .01$, table 4) and Warner-Bratzler shear ($r = .50$, $P < .01$). Comparable correlations were observed in experiment 2 (table 5).

Intramuscular Collagen

In experiment 1, neither chilling temperature, nor postmortem aging differed significantly ($P < .05$) in percentage intramuscular collagen in the longissimus muscle of fat and thin carcasses of cows, bullocks or Holstein steers (tables 12 and 13). The percentage collagen of the longissimus muscles of cows, bullocks and Holstein steers essentially did not differ and these results agree with those of Goll et al. (1963), McClain et al. (1965) and Herring et al. (1967) in that as tenderness decreased due to increased animal age there was essentially no change in

TABLE 10. MEANS OF FRAGMENTATION OF COWS AND HOLSTEIN STEERS [a,b,c]

COWS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	38.73	38.00	36.20	43.77
8	28.98	22.68	29.70	38.01

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 7.963	18.362	26.716
Fast vs slow	± 2.827	6.519	9.485
2 vs 8 days	± 2.503	5.771	8.398

HOLSTEIN STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	32.18	39.07	39.94	51.62
8	33.22	37.38	31.62	41.35

	[a]Standard errors of difference among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 8.388	19.343	28.144
Fast vs slow	± 5.836	13.457	19.580
2 vs 8 days	± 5.046	11.636	16.929

[c]Percent transmittance per mg nitrogen.

TABLE 11. MEANS OF FRAGMENTATION OF BULLOCKS AND BEEF-TYPE STEERS [a,b,c]

BULLOCKS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	39.93	48.05	38.40	45.46
8	38.14	34.48	33.61	35.75

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 8.055	14.982	27.025
Fast vs slow	± 2.351	4.373	7.888
2 vs 8 days	± 7.137	13.275	23.945

BEEF-TYPE STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	28.51	35.60	32.55	34.29
8	27.79	28.61	33.34	32.20

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 3.285	6.902	9.454
Fast vs slow	± 2.311	4.855	6.651
2 vs 8 days	± 2.324	4.883	6.688

[c]Percent transmittance per mg nitrogen.

total amount of collagen present in muscle. These authors also observed that although tenderness of muscle increased due to postmortem aging, there was little change in the total collagen during the postmortem aging period.

The results of experiment 2 were similar to those in experiment 1, however, the percentage intramuscular collagen of beef-type steers was much lower than that of the cattle studied in experiment 1. This observation indicates that constitution of beef-type steers muscles differs from cows, bullocks and Holstein steers. These data also show that the differences in tenderness were due to factors other than quantity of intramuscular collagen.

In both experiment 1 and 2 (tables 4 and 5), the intramuscular collagen percentage was not correlated with panel tenderness, Warner-Bratzler shear or sarcomere length and fragmentation. Thus connective tissue content did not have an effect on muscle tenderness, extent of contraction or postmortem aging.

Moisture, Marbling and Ether Extract

At 4 hr and 8 days postmortem, pH was correlated with moisture content in experiment 1 ($r = .32$ and $.28$, $P < .05$, table 4) and in experiment 2 ($r = .34$ and $.36$, $P < .05$, table 5).

In experiment 1, percent moisture content was negatively correlated with panel tenderness ($r = -.27$, $P < .05$) but was not significantly correlated with Warner-Bratzler shear (table 4). In experiment 2 the

TABLE 12. MEANS OF PERCENTAGE INTRAMUSCULAR COLLAGEN OF COWS AND HOLSTEIN STEERS [a,b,c]

COWS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	6.77	6.75	7.26	7.18
8	6.49	7.33	7.24	7.34

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .996	2.297	3.241
Fast vs slow	± .385	.887	1.292
2 vs 8 days	± .460	1.062	1.543

HOLSTEIN STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	7.33	7.11	6.88	7.25
8	7.05	7.29	6.99	6.90

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .611	1.408	2.050
Fast vs slow	± .399	.920	1.339
2 vs 8 days	± .446	1.029	1.496

[c]Percent of fresh tissue.

TABLE 13. MEANS OF PERCENTAGE INTRAMUSCULAR COLLAGEN OF BULLOCKS AND BEEF-TYPE STEERS [a,b,c]

BULLOCKS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	5.94	5.62	6.80	6.77
8	6.70	5.98	6.27	5.91

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 1.231	2.838	4.130
Fast vs slow	± .487	1.123	1.634
2 vs 8 days	± .634	1.462	2.127

BEEF-TYPE STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	5.19	4.99	5.49	5.35
8	5.28	5.42	5.52	5.80

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± .514	1.080	1.479
Fast vs slow	± .255	.536	.734
2 vs 8 days	± .286	.601	.823

[c]Percent of fresh tissue.

same results were obtained (table 5). These data indicate that organoleptic determination of tenderness was better than mechanical shear to determine meat tenderness. In experiment 1, there was a low correlation between moisture content and sarcomere length (r = .21) but no relationship between moisture content and fragmentation was observed. However, in experiment 2, no relationship was shown between moisture content and fragmentation.

As expected, ether extract was highly associated with moisture content in both experiments (r = - .93 and - .95). Thus fat animals had lower water contents than thin animals.

The high correlation in experiment 1 (r = .85) and experiment 2 (r = .74) between marbling degree and percent ether extract agree with the results of others (Wooten et al., 1974; Dikeman et al., 1972). Degree of marbling was highly negatively associated with percent moisture in experiment 1 (r = - .76) and experiment 2 (r = - .79). In both experiments, degree of marbling showed nonsignificant correlations with panel tenderness and Warner-Bratzler shear value which agreed with Tuma et al. (1962), Romans et al. (1965), Breidenstein et al. (1968), and Berry et al. (1974).

Twelfth rib fat thickness was highly correlated with ether extract, marbling degree and moisture content in experiment 1. However, in experiment 2 marbling was correlated with twelfth rib fat thickness, but the correlation was low. This indicated that beef type steers with thick subcutaneous fat did not always have more intramuscular fat.

In both experiment 1 and 2, chilling treatment and postmortem aging

did not have a significant effect on the percent moisture (tables 14 and 15) and ether extract (tables 16 and 17) of the longissimus muscle. In experiment 1, the percent moisture and ether extract from cattle differing in fatness were widely different, however, in experiment 2 there was little difference between fat and thin carcasses, and the marbling scores of the cattle in experiment 2 were also very similar (table 18). The latter observation may possibly explain why the cold shortening response was similar in fat and thin beef-type steers, even though the extent of fat thickness differed widely.

TABLE 14. MEANS OF MOISTURE OF COWS AND HOLSTEIN STEERS [a,b,c]

COWS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	72.67	72.57	73.31	75.39
8	72.74	72.17	75.16	75.29

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 1.153	2.659	3.868
Fast vs slow	± .290	.669	.973
2 vs 8 days	± .241	.555	.809

HOLSTEIN STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	70.90	71.54	75.12	75.18
8	70.54	70.54	74.75	75.09

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 1.744	4.021	5.851
Fast vs slow	± .947	2.183	3.177
2 vs 8 days	± .977	2.252	3.278

[c]Percent of fresh tissue.

TABLE 15. MEANS OF MOISTURE OF BULLOCKS AND BEEF-TYPE STEERS [a,b,c]

BULLOCKS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	73.53	73.63	73.85	73.43
8	72.82	72.87	73.98	73.96

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 1.000	2.307	3.355
Fast vs slow	± .430	.992	1.443
2 vs 8 days	± .547	1.261	1.835

BEEF-TYPE STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	72.03	72.21	72.54	72.70
8	72.16	72.00	72.24	72.30

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 1.460	3.067	4.202
Fast vs slow	± .315	.662	.907
2 vs 8 days	± .405	.851	1.166

[c]Percent of fresh tissue.

TABLE 16. MEANS OF ETHER EXTRACT OF COWS AND HOLSTEIN STEERS [a,b,c]

COWS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	3.78	3.91	1.52	1.60
8	3.65	4.16	1.47	1.28

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 1.265	2.917	4.244
Fast vs slow	± .297	.684	.996
2 vs 8 days	± .036	.438	.121

HOLSTEIN STEERS

Days Postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	6.03	5.80	1.03	1.26
8	6.49	6.83	1.13	1.41

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 2.325	5.361	7.800
Fast vs slow	± .973	2.243	3.264
2 vs 8 days	± .953	2.197	3.197

[c]Percent of fresh tissue.

TABLE 17. MEANS OF ETHER EXTRACT OF BULLOCKS AND BEEF-TYPE STEERS [a,b,c]

BULLOCKS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	2.31	2.16	1.62	1.58
8	2.77	2.67	1.54	1.71

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 1.064	2.453	3.570
Fast vs slow	± .436	1.005	1.463
2 vs 8 days	± .509	1.174	1.708

BEEF-TYPE STEERS

Days postmortem	Fat		Thin	
	Slow	Fast	Slow	Fast
2	3.73	3.41	3.17	3.17
8	3.79	4.19	3.51	3.89

	[a]Standard errors of differences among treatment combination means	[b]Mean significant difference	
		P < .05	P < .01
Fat vs thin	± 1.816	3.815	5.226
Fast vs slow	± .504	1.059	1.451
2 vs 8 days	± .456	.958	1.312

[c]Percent of fresh tissue.

TABLE 18. MARBLING SCORES [a]

	Fat	Thin
Cows	13.4	5.4
Bullocks	6.2	5.8
Holstein steers	15.2	4.8
Beef-type steers	25.4	20.8

[a] 1 = practically devoid^{-}, 2 = practically devoid ^{o} etc.

SUMMARY

This study consisted of two separate experiments to investigate the effect of cold shortening on bovine muscle and its relationship of sex, degree of fatness, postmortem aging and postmortem pH and temperature decline. Ten cows, 10 bullocks and 10 Holstein steers were used in experiment 1, 20 beef-type steers were used in experiment 2. All cattle were slaughtered and divided into two groups (fat and thin) based on their fat thickness at 12th rib. All carcasses were split into right and left sides and placed in a -1° to 1°C chilling cooler (fast chilling) and 14°C to 15°C chilling cooler (slow chilling), respectively. Internal temperatures and pH of the longissimus muscle were monitored. At 2 and 8 days postmortem samples were removed from the longissimus muscle in the lumbar region for tenderness, sarcomere length, myofibrillar fragmentation, moisture, ether extract and collagen determinations. Tenderness was determined using Warner-Bratzler shear device and by taste panels. Sarcomere length was measured by use of a phase-contrast photo-microscope to detect the extent of muscle contraction. Myofibril fragmentation was read spectrophotometrically as percent transmittance.

Postmortem temperature changes were fatness and chilling rate dependent. Fat carcasses had higher initial postmortem temperatures than thin carcasses. Slow chilling rate caused slower postmortem temperature decline than did fast chilling rates. Temperature decline in fat carcasses was slower than thin carcasses. Carcasses fatness had an effect on chilling rate but could not overcome the effect of different chilling

temperatures. The fat carcasses had faster pH decline than did the thin carcasses and fast chilling rate caused the pH to decline more slowly than did the slow chilling rate. The ultimate pH attained in the fast chilled carcasses was significantly higher than those chilled slowly. There were no significant differences in postmortem pH decline among cows, bullocks and Holstein steers. The beef-type steers had the same pH decline pattern as the cattle in experiment 1 but there was little difference in the rate between fat and thin steers as well as between fast and slow chilling rates.

Steaks from carcasses chilled slowly had higher panel tenderness scores and lower Warner-Bratzler shear values than those from fast chilled carcasses. Steaks from fat carcasses tended to be more tender than those from thin carcasses but only the differences in the thin group were significant. All 8 days steaks had higher panel tenderness scores and lower shear values than did the 2 days steaks. However, only fat cows, thin bullocks and thin Holstein steers showed significant aging effects in panel tenderness scores and only thin cows chilled rapidly, thin Holstein steers and thin bullocks differed significantly. In experiment 2, steaks from either the fat or thin carcasses chilled slowly had lower ($P < .05$) shear values than those chilled rapidly. Fatness did not have much effect on shear values in the beef-type steers. After 8 days postmortem aging, steaks from fat carcasses had lower shear values than those from thin carcasses ($P < .01$). Postmortem aging did not improve the tenderness of steaks from thin beef-type steers. The sarcomere of longissimus muscles from the slowly chilled carcasses were

longer than those chilled rapidly. However, the differences were not significant in either experiments 1 or 2. Steaks after 8 days postmortem aging tended to have shorter sarcomere lengths than those after 2 days aging. Cold shortening did not have an effect on beef-type steers. Sarcomere length was not significantly correlated with panel tenderness or shear values in this study.

Myofibril fragmentation was highly correlated with tenderness ($P < .01$). Sample from slow chilled carcasses almost always had more myofibril fragmentation than those from fast chilled carcasses. Fragmentation was not different among fatness groups. Postmortem aging did not cause any significant change in myofibril fragmentation. No significant fragmentation differences were observed in beef-type steers. Neither chill temperature, nor postmortem aging differed significantly in percentage intramuscular collagen in the longissimus muscle of fat and thin carcasses of cows, bullocks or Holstein steers and beef-type steers. Intramuscular collagen percentage was not correlated with panel tenderness, shear or sarcomere length and fragmentation in either experiment.

Percent moisture was negatively correlated with panel tenderness ($P < .01$) in both experiments. Degree of marbling showed nonsignificant correlations with tenderness in both experiments. Twelfth rib fat thickness was highly correlated with ether extract, marbling degree and moisture aontant in experiment 1. However, in experiment 2 marbling was only correlated with 12th rib fat thickness ($r = .45$).

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APPENDIX

Appendix I. Raw data of temperature (°C) decline in fat beef-type steers at various postmortem hours.

Animal number	Muscle temperature									
	0	1	2	3	4	6	8	12	24	48
Slow chilling										
41	39	35	33	31	29	27	24	21	18	4
43	38	35	33	31	29	27	25	23	20	4
44	39	38	36	35	34	28	26	23	21	5
45	40	39	37	36	34	30	26	21	21	5
46	39	37	35	34	32	31	28	25	20	7
47	40	37	35	33	31	30	27	24	20	6
48	41	39	36	35	30	30	28	24	19	8
49	41	40	37	35	34	30	28	25	20	8
50	39	37	35	33	31	27	24	23	21	4
51	39	38	37	35	33	30	27	24	20	5
Average	39.5	37.5	35.4	33.8	31.7	29.0	26.3	23.3	20.0	5.6
Fast chilling										
41	38	35	34	30	26	23	20	15	6	1.5
43	39	35	31	30	25	21	18	14	6	2
44	39	37	36	33	31	30	26	16	7	2
45	40	37	34	30	26	24	20	12	7	3
46	38	35	33	31	29	25	21	17	5	2
47	39	35	33	32	28	24	20	16	5	2
48	39	37	34	29	25	23	21	12	4	2
49	40	37	34	30	28	25	23	17	5	2
50	39	36	34	31	28	23	18	15	5	1
51	39	36	35	32	28	27	19	14	7	2
Average	39.0	36.0	33.8	30.8	27.4	24.5	20.6	14.8	5.7	1.9

Appendix II. Raw data of temperature (°C) decline in thin beef-type steers at various postmortem hours.

Animal number	Muscle temperature									
	0	1	2	3	4	6	8	12	24	48
Slow chilling										
40	38	33	33	30	28	26	23	20	18	3
33	38	34	32	29	28	25	23	20	27	2
38	38	34	34	32	30	26	24	21	17	3
32	38	33	32.5	30	28	25	23	20	17	2
37	39	38	36	33	31	27	25	22	18	4
42	38	36	33	29	27	25	23	20	17	2
36	39	37	36	34	31	27	25	22	18	5
35	40	38	37	34	32	28.5	25	23	18	2
39	39	37	35	33	30	27	24	21	17	4
34	36	35.5	34	30.5	29.5	26	24	21	19	2
Average	38.3	35.6	34.3	31.5	29.5	26.3	23.9	21.0	17.6	2.9
Fast chilling										
40	37	35	28	26	24	20	16	12	4	1
33	38	35	30.5	26	20	15	12	8	1.5	1
38	38	33	31	29	26	22	18	12	5	1
32	39	34	31	26.5	23	17	14	8	2	.5
37	39	36	33	29	26	20	17	12	3	2
42	37	30	27	27	24	20	17	11	2	0
36	39	36	33	28	25	19	17	11	2	1
35	38	34.5	31	26.5	24	20	16	10	3	1.1
39	39	37	34	30	27	23	18	15	6	1.5
34	36	32	30.5	27.5	25	20	17	12	3	1.1
Average	38.0	34.3	30.9	27.6	24.4	19.6	16.2	11.1	3.2	1.0

Appendix III. Raw data of pH decline in cows at various postmortem hours.

Animal number	Muscle pH										
	0	1	2	3	4	6	8	12	24	48	192
Fat group, slow chilling											
2	6.8	6.6	6.6	6.6	6.6	6.2	6.5	5.6	5.8	5.6	5.9
21	6.6	6.4	6.2	6.0	5.8	5.6	5.5	5.4	5.4	5.5	5.2
3	6.8	6.2	5.9	5.8	6.0	5.8	5.8	5.7	5.5	5.4	5.6
22	6.5	6.3	6.1	5.8	5.6	5.5	5.5	5.4	5.5	5.4	5.3
4	6.8	6.4	6.0	5.7	5.8	5.8	5.6	5.6	5.6	5.3	5.6
Fat group, fast chilling											
2	6.8	6.6	6.6	6.6	6.6	6.2	6.5	5.6	5.8	5.6	5.9
21	6.6	6.4	6.2	6.0	5.8	5.6	5.5	5.4	5.4	5.5	5.2
3	6.8	6.2	5.9	5.8	6.0	5.8	5.8	5.7	5.5	5.4	5.6
22	6.5	6.3	6.1	5.8	5.6	5.5	5.5	5.4	5.5	5.4	5.3
4	6.8	6.4	6.0	5.7	5.8	5.8	5.6	5.6	5.6	5.3	5.6
Thin group, slow chilling											
7	7.2	6.9	6.5	6.3	6.3	6.0	5.8	5.8	5.6	5.8	5.9
5	6.6	6.4	6.0	6.0	5.9	5.7	5.5	5.5	5.5	5.6	5.7
8	7.0	6.8	6.4	6.2	6.2	5.9	5.6	5.6	5.5	5.6	5.7
6	6.9	6.4	6.2	6.2	5.9	5.8	5.5	5.6	5.6	5.6	5.6
1	6.6	6.5	6.3	6.4	6.2	6.2	5.8	5.5	5.8	5.6	5.8
Thin group, fast chilling											
7	7.1	6.5	6.5	6.6	6.6	6.3	6.1	5.9	5.6	5.7	5.7
5	6.8	6.4	6.4	6.4	6.2	6.0	5.8	5.8	5.5	5.6	5.6
8	7.1	6.4	6.4	6.1	6.2	5.9	5.9	5.9	5.5	5.5	5.6
6	7.0	6.6	6.4	6.4	6.2	5.9	5.6	5.6	5.6	5.6	5.8
1	6.9	6.6	6.4	6.5	6.1	6.3	6.3	5.9	5.8	5.6	5.7

Appendix IV. Raw data of pH decline in bullocks at various postmortem hours.

Animal number	Muscle pH										
	0	1	2	3	4	6	8	12	24	48	192
Fat group, fast chilling											
27	6.4	5.9	5.8	5.8	5.7	5.6	5.6	5.6	5.6	5.6	5.5
30	6.0	5.6	5.5	5.3	5.5	5.5	5.5	5.6	5.5	5.4	5.5
19	6.7	6.0	5.9	5.7	5.5	5.4	5.5	5.4	5.4	5.4	5.2
20	6.6	6.5	6.2	5.8	6.1	5.6	5.5	5.6	5.4	5.4	5.6
29	5.8	5.6	5.6	5.4	5.5	5.5	5.5	5.5	5.4	5.4	5.5
Fat group, slow chilling											
27	6.3	5.6	5.7	5.8	5.7	5.6	5.6	5.6	5.6	5.6	5.4
30	6.2	6.0	5.4	5.5	5.5	5.5	5.5	5.6	5.5	5.4	5.4
19	6.7	5.9	5.8	5.8	5.5	5.3	5.4	5.5	5.4	5.5	5.5
20	6.5	5.9	5.8	5.7	5.4	5.4	5.4	5.5	5.4	5.4	5.2
29	6.1	5.6	5.5	5.5	5.5	5.5	5.6	5.6	5.6	5.6	5.4
Thin group, fast chilling											
16	6.5	6.1	5.9	6.0	5.8	5.5	5.4	5.4	5.5	5.3	5.4
17	6.4	6.0	6.0	5.7	5.7	5.6	5.5	5.6	5.6	5.6	5.5
18	5.5	6.2	6.2	5.9	5.8	5.7	5.6	5.5	5.5	5.6	5.4
28	6.9	6.1	5.7	5.6	5.5	5.5	5.5	5.4	5.4	5.4	5.5
31	6.3	6.1	6.0	5.7	5.6	5.6	5.5	5.5	5.4	5.5	5.5
Thin group, slow chilling											
16	6.2	6.0	5.8	5.5	5.4	5.3	5.3	5.3	5.5	5.3	5.5
17	7.0	6.2	6.0	5.8	5.6	5.6	5.5	5.4	5.5	5.7	5.6
18	6.3	5.8	5.7	5.7	5.5	5.5	5.4	5.4	5.6	5.6	5.6
23	6.7	6.2	5.7	5.6	5.5	5.5	5.5	5.5	5.4	5.5	5.4
31	6.2	6.1	5.5	5.5	5.5	5.5	5.5	5.5	5.4	5.4	5.5

Appendix V. Raw data of pH decline in Holstein steers at various postmortem hours.

Animal number	Muscle pH										
	0	1	2	3	4	6	8	12	24	48	192
Fat group, fast chilling											
14	6.7	6.1	5.9	5.8	5.8	5.7	5.6	5.6	5.6	5.6	5.4
10	6.6	5.9	6.0	5.7	5.6	5.6	5.6	5.6	5.6	5.5	5.6
12	6.7	6.2	6.0	5.8	5.7	5.6	5.6	5.6	5.6	5.6	5.5
23	6.2	5.7	5.7	5.7	5.6	5.6	5.6	5.6	5.2	5.5	5.5
26	6.7	6.2	6.0	5.9	5.7	5.6	5.7	5.5	5.5	5.5	5.4
Fat group, slow chilling											
14	6.7	6.3	6.1	6.2	5.9	5.8	5.8	5.8	5.6	5.6	5.5
10	6.5	5.6	5.7	5.6	5.6	5.6	5.5	5.6	5.7	5.6	5.6
12	6.4	5.8	5.8	5.8	5.7	5.7	5.7	5.7	5.6	5.7	5.6
23	6.2	5.6	5.8	5.6	5.6	5.6	5.7	5.7	5.5	5.4	5.5
26	6.7	6.0	5.8	5.7	5.8	5.6	5.7	5.6	5.5	5.5	5.5
Thin group, fast chilling											
13	7.0	6.3	6.0	5.8	5.8	5.7	5.6	5.6	5.6	5.5	5.6
11	6.2	5.9	5.8	5.7	5.7	5.6	5.6	5.5	5.6	5.5	5.4
9	6.6	6.1	6.2	5.6	5.6	5.6	5.5	5.6	5.7	5.6	5.6
25	6.2	5.9	5.6	5.7	5.7	5.7	5.7	5.7	5.5	5.4	5.3
15	6.7	6.2	6.3	6.2	6.2	5.9	5.6	5.4	5.4	5.3	5.4
Thin group, slow chilling											
13	6.8	6.4	6.0	6.0	5.6	5.6	5.6	5.7	5.6	5.6	5.7
11	6.2	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
9	6.6	5.8	5.7	5.7	5.7	5.6	5.6	5.6	5.8	5.6	5.5
25	6.5	6.0	5.9	5.5	5.7	5.6	5.6	5.5	5.4	5.4	5.4
15	6.4	6.4	6.1	6.0	5.8	5.6	5.3	5.3	5.4	5.2	5.4

Appendix V. Raw data of pH decline in Holstein steers at various postmortem hours.

Animal number	Muscle pH										
	0	1	2	3	4	6	8	12	24	48	192
Fat group, fast chilling											
14	6.7	6.1	5.9	5.8	5.8	5.7	5.6	5.6	5.6	5.6	5.4
10	6.6	5.9	6.0	5.7	5.6	5.6	5.6	5.6	5.6	5.5	5.6
12	6.7	6.2	6.0	5.8	5.7	5.6	5.6	5.6	5.6	5.6	5.5
23	6.2	5.7	5.7	5.7	5.6	5.6	5.6	5.6	5.2	5.5	5.5
26	6.7	6.2	6.0	5.9	5.7	5.6	5.7	5.5	5.5	5.5	5.4
Fat group, slow chilling											
14	6.7	6.3	6.1	6.2	5.9	5.8	5.8	5.8	5.6	5.6	5.5
10	6.5	5.6	5.7	5.6	5.6	5.6	5.5	5.6	5.7	5.6	5.6
12	6.4	5.8	5.8	5.8	5.7	5.7	5.7	5.7	5.6	5.7	5.6
23	6.2	5.6	5.8	5.6	5.6	5.6	5.7	5.7	5.5	5.4	5.5
26	6.7	6.0	5.8	5.7	5.8	5.6	5.7	5.6	5.5	5.5	5.5
Thin group, fast chilling											
13	7.0	6.3	6.0	5.8	5.8	5.7	5.6	5.6	5.6	5.5	5.6
11	6.2	5.9	5.8	5.7	5.7	5.6	5.6	5.5	5.6	5.5	5.4
9	6.6	6.1	6.2	5.6	5.6	5.6	5.5	5.6	5.7	5.6	5.6
25	6.2	5.9	5.6	5.7	5.7	5.7	5.7	5.7	5.5	5.4	5.3
15	6.7	6.2	6.3	6.2	6.2	5.9	5.6	5.4	5.4	5.3	5.4
Thin group, slow chilling											
13	6.8	6.4	6.0	6.0	5.6	5.6	5.6	5.7	5.6	5.6	5.7
11	6.2	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
9	6.6	5.8	5.7	5.7	5.7	5.6	5.6	5.6	5.8	5.6	5.5
25	6.5	6.0	5.9	5.5	5.7	5.6	5.6	5.5	5.4	5.4	5.4
15	6.4	6.4	6.1	6.0	5.8	5.6	5.3	5.3	5.4	5.2	5.4

Appendix VI. Raw data of pH decline in Beef-type steers at various postmortem hours.

Animal number	Muscle pH										
	0	1	2	3	4	6	8	12	24	48	192
Fat group, fast chilling											
41	6.5	5.6	5.6	5.6	5.5	5.4	5.5	5.4	5.5	5.4	5.5
43	6.4	5.5	5.4	5.4	5.4	5.4	5.5	5.5	5.5	5.5	5.5
44	6.7	6.0	5.6	5.5	5.5	5.5	5.5	5.5	5.5	5.4	5.4
45	6.6	6.0	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.4	5.5
46	6.5	6.0	5.9	5.8	5.7	5.6	5.5	5.6	5.5	5.4	5.5
47	6.4	5.8	5.7	5.6	5.6	5.6	5.6	5.6	5.6	5.5	5.4
48	6.3	5.5	5.5	5.5	5.5	5.4	5.5	5.5	5.4	5.5	5.5
49	6.2	5.8	5.6	5.6	5.6	5.5	5.5	5.5	5.4	5.5	5.4
50	6.7	5.8	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.6	5.6
51	6.4	5.5	5.5	5.5	5.4	5.5	5.4	5.5	5.5	5.6	5.6
Fat group, slow chilling											
41	6.6	5.8	5.5	5.5	5.5	5.5	5.4	5.5	5.5	5.3	5.6
43	6.4	6.2	6.0	5.5	5.5	5.7	5.5	5.5	5.6	5.5	5.6
44	6.6	6.1	5.6	5.6	5.6	5.6	5.5	5.4	5.4	5.4	5.5
45	6.8	6.1	5.5	5.5	5.5	5.6	5.5	5.5	5.5	5.3	5.5
46	6.4	6.4	6.0	5.8	5.6	5.6	5.6	5.6	5.4	5.3	5.4
47	6.4	6.0	5.8	5.6	5.6	5.4	5.5	5.6	5.6	5.6	5.6
48	6.0	5.5	5.6	5.5	5.6	5.5	5.5	5.4	5.4	5.4	5.4
49	6.0	5.6	5.6	5.6	5.6	5.4	5.5	5.5	5.4	5.3	5.4
50	6.5	5.6	5.5	5.5	5.5	5.5	5.5	5.5	5.3	5.3	5.4
51	6.4	5.6	5.5	5.5	5.5	5.6	5.5	5.5	5.4	5.4	5.5

Appendix VI. Raw data of pH decline in beef-type steers at various postmortem hours. (continued)

Animal number	Muscle pH										
	0	1	2	3	4	6	8	12	24	48	192
Thin group, fast chilling											
32	6.3	6.0	5.5	5.5	5.5	5.4	5.4	5.3	5.3	5.4	5.6
33	6.6	6.0	5.9	5.5	5.5	5.5	5.3	5.3	5.3	5.4	5.6
34	6.4	5.7	5.7	5.6	5.5	5.4	5.5	5.6	5.7	5.5	5.6
35	6.4	5.7	5.7	5.6	5.5	5.5	5.5	5.6	5.6	5.6	5.3
36	6.3	5.9	5.4	5.6	5.5	5.4	5.5	5.3	6.0	5.4	5.4
37	6.5	5.9	5.4	5.6	5.6	5.4	5.5	5.4	5.5	5.4	5.4
38	6.4	5.9	5.6	5.6	5.6	5.5	5.4	5.5	5.4	5.4	5.4
39	6.6	5.9	5.8	5.7	5.6	5.5	5.4	5.5	5.4	5.4	5.4
40	6.4	5.6	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.4	5.6
42	6.6	5.7	5.7	5.7	5.6	5.5	5.5	5.5	5.5	5.3	5.5
Thin group, slow chilling											
32	6.4	6.1	5.6	5.5	5.6	5.4	5.4	5.4	5.5	5.3	5.7
33	6.6	6.0	5.6	5.6	5.6	5.5	5.4	5.4	5.5	5.4	5.8
34	6.4	5.9	5.6	5.6	5.6	5.5	5.5	5.4	5.6	5.5	5.6
35	6.3	5.9	5.6	5.6	5.6	5.5	5.5	5.5	5.6	5.5	5.4
36	6.3	5.8	5.4	5.5	5.4	5.4	5.5	5.4	5.4	5.4	5.4
37	6.4	5.8	5.4	5.5	5.5	5.5	5.5	5.3	5.4	5.4	5.6
38	6.4	6.0	5.6	5.5	5.4	5.6	5.5	5.5	5.4	5.3	5.5
39	6.8	5.9	5.5	5.5	5.4	5.5	5.4	5.4	5.4	5.3	5.4
40	6.4	5.6	5.6	5.5	5.5	5.5	5.4	5.5	5.5	5.3	5.6
42	6.4	6.1	5.9	5.5	5.6	5.5	5.5	5.6	5.6	5.6	5.6

Appendix VII. Raw data of chemical and physical traits.

A 1. Identification of variable number.

Variable number	Variable item	Decimal places
1	Animal number	0
2	Sex [a]	0
3	Chilling rate [b]	0
4	Postmortem aging [c]	0
5	Fatness group [d]	0
6	Panel tenderness [e]	2
7	W-B shear, kg/cm^2	2
8	Sarcomere length, μm	3
9	Fragmentation [f]	2
10	Moisture %	2
11	Ether extract %	2
12	Collagen %	2
13	12th rib fat thickness, cm	2
14	Marbling score [g]	0

[a] 1 = cow. 2 = bullocks. 3 = Holstein steer. 4 = beef-type steer

[b] 1 = slow chilling. 2 = fast chilling.

[c] 1 = 2-day postmortem. 2 = 8-day postmortem.

[d] 1 = fat group. 2 = thin group.

[e] 1 = extremely tough. 9 = extremely tender

[f] 1 = percent transmittance per mg nitrogen.

[g] 1 = practically devoid $^-$, 2 = practically devoid ^{o} etc.

Appendix VII. Raw data of chemical and physical traits. A 2. Raw data

					Variable number								
1	2	3	4	5	6	7	8	9	10	11	12	13	14
02	1	2	2	1	533	351	1664	3910	7346	0364	736	076	10
21	1	2	2	1	367	429	1832	3035	7266	0256	648	076	11
03	1	2	2	1	580	283	1598	2568	7220	0420	843	076	11
22	1	2	2	1	700	285	1958	4072	7078	0585	596	102	18
04	1	2	2	1	575	323	1675	3254	7176	0454	843	127	17
07	1	2	2	2	350	261	1910	3850	7595	0042	635	001	01
05	1	2	2	2	334	346	1820	3177	7675	0042	796	013	01
08	1	2	2	2	275	400	1621	4725	7514	0152	670	025	09
06	1	2	2	2	458	337	1904	3342	7440	0136	719	025	07
01	1	2	2	2	466	369	1580	3910	7422	0266	849	025	09
27	2	2	2	2	567	280	1676	3372	7356	0157	656	038	07
30	2	2	2	1	550	294	1960	3134	7072	0486	545	051	08
19	2	2	2	1	575	325	1865	1905	7436	0086	689	051	02
20	2	2	2	1	692	285	2014	3654	7359	0118	703	051	06
29	2	2	2	1	367	375	1703	4339	7357	0282	507	051	08
16	2	2	2	2	484	358	1861	3315	7466	0140	687	025	05
17	2	2	2	2	650	312	1948	2970	7472	0112	534	025	04
18	2	2	2	2	500	328	1902	4902	7458	0124	601	025	04
28	2	2	2	2	642	267	1717	3314	7226	0324	477	025	09
31	2	2	2	1	333	332	1870	4210	7210	0361	545	038	07
14	3	2	2	1	675	327	1695	2952	7123	0624	726	038	11
10	3	2	2	1	659	267	1705	2430	7162	0366	766	051	18
12	3	2	2	1	417	366	1751	3862	7404	0398	756	051	11
23	3	2	2	1	542	349	1778	5492	6656	1144	698	102	21
26	3	2	2	1	508	364	1820	3952	6926	0882	648	102	15
13	3	2	2	2	383	396	1771	5150	7542	0094	621	013	04
11	3	2	2	2	359	304	1919	5170	7550	0124	694	013	04
09	3	2	2	2	409	372	1859	3577	7566	0176	668	013	04
25	3	2	2	2	658	292	1692	3887	7383	0206	668	025	07
15	3	2	2	2	550	334	1792	2890	7504	0104	798	025	05
33	4	2	2	2	542	351	1706	3734	7483	0076	639	025	05
32	4	2	2	2	442	387	1708	3964	7372	0156	567	025	07
42	4	2	2	2	358	397	1789	3764	7488	0106	560	025	04
35	4	2	2	2	467	409	1684	3355	7377	0176	542	038	09
34	4	2	2	2	508	342	1708	2982	7352	0161	590	051	07
40	4	2	2	2	430	308	1911	2861	7239	0419	528	051	08
36	4	2	2	2	708	294	1640	2631	6381	1444	661	064	15
37	4	2	2	2	558	360	1885	.2897	7213	0360	608	064	09
38	4	2	2	2	625	313	1726	2226	7238	0535	515	064	10
39	4	2	2	2	475	348	1838	3790	7159	0458	592	064	08
50	4	2	2	1	533	292	1734	2715	7104	0545	667	089	08
51	4	2	2	1	467	320	1995	3356	7112	0559	628	102	09
44	4	2	2	1	442	270	1784	2906	7224	0463	488	140	09
41	4	2	2	1	500	287	1613	3129	7214	0413	363	165	09
45	4	2	2	1	500	281	1701	3068	7130	0432	482	178	11
49	4	2	2	1	600	279	1651	2510	7163	0453	683	178	11
43	4	2	2	1	642	256	1990	2122	7201	0464	435	203	10
47	4	2	2	1	558	261	1648	2804	7343	0273	453	191	08
46	4	2	2	1	542	286	1711	3448	7260	0344	556	216	10
48	4	2	2	1	467	315	1711	2556	7245	0248	661	216	11

Appendix VII. Raw data of chemical and physical traits. A 2. Raw data

	Variable number												
1	2	3	4	5	6	7	8	9	10	11	12	13	14
02	1	1	1	1	433	360	1759	4000	7330	0301	896	076	10
21	1	1	1	1	633	329	2276	3597	7356	0209	561	076	11
03	1	1	1	1	317	220	1904	2358	7254	0400	766	076	11
22	1	1	1	1	583	279	2019	4820	7188	0500	519	102	18
04	1	1	1	1	217	343	1893	4588	7207	0482	645	127	17
07	1	1	1	2	442	328	1992	3715	7553	0082	754	001	01
05	1	1	1	2	475	302	1804	2912	7706	0058	654	013	01
08	1	1	1	2	458	276	2256	4770	7510	0211	729	025	09
06	1	1	1	2	616	272	2179	3434	7481	0225	628	025	07
01	1	1	1	2	543	297	1974	3270	7406	0186	864	025	09
27	2	1	1	2	475	397	1681	2849	7424	0142	668	038	07
30	2	1	1	1	583	319	1752	3235	7301	0260	500	051	08
19	2	1	1	1	625	281	2071	3142	7412	0110	724	051	02
20	2	1	1	1	517	378	2027	5272	7374	0218	743	051	06
29	2	1	1	1	467	362	1878	3455	7294	0318	507	051	08
16	2	1	1	2	608	246	1957	3315	7380	0129	857	025	05
17	2	1	1	2	575	335	2082	4605	7404	0096	812	025	04
18	2	1	1	2	384	372	2037	5220	7489	0102	554	025	04
28	2	1	1	2	550	419	1839	3212	7230	0340	507	025	09
31	2	1	1	1	525	252	1961	4860	7383	0248	496	038	07
14	3	1	1	1	700	265	2120	2343	7234	0384	871	038	11
10	3	1	1	1	709	250	1992	2335	7138	0378	791	051	18
12	3	1	1	1	625	320	2139	2992	7382	0374	717	051	11
23	3	1	1	1	558	432	1774	4792	6723	1068	608	102	21
26	3	1	1	1	492	316	1736	3630	6972	0810	680	102	15
13	3	1	1	2	550	356	2177	4384	7608	0068	645	013	04
11	3	1	1	2	467	324	2091	4352	7556	0122	722	013	04
09	3	1	1	2	542	332	1954	3480	7559	0080	608	013	04
25	3	1	1	2	592	278	2068	3560	7378	0174	617	025	07
15	3	1	1	2	625	298	1975	2695	7460	0070	850	025	05
33	4	1	1	2	675	277	1791	3270	7421	0065	615	025	05
32	4	1	1	2	450	373	1785	4403	7321	0170	694	025	07
42	4	1	1	2	475	392	1959	2626	7458	0169	510	025	04
35	4	1	1	2	642	237	1768	3258	7335	0329	602	038	09
34	4	1	1	2	642	244	1789	3119	7361	0085	541	051	07
40	4	1	1	2	630	271	1809	3419	7306	0362	402	051	08
36	4	1	1	2	775	282	1895	2858	6837	0812	527	064	14
37	4	1	1	2	633	239	1853	2887	7253	0261	458	064	07
38	4	1	1	2	560	294	1849	3005	7200	0473	567	064	11
39	4	1	1	2	417	384	1927	3700	7049	0445	576	064	10
50	4	1	1	1	683	241	1903	3061	7310	0319	519	089	08
51	4	1	1	1	658	252	1824	2925	7083	0564	494	102	12
44	4	1	1	1	550	288	1532	2562	7251	0302	656	127	11
41	4	1	1	1	660	286	1721	3126	7256	0354	426	165	09
45	4	1	1	1	650	286	1926	2600	7118	0392	465	178	09
49	4	1	1	1	600	298	1872	3116	7251	0346	548	178	12
43	4	1	1	1	708	269	1841	2604	7147	0447	450	191	07
47	4	1	1	1	692	318	2013	2850	7214	0267	526	191	10
46	4	1	1	1	567	344	1903	2935	7224	0338	556	216	11
48	4	1	1	1	525	349	1974	2726	7173	0403	550	216	11

Appendix VII. Raw data of chemical and physical traits, A 2. Raw data

Variable number													
1	2	3	4	5	6	7	8	9	10	11	12	13	14
02	1	1	2	1	683	228	1818	3534	7435	0294	791	076	10
21	1	1	2	1	767	237	1973	2773	7373	0232	547	076	11
03	1	1	2	1	670	203	1842	2476	7292	0301	628	076	11
22	1	1	2	1	733	228	2061	3092	7122	0479	631	102	18
04	1	1	2	1	640	288	1679	2614	7149	0521	647	127	17
07	1	1	2	2	697	261	1981	3197	7551	0052	733	001	01
05	1	1	2	2	542	248	1905	2310	7638	0020	740	013	01
08	1	1	2	2	609	308	1915	3430	7510	0194	661	025	09
06	1	1	2	2	717	205	1936	2884	7457	0186	719	025	07
01	1	1	2	2	592	277	1788	3030	7424	0284	766	025	09
27	2	1	2	2	567	280	1672	3379	7353	0193	649	038	07
30	2	1	2	1	558	285	1893	2910	7114	0436	596	051	08
19	2	1	2	1	718	238	1761	3731	7452	0135	917	051	02
20	2	1	2	1	715	261	1992	3814	7315	0222	724	051	06
29	2	1	2	1	542	334	1740	4079	7281	0298	556	051	08
16	2	1	2	2	667	244	1822	3015	7402	0124	789	025	05
17	2	1	2	2	783	218	2015	2880	7512	0078	575	025	04
18	2	1	2	2	633	328	1906	3720	7458	0120	642	025	04
28	2	1	2	2	733	259	1784	3812	7266	0258	482	025	09
31	2	1	2	1	433	344	1904	4538	7248	0293	556	038	07
14	3	1	2	1	700	282	1924	2313	7121	0576	715	038	11
10	3	1	2	1	750	239	1794	2533	7124	0348	633	051	18
12	3	1	2	1	625	296	1817	3052	7368	0374	810	051	11
23	3	1	2	1	692	277	1782	4962	6650	1164	649	102	21
26	3	1	2	1	667	324	1821	3752	7007	0784	717	102	15
13	3	1	2	2	633	228	1908	3028	7544	0072	645	013	04
11	3	1	2	2	617	265	2002	3147	7468	0078	743	013	04
09	3	1	2	2	733	228	1874	2690	7568	0136	724	013	04
25	3	1	2	2	642	243	1878	4285	7325	0216	587	025	07
15	3	1	2	2	683	279	1934	2658	7472	0064	798	025	05
33	4	1	2	2	667	284	1758	4400	7359	0171	626	025	05
32	4	1	2	2	567	347	1995	5553	7264	0183	584	025	07
42	4	1	2	2	416	331	1679	3268	7488	0103	510	025	04
35	4	1	2	2	517	366	1708	2660	7189	0529	597	038	09
34	4	1	2	2	517	302	1779	2777	7392	0100	580	051	07
40	4	1	2	2	508	314	1690	3121	7267	0285	398	051	08
36	4	1	2	2	783	237	1653	2313	6662	0979	565	064	14
37	4	1	2	2	683	310	1722	2753	7310	0159	495	064	07
38	4	1	2	2	560	360	1717	2686	7022	0670	572	064	11
39	4	1	2	2	430	380	1794	3812	7284	0334	590	064	10
50	4	1	2	1	671	249	1696	2635	7223	0326	650	089	08
51	4	1	2	1	633	292	1776	2871	7137	0428	577	102	12
44	4	1	2	1	592	211	1775	2568	7224	0307	470	127	11
41	4	1	2	1	592	285	1632	2735	7110	0548	421	165	09
45	4	1	2	1	500	219	1594	3132	7331	0269	505	178	09
49	4	1	2	1	558	310	1628	3074	7080	0561	686	178	12
43	4	1	2	1	758	222	1708	2318	7298	0356	428	191	07
47	4	1	2	1	600	229	1651	2923	7302	0244	539	191	10
46	4	1	2	1	542	229	1711	3112	7237	0385	467	216	11
48	4	1	2	1	617	257	1692	2422	7219	0363	541	216	11

Appendix VII. Raw data of chemical and physical traits. A 2. Raw data

Variable number													
1	2	3	4	5	6	7	8	9	10	11	12	13	14
02	1	2	1	1	317	473	1669	4605	7377	0336	817	076	10
21	1	2	1	1	367	419	1825	4132	7279	0282	648	076	11
03	1	2	1	1	196	297	1762	3358	7291	0390	726	076	11
22	1	2	1	1	583	339	1849	4460	7127	0520	580	102	18
04	1	2	1	1	217	235	1966	2444	7210	0426	604	127	17
07	1	2	1	2	200	408	1759	4180	7638	0086	733	001	01
05	1	2	1	2	241	409	1823	3480	7560	0076	759	013	01
08	1	2	1	2	233	397	1645	6185	7452	0208	670	025	09
06	1	2	1	2	275	460	2021	4072	7534	0146	638	025	07
01	1	2	1	2	275	378	1668	3970	7510	0386	791	025	09
27	2	2	1	2	375	526	1732	3477	7409	0123	673	038	07
30	2	2	1	1	425	356	1803	3893	7214	0336	477	051	08
19	2	2	1	1	409	454	2186	5310	7441	0120	668	051	02
20	2	2	1	1	533	383	2159	5722	7420	0155	668	051	06
29	2	2	1	1	492	372	1987	3845	7366	0222	500	051	08
16	2	2	1	2	442	375	1781	3758	7472	0160	812	025	05
17	2	2	1	2	433	381	2064	4768	7536	0098	747	025	04
18	2	2	1	2	408	410	1984	7114	7532	0096	621	025	04
28	2	2	1	2	542	372	1867	3612	7266	0317	533	025	09
31	2	2	1	1	500	291	1989	5254	7375	0249	496	038	07
14	3	2	1	1	659	336	1989	3252	7305	0342	775	038	11
10	3	2	1	1	517	387	1774	2847	7158	0491	729	051	18
12	3	2	1	1	454	369	1950	4380	7410	0331	763	051	11
23	3	2	1	1	583	350	1800	5580	6756	1074	628	102	21
26	3	2	1	1	358	345	1800	3477	7140	0662	662	102	15
13	3	2	1	2	250	396	2024	5668	7540	0112	668	013	04
11	3	2	1	2	233	405	1779	5602	7500	0138	694	013	04
09	3	2	1	2	250	398	1797	5520	7616	0110	766	013	04
25	3	2	1	2	400	323	1803	3933	7432	0142	654	025	07
15	3	2	1	2	358	378	1848	5085	7504	0130	843	025	05
33	4	2	1	2	525	321	1720	2903	7429	0159	491	025	05
32	4	2	1	2	350	382	1685	2839	7312	0231	530	025	07
42	4	2	1	2	275	394	1865	3218	7551	0144	476	025	04
35	4	2	1	2	600	257	1893	3741	7312	0295	624	038	09
34	4	2	1	2	575	264	1767	3318	7393	0088	509	051	07
40	4	2	1	2	450	338	1806	3541	7214	0354	537	051	08
36	4	2	1	2	475	393	1997	3506	6799	0917	600	064	15
37	4	2	1	2	458	323	1904	3672	7281	0212	491	064	09
38	4	2	1	2	492	339	1847	3355	7221	0371	555	064	10
39	4	2	1	2	442	384	2102	4195	7186	0401	541	064	08
50	4	2	1	1	425	299	1869	3146	7292	0291	457	089	08
51	4	2	1	1	425	312	1845	3843	7229	0360	519	102	09
44	4	2	1	1	425	384	1852	3368	7133	0436	497	140	09
41	4	2	1	1	425	420	1959	4205	7247	0237	405	165	09
45	4	2	1	1	460	353	1693	3810	7151	0427	517	178	11
49	4	2	1	1	542	327	1711	3476	7119	0533	632	178	11
43	4	2	1	1	442	327	1726	2808	7210	0396	422	203	10
47	4	2	1	1	592	308	1747	3452	7281	0284	508	191	08
46	4	2	1	1	542	360	1835	3854	7287	0188	504	216	10
48	4	2	1	1	442	366	1859	3640	7263	0253	530	216	11