RELATIONSHIP OF MUSCLE STRUCTURE TO MEAT QUALITY

ROBERT N. SAYRE

UNIVERSITY OF WISCONSIN

Extremes in gross muscle structure have caused many problems in the processing and retailing of meat and have resulted in considerable research dealing with the post-mortem changes occurring in muscle. The problem of "dark cutter" beef has been studied extensively and many of the factors contributing to this condition are now understood. The other extreme of muscle structure, exemplified by pale, soft, watery pork muscle, has also been the object of numerous investigations. This paper will deal primarily with work done on post-mortem changes in pork muscle as related factors affecting rate of glycolysis, time course of rigor mortis and gross structural characteristics.

Pork muscles range in character from extremely watery, pale and soft to dry, dark and firm. The incidence of pale, soft, watery muscle varies from day-to-day and from season-to-season. Judge et al. (9) found that pigs grown and fattened during cool weather yielded darker, more highly marbled longissimus dorsi muscles while Wismer-Pedersen (17) stated that the frequency of muscles with low water-binding properties was greater in the hot months. A study now in progress at Wisconsin shows a progressive increase in the percentage of pale, soft, watery hams during the late winter and spring months as mean ambient temperatures increase.

The high incidence of pale, watery muscle is of particular consequence to the manufacturer of processed meats, because juice retention properties are inferior for these muscles and lower the quality and yield of the product. Carpenter (5) found that soft, watery, light colored hams lost 3.5 percent more weight during curing and smoking than did hams possessing a firm, dark, dry structure.

Fresh pork cuts may lose considerable "drip" during their passage through retail channels. Along with the inconvenience and unsightliness of accumulated "drip", there is considerable nutrient loss in the form of soluble proteins, vitamins and minerals. Studies by Carpenter (5) indicated that there was a greater cooking loss in pale, watery muscle and that the palatability characteristics of this muscle were less desirable than for dark, firm muscle. Lewis et al. (12) found that muscles with higher pH were more tender and were improved with regard to texture and juiciness as compared to muscles with lower pH values. In opposition to these findings, Judge et al. (8) reported that dark, firm muscle was less tender than light, soft muscle.

Changes in the color and texture of muscle post-mortem are apparently the result of altered protein structure. Wierbicki et al. (15) have postulated that redistribution of ions within the muscle resulted in increased hydration, and Hamm (7) has stated that hydration of muscle protein was dependent upon net charge and steric configuration of the protein.
Presumably, the degree of firmness of the muscle is related to the state of hydration of the muscle protein. Hamm (6) further postulated that release of water from the muscle at low pH, allowing the structure to become more dense, resulted in reflection of shorter wave lengths of light which produced a lighter color. Bendall and Wismer-Pedersen (2) recently have postulated that myofibrils of watery muscle were coated with denatured sarcoplasmic protein, thus decreasing the water-binding properties of the muscle proteins.

Changes in the post-mortem physical characteristics of muscle have long been associated with lactic acid production from post-mortem glycolysis. Various workers have investigated methods of altering the glycogen content of muscle at the time of slaughter in an effort to regulate the characteristics of chilled muscle. Administration of a 50 percent sucrose ration for either a long or short period of time prior to slaughter has been shown to elevate glycogen stores in muscle at the time of slaughter. This muscle is generally characterized by a relatively low pH of 5.3 to 5.5 at 24 hr. post-mortem and tends to be pale in color and have an inferior water-binding capacity. Previous work at the Wisconsin station (3) has shown that muscle glycogen can be depleted prior to slaughter by the use of exhaustive exercise, and Lewis et al. (11) have accomplished this same result with periodic electric shocks throughout a 5-hr. period prior to slaughter. Glycogen depleted muscle has pH values above 6.0 and is dark and firm with high water-binding properties.

Recent studies at Wisconsin have indicated that in some animals a large proportion of the glycogen which disappeared during post-mortem glycolysis was not metabolized to lactic acid or other acid components. Wismer-Pedersen (16) has reported that there is substantial accumulation of hexose monophosphates in muscle following anaerobic glycolysis. Sharp (14) has stated that free glucose accumulates in the muscle of some animals. High levels of inorganic phosphate in the tissues resulting from the post-mortem breakdown of high energy phosphates could theoretically promote glycogen breakdown to hexose monophosphates but would not promote hexose diphosphate production.

From these observations, it can be seen that the amount of glycogen stored in the muscle at the time of slaughter was important in determining the ultimate condition of the muscle, if the amount of glycogen was less than necessary to reach pH 5.3 to 5.5 where glycolytic enzymes were inhibited. It is also especially pertinent that in some cases a large proportion of the degraded muscle glycogen did not appear as acid components.

The rate of post-mortem anaerobic glycolysis has been shown to be an important factor in the determination of ultimate muscle characteristics. Wismer-Pedersen (17) demonstrated that water-binding capacity of the chilled muscle was much more closely associated with pH measurements taken at 45 min. after death than with 24 hr. pH values. Lawrie (10) has pointed out that "normal" muscle in some cases may have a lower ultimate pH than muscle which is pale and watery. Briskey and Wismer-Pedersen (4) in a study of the rate of anaerobic glycolysis described four distinct types of post-mortem pH patterns. It was noted that a sharp decrease in pH from 7.0 to about 5.1 in 1.5 hr. post-mortem, and a subsequent elevation to 5.3 - 5.6 resulted in pale exudative tissue with soft, inferior structure.
A rapid rate of pH decline post-mortem resulted in a high degree of acidity while the muscle remained at a relatively high temperature. Under normal slaughter conditions, it was found that the temperature of the longissimus dorsi muscle remained constant for more than 45 min. after death and was not greatly decreased even at 2 hr. post-mortem. Wismer-Pedersen and Briskey (19) have pointed out the importance of the muscle temperature-pH relationship. They found that rapid cooling of muscle which was ultimately pale and soft under normal chilling conditions resulted in muscle with normal color, texture and water-binding properties. Conversely, holding normal muscle at 37°C for an extended period post-mortem resulted in the occurrence of pale, soft, watery muscle.

Variation in the buffering capacity of muscle has been offered as a partial explanation for observed differences in the rate and amount of pH decline. Recent studies at Wisconsin in which the buffer capacity of the longissimus dorsi muscle from 84 pigs was determined, failed to show any consistent difference between muscles which were dark and dry versus those which were ultimately pale and wet. Buffer capacity generally increased between pre-rigor and post rigor determinations and the largest increases tended to be in muscles which were pale and watery. This observation could be explained by the possibility of more extensive protein denaturation in pale, watery muscle resulting in the availability of a greater number of charged groups. This postulation is supported by the work of Wismer-Pedersen and Briskey (18) who noted increased dye-binding properties in pale, watery muscle.

Several factors apparently influence the rate of post-mortem glycolysis. Short term excitement and exercise immediately prior to slaughter has been shown to significantly lower the initial pH of the longissimus dorsi muscle, and has also resulted in a more rapid and complete glycolysis as indicated by glycogen disappearance. The brief strenuous exercise caused some glycogen disappearance and lactic acid accumulation in the muscle prior to slaughter. Ludvigsen (13) has postulated that the vasoconstrictor effect of epinephrine prevents lactic acid produced in the muscle, under stress conditions, from entering the general circulation. Wismer-Pedersen (17) has also pointed out that fright and shock prior to slaughter are much more detrimental to muscle characteristics than mere exercise.

A controlled high temperature chamber has been used at Wisconsin to study the effects of elevated preslaughter temperatures and post-mortem changes in muscle. Subjecting animals to ambient temperatures of 42 to 45 degrees C. in this chamber for a period of 1 hr. prior to slaughter has been found to elevate the temperature of the longissimus dorsi muscle to the range of 37.8 to 41.7 degrees C. at slaughter. The effects of heat treatment were similar to those resulting from excitement and exercise. Muscle from pigs subjected to these high temperatures possessed low water-binding properties and was very pale and soft after a 24 hr. chilling period. In contrast to muscle from pigs receiving excitement and exercise treatment, the muscle from heat treated animals had the same initial pH as muscle from control animals. However, the rate of pH decline was very rapid indicating an accelerated post-mortem glycolysis. The accelerated glycolytic rate was apparently the result of the elevated muscle temperature. This is in agreement with Bate-Smith and Bendall (1) and Wismer-Pedersen and Briskey (19) who found that glycolytic rate was markedly influenced by temperature.
The longissimus dorsi muscle of some animals receiving the heat treatment was severely affected. In these cases the post-rigor muscle was white and dry, exhibiting a very loose, open structure which gave the appearance of having been cooked. Animals from the Chester White breed reacted quite differently to heat treatment. Although the muscle temperature was the same as in the muscle of other breeds studied, the pH values did not fall below 5.8 at 24 hr. post-mortem and the muscle appeared dark and firm. Ludvigsen (13) has postulated that, at least in some cases, pale, soft, watery muscle in pigs results from the inability of the animal to adapt to stress conditions. It is possible that the difference in reaction to heat treatment could be explained in these terms. If the Chester White breed possessed the inherent ability to adjust to stress by counteracting the vasoconstrictor action of epinephrine with adrenal cortical steroids then peripheral circulation could actually be increased, resulting in increased aerobic glycolysis in the muscle anti-mortem, thus lowering the glycogen stores.

If the muscle glycogen stores were depleted prior to death and the resulting lactic acid removed from the muscle into the blood stream then post-mortem lactic acid production would be precluded resulting in dark, firm muscle. As previously mentioned, the elevated muscle temperature resulted in a very rapid rate of glycolysis and pH decline. Wismer-Federsen and Briskey (19) in studying the effects of the relationship of temperature and pH in pork muscle found that at a given pH, an elevated temperature caused low water retention and a pale, soft appearance. An interesting phenomenon was noted in removing the entire longissimus dorsi muscle from the chilled carcass. After severing the connective tissue sheath covering the muscle, it was found that there was no further attachment to the costal bones and the muscle could be easily pulled from the carcass as illustrated. Apparently the combination of high temperature under conditions of low pH resulted in hydrolysis of connective tissue attachments to the bone allowing release of the muscle.

Many differences have been found among the physical and chemical characteristics of the longissimus dorsi muscle from the Hampshire, Chester White and Poland China breeds. The initial glycogen level in Hampshire muscle was more than twice as high as that found in the muscle of Chester Whites and more than three times as high as the glycogen level in the Poland China muscle. Even after 24 hours had elapsed, post-mortem, more glycogen remained in the muscle of Hampshires than was initially present in either of the other two breeds. Although 24 hr. pH and lactic acid values were very similar for all breeds, there were marked differences in the amount of glycogen disappearance among breeds. Glycogen disappearance was approximately 110 and 40 percent greater in Hampshire and Chester White muscle, respectively, than in Poland China muscle. As previously mentioned, a possible explanation for this observation could be either hexose monophosphate accumulation of free glucose production.

Phosphorylase activity was found to be highest in Hampshire muscle and lowest in Poland China muscle paralleling the levels of glycogen stored in the muscle of the respective breeds. Apparently the level of activity of this enzyme, within breeds, was not associated with the level of glycogen stored in the muscle, the rate of post-mortem glycolysis or the ultimate pH
of the muscle. Similar findings were obtained in studying phospho-
fructokinase activity. The possibility exists that although these enzyme
levels were not associated with rate of post-mortem glycolysis, they might
be associated with an increased glycogen metabolism and turnover in the
live animal.

The initial pH of Poland China muscle consistently has been found
to be lower than for the muscle of the other two breeds. The rates of post-
mortem pH decline and change in muscle color intensity also tended to be
accelerated in Poland China muscle. Therefore, a more acid condition ex-
isted in the muscle of Poland China pigs during the first 1-2 hr. after
slaughter while the muscle temperature remained high. The combination of
high temperature and low pH resulted in the Poland China muscle being in-
ferior in water-binding properties as well as being pale and soft in color
and structure.

High muscle glycogen levels were not significantly correlated
with the rate of pH decline at the 5 percent level of probability. Within
breed correlations, though nonsignificant, were positive for initial muscle
glycogen level and pH values prior to and including 1 hr. post-mortem.
Conversely, a nonsignificant negative correlation existed for initial glyco-
gen levels and 24 hr. pH values. These findings indicate a tendency for
muscle with a high initial glycogen content to have a slightly slower but
totally greater pH drop post-mortem.

Investigations of the branching characteristics of glycogen were
conducted to determine if there was an association between rate of break-
down and glycogen structure. Average external chain lengths of muscle
glycogen tended to decrease by approximately one glucose residue during
post-mortem glycolysis. Sucrose feeding tended to lengthen both the ex-
ternal and internal chain length of muscle glycogen when compared to glyco-
gen from the muscle of animals which were fasted 70 hr. prior to slaughter.
The chain lengths of Hampshire glycogen sampled immediately after slaughter
tended to be longest and those of the Poland China glycogen shortest for
the three breeds. Although, the branching characteristics of Chester White
glycogen were similar to those for Hampshire glycogen at 0 hr. the chain
length of Chester White glycogen appeared to shorten more rapidly during
post-mortem glycolysis. When associated with observed rates of glycolysis
occurring in different breeds or resulting from sugar feeding, these find-
ings indicated a trend toward retarded glycolysis as chain length was
shortened.

In view of these findings, it seemed necessary to associate the
post-mortem changes in muscle with the characteristics of the rigor-mortis
process. An apparatus has been constructed at the Wisconsin station which
will measure the time course of rigor-mortis and some of its associated
changes. The muscle sample was held in a chamber under controlled environ-
mental conditions. A weight was periodically applied and released, and the
elasticity and extensibility of the muscle was continuously recorded. Four
types of rigor-mortis patterns have been observed. Both rapid "acid" rigor
and moderately slow "acid" rigor resulted in pale, soft, watery tissue.
Normal tissue was associated with a short "delay", moderately long "onset"
phase when the pH of the muscle at 45 min. remained high. A long "delay"
phase and an extremely long "onset" phase resulted in dark firm muscle even
though the ultimate pH was 5.4. This muscle showed considerable elasticity and electrical resistance during the "delay" phase and had virtually no shortening after completion of the rigor process.

Other examples of rapid "acid" or "alkaline" Bate-Smith and Bendall, (1) rigor showed severe shortening of as much as 40 percent and subsequent lengthening of samples equal to or greater than their original length. These muscles appeared to be dark, normal or pale depending not only upon the pH of the muscle at the onset of rigor, but also upon the duration of the "onset" phase. It is, therefore, postulated that many of the variations in pork muscle properties can be associated with the time course of rigor-mortis.

In summary - The rate of post-mortem pH decline appears to be one of the most important factors in the determination of the ultimate gross muscle characteristics. Both excitement and/or elevated muscle temperature have been shown to accelerate the rate of anaerobic glycolysis with a resultant rapid rate of acid formation. It has been shown that there are marked differences in chemical and physical characteristics of muscles from pigs of different breeds. Recent studies indicate that the time of course of rigor-mortis may be associated with gross structure, meat quality and characteristics of the muscle proteins.

LITERATURE CITED


(Applause)

MR. BRISKEY: Thank you, Bob. I think you will agree that Robert has earned his degree. We are well on schedule, and