Relationship Between Muscle Growth and Poultry Meat Quality

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ABSTRACT For a number of years, poultry selection has concentrated on growth velocity in meat lines, producing improvements in growth that have not been without consequence for muscle structure, metabolism, and meat quality. Higher growth rates may induce morphological abnormalities, induce larger fiber diameters and a higher proportion of glycolytic fibers, and a lower proteolytic potential in the muscles. After death, the faster development of rigor mortis increases the likelihood of paler color and reduced water holding capacity and poorer quality of further processed products. Reduced proteolytic potential is likely to increase toughness of poultry meats.

(*Key words*: growth, fiber size and type, focal myopathy, postmortem glycolysis, proteolysis)

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INTRODUCTION

Poultry selection has concentrated on growth velocity and muscle mass in meat lines, so in less than 30 yr, the production time to raise a 1.3-kg chicken has halved to 5 wk and we may soon have a 25-kg turkey raised in 20 wk. These performance criteria continue to dominate decision making for least cost production but are being questioned after the appearance of morphological disorders in skeletal muscles. Poultry carcass grading continues to be based on criteria such as bruising and discoloration, and does not take into account other qualities important to the processor and consumer. The continuing shift in the market from whole birds to further processed products has highlighted an increase in meat quality problems associated with toughness and poor cohesiveness, color, and water holding properties (Sosnicki and Wilson, 1991). This paper will concentrate on the origins of the inherent qualities of the meat related to the differing number, size, and biochemical and physiological characteristics of muscle fibers.

FIBER SIZE

In general, the number of fibers is related to changes throughout growth, and fast-growing farm animals have more muscle fibers than slower growing strains. Within strain, the fiber number may increase with increasing average daily gain and gain:feed ratio (Stickland, 1995).

In poultry, the muscle fiber cross-sectional area increases with age (Table 1). Geese, selected for meat yield, have larger fibers than birds selected for egg production (Klosowska *et al.*, 1993) and fast-growing chickens have larger diameter fibers than slow-growing lines (Table 1). This increase is also associated with an increase in the number of giant fibers, which typically have cross-sectional areas three to five times larger than normal, although these may also result from severe contraction (hypercontracted fibers).

Smaller fiber diameters may allow a higher packing density and increase toughness of the meat. Across fish species, a decrease in fiber diameter from 38,000 μ^2 (dab) to 8,000 μ^2 (tuna) increases the bite firmness of the cooked meat threefold (Hurling *et al.*, 1996); however, in pork and beef, an increase in fiber diameter is associated with both tender and tougher meat and no conclusions can be drawn for the effect in those meats (see Dransfield, 1997a).

With the increase in growth rate and muscle size, there has been an increase in incidence of leg weakness and edema, deep pectoral myopathy, and focal myopathy. During growth of turkey *Pectoralis* to 15 wk, a 35-fold increase in cross-section of muscle fibers occurs that is greater than that in endomysial and perimysial connective tissues (Swatland, 1990), and suggests that selection for rapid growth has created muscles that outgrow their life support systems and bring about muscle damage (Wilson, 1990). Focal myopathy, with its Z-line streaming, appears similar to ischemia, which can be induced by arterial blockage. Indeed, capillary

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Abbreviation Key: ATP = adenosine triphosphate; PSE = pale, soft, and exudative.

TABLE 1. Growth, fiber diameter, and fiber type in two strains of chicken[1]

Age	Live weight		Fiber area		Citrate synthase activity[2]	
	Rapid	Slow	Rapid	Slow	Rapid	Slow
(wk)	(g)		(μm^2)			
0	36	31	20	23	6.4	7.4
11	1,882	675	1,256	664	4.4	3.9
55	3,285	1,883	2,755	1,946	4.6	3.6

[1]Values are the means of the *Pectoralis* muscle for rapid- and slow-growing strains of male chickens. Data from Rémignon *et al.* (1993).

[2]Micromoles of substrate per minute per gram of muscle.

density and capillary to fiber ratio are reduced in necrotic regions, which are associated with a proliferation of connective tissue (Figure 1).

FIBER TYPE

The structure and function of avian muscle fiber types are revealed in metabolic differences in the red and white fibers. Red fibers are narrow in diameter, myoglobin rich, and adapted to aerobic (oxidative) metabolism for rapid, fatigue-resistant activity, whereas white fibers are larger in diameter, adapted to anaerobic (glycolytic) metabolism, fast-fatiguing, and used for brief bursts of activity (George and Berger, 1966). With increasing growth rate, fibers become more glycolytic (fast twitch, glycolytic; type IIB fibers). Italian geese, selected for meat production with higher growth rates and good meat yield, have muscles with higher white (glycolytic) fiber contents with greater fiber diameters than those selected for egg production (Klosowska *et al.*, 1993). Ducks kept on pasture had more red fibers and had smaller diameter red and white fibers than those kept intensively (Pingel and Knust, 1993). However, in male chickens compared at different ages and body weights (Rémignon *et al.*, 1993) the *Pectoralis major* is entirely composed of IIB fast glycolytic fibers and, in two selected lines, neither the distribution of fiber type nor the three fast myosin isoforms differed. Only small changes occurred in metabolic pattern shown by a slight increase in oxidative capacity as an increase in citrate synthase (Table 1), which is the first enzyme entering into the Krebs cycle.

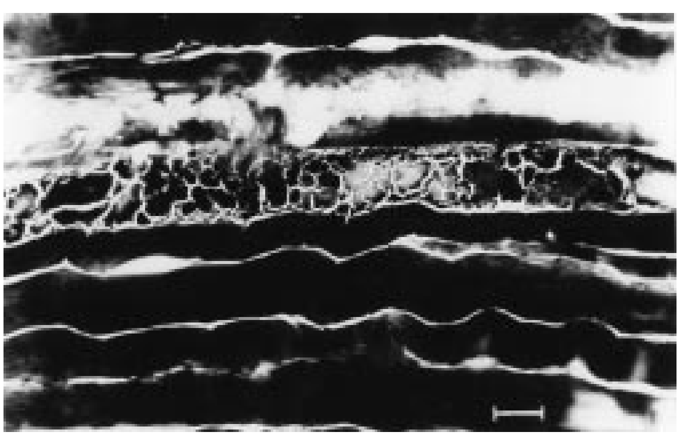

FIGURE 1. Turkey biceps femoris undergoing necrosis (white area) and a proliferation of the network of endomysial connective tissue (above center). Longitudinal section of fibers stained with modified trichrome (bar = 50 μm).

PROTEIN ACCRETION

Increasing growth rate also changes the protein dynamics. Accretion of muscle is a dynamic process between opposing anabolism and catabolism and changes in either or both sides of the equilibrium will result in changes in size of the muscle. Administration of β-agonists results in muscle hypertrophy in rats, lambs, cattle, and chickens by changing the proteolytic activity. In the study of Reeds *et al.* (1986), administration of the β-agonist, clenbuterol, to rats suggested that the hypertrophy was entirely due to a reduced protein catabolism. Degradation of muscular proteins therefore constitutes an important regulatory mechanism for muscle growth (Goll *et al.*, 1992).

There are three proteolytic systems in muscle: the cathepsins (lysosomal), the calpains (calcium-dependent) and the proteasome [adenosine triphosphate (ATP)/ ubiquitin dependent]. All of these enzymes have been sequenced and specific inhibitors (cystatins and calpastatin, respectively) have been purified for the first two systems. *In vivo*, the proteasome appears to be responsible for the majority of protein turnover (Goldberg *et al.*, 1997), calpains appear to be responsible for the degradation of the cytoskeleton, whereas lysosomal activity

TABLE 2. Proteolytic capacities in relation to growth rate[1]

Strain	Feed conversion ratio	μ-Calpain	Cathepsin B and L	Cathepsin H
White Leghorns	2.527	7.08	3.40	1.44
Ross	1.758	0.37	1.53	1.28
Very high growth rate	1.701	0.57	1.29	1.09

[1]Values are the potential proteolytic activities for calpain and cathepsins taken as the ratio of the amount of enzyme to that of their specific inhibitor for *Pectoralis* muscles from male chickens from White Leghorn (650 g at 6 wk), Ross (2.4 kg at 6 wk), and one selected for very high growth rate (2.5 kg at 6 wk). Data taken from Schreurs *et al.* (1995). Enzyme activities are in micromoles of substrate per minute per gram of muscle.

increases after damage or disease. The cathepsins and calpains have been studied extensively, but little information is available on proteasome in relation to muscle growth.

Studies of the effect of growth rate on the proteolytic capacity of breast muscle (Table 2) show that slow-growing birds have a higher ratio of enzyme to inhibitor. In the slow-growing birds, the enzyme is in excess, whereas in fast-growing birds, the inhibitor is in excess. White Leghorns showed the largest proteolytic capacity of the calpain system and a high activity of cathepsin H and cystatins. These studies suggest that the increased growth and muscle mass in modern lines could be largely governed by reduced protein catabolism. Cathepsins, and particularly calpains, have been implicated in postmortem proteolysis and weakening of the muscle fibers leading to tenderization. With the reduced proteolytic potential in faster growing lines, there is less activity and, therefore, reduced tenderization in the meat.

POSTMORTEM EVENTS

After death of the animal, anaerobic metabolism reduces the pH from about 7.2 in muscle to 5.8 in meat and stiffness develops (rigor mortis). The rate of rigor mortis development can be affected at all stages of production (Froning *et al.*, 1978), both pre- and post-slaughter, and variations in its rate in turn affect the sensory and functional properties of raw meat and of further processed products (Richardson, 1995). Heat stress is one of the prominent antemortem environmental factors that cause a rapid early postmortem glycolysis (McKee and Sams, 1997).

Glycolytic fibers have a more rapid rigor mortis development. Thus in beef, rigor would normally take about a day, whereas in pork, rigor is complete in several hours and in chicken breast muscle takes about 1 h. Growth performance can influence the rate and extent of rigor development in the meat. For example, the rate of pH fall was the same in breast muscle of selected lines for high growth rate but a protein-inefficient line (White Leghorn) had higher ultimate pH values (Schreurs *et al.*, 1995). At high ultimate pH, water-holding properties of myosin will remain high. Also, in fast-growing turkeys, the rate of pH decline in pectoral muscle was about 0.04 units/min, about twice the rate than that of a slow-growing line (Santé *et al.*, 1995). The rate of pH decline varies among chicken genetic lines and between individual birds, typically pH values at 15 min. after slaughter vary from 6.2 to 6.6 (Gardzielewska *et al.*, 1995). Arbor Acres broilers showed the fastest decline with 6% of breast muscles having a pH $\leq$ 5.7. In commercial production, with the variety of environmental factors, pH at 20 min postmortem may typically vary from 6.2 to 6.8 in breast muscle from 10-wk-old turkey hens and vary more widely in male and female chicken muscles.

TABLE 3. Interaction of rate of rigor mortis development and temperature in determining the quality of poultry meat

	Rapid chill	Slow chill
Rapid rigor		High drip, pale meat, tough, rapid aging
Slow rigor	High drip, tough, slow aging	

Rapid pH decline at high temperature will inactivate the calpain system and reduce postmortem tenderization (Dransfield, 1994), leading to toughening (Table 3). With a faster pH decline, myosin will be more susceptible to denaturation. Rapid denaturation of myosin increases the likelihood of reduced water-holding capacity, pale color, similar to pale, soft, and exudative (PSE) condition in pork. *In vitro* studies show that lowering the pH by 1 unit increases the rate of denaturation 12 times (Offer, 1991). Temperature is also critical, with an increase in temperature of 10 C (in the region of 30 C) increasing denaturation 20-fold. Thus, the potential detrimental PSE-like effect of fast-growing lines could be partially offset by increasing the rate of carcass cooling (Table 3). However, rapid cooling will toughen slow glycolysing muscles (Wakefield *et al.*, 1989). Ideally, the most tender meat will be produced by reaching about 10 C when the pH is 6.2. So, for example, those carcasses with rapid rigor should be chilled quickly to reduce protein denaturation and those with slower rigor mortis development chilled more slowly reducing their toughening (Table 3).

In the future, an automatic system to measure rigor mortis development in-line (Dransfield, 1997b) can be envisaged and then each carcass could be measured individually and processed appropriately (Table 1). In this way, the interaction between production, processing, and quality can be accommodated with close cooperation between producers, the meat industry, and the consumer.

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