MUSCLE EXTRACELLULAR MATRIX

Role in Growth, Development, and Meat Tenderness

R. J. McCormick and A. L. Phillips

Department of Animal Science, University of Wyoming
Laramie, Wyoming 82071

Muscle extracellular matrix (ECM) is composed primarily of collagen, with lesser amounts of other constituents including proteoglycans. This review summarizes the role of the major muscle collagens, types I and III, and the small, leucine-rich proteoglycan decorin in development of a mature, skeletal muscle matrix and subsequent meat characteristics. A stabilized ECM is essential for functional muscle; the stabilizing force is provided predominantly by the covalent, lysine-derived crosslinks of collagen. Information regarding the chemical structure and specific location of crosslinks is available; however, steps which control and regulate crosslink formation are less well understood. Recent studies suggest a potential role for decorin in regulating fibrillogenesis of collagen, ordering the spatial arrangement of collagen molecules and fibrils and influencing crosslinking patterns. Finally, the extent to which altered muscle collagen development may affect muscle growth and postmortem muscle characteristics will be discussed.

1. INTRODUCTION

The connective tissue of skeletal muscle, composed mostly of collagen and proteoglycan, forms a scaffold which provides support for muscle cells and a structure for transmission and absorption of force generated during muscle contraction. An alignment of collagen molecules that allows both fibril formation and covalent crosslinking stabilizes the connective tissue matrix and is a primary factor in meat texture variation.

Epimysium, perimysium and endomysium are the three morphologically discrete collagen depots in muscle. Epimysium is the heavy sheath of connective tissue surrounding individual muscles which thickens at both origin and insertion. Epimysium is usually separated from muscle prior to consumption and is, thus, not a factor in meat texture. Perimysium surrounds bundles of muscle fibers, while endomysium encircles individual muscle fiber (or cells) and overlays the basement membrane. Perimysium and epimysium comprise the intramuscular connective tissue (IMCT), are not generally separable from...
meat and form the connective structures which influence meat texture. The bulk (90%) of IMCT consists of perimysium and is probably the main contributor to meat texture (Light et al., 1985; McCormick, 1994).

The contribution that connective tissue makes to cooked meat texture is a function of muscle collagen concentration (amount) and degree of covalent crosslinking of that collagen (Bailey, 1989). Upon heating, both endomysial and perimysial fractions shrink and develop tension. Shrinkage and force development occurs incrementally with temperature increase (endomysial fraction preceding perimysial) and a biphasic increase in shear force is observed prior to collagen gelatinization (Davey and Gilbert, 1974). This brief review focuses on the role that enzymatic, lysine aldehyde-derived collagen crosslinking plays in meat texture variations and how crosslinking patterns may be regulated.

2. COLLAGEN AND COLLAGEN CROSSLINK CHEMISTRY

Nineteen different collagen phenotypes (the products of 25 genes) exhibiting a wide degree of structural and functional diversity have been identified. The primary collagen phenotypes in muscle, specifically in the perimysial fraction, are the banded, fibrillar collagens, types I and III (Nimni and Harkness, 1988). This review addresses only their structures and mechanisms of crosslink formation.

2.1. The Collagen Molecule

The fibrillar collagen molecule consists of three polypeptide subunits, called α-chains, which associate via hydrogen bonding to form a superhelix. Both I and III phenotypes possess a large, central triple helical domain consisting of a repeating (GLY-X-Y) triplet and small, non-helical regions at the carboxyl and amino termini called telopeptides. Interchain hydrogen bonding is enhanced by the large proportions of glycine, proline, alanine and hydroxyproline amino acids and constitutional water present in collagen α-chains (Nimni and Harkness, 1988).

Collagen molecules undergo extensive post-translational modifications. Intracellularly, selected proline and lysine residues are enzymatically hydroxylated and some lysines are then glycosylated. Extracellularly, telopeptide regions, which promote α-chain assembly into the helix, are proteolytically processed. Collagen molecules assemble via hydrophobic and electrostatic interactions into a head-to-tail array forming microfibrils. Molecules aggregate laterally into nascent fibrils with five molecules to the row (penta-fibril) with each molecule overlapping the adjacent by approximately one-quarter of its length. Such an arrangement produces the quarter-staggered array (Nimni and Harkness, 1988).

2.2. Crosslink Biosynthesis

Several comprehensive reviews of collagen crosslink biosynthesis have been published (Eyre et al., 1984; Eyre, 1987; Bailey, 1989; Reiser et al., 1992). Initial fibril orientation is unstable because collagen molecules associate only via non-covalent interactions in the immature fibril. Collagen molecules can slide past one another and the immature fiber is more subject to disruption by collagenolysis, variations in ionic strength and temperature. Tensile strength and functionality of the collagen fibril is due primarily to the formation of intermolecular crosslinks. Crosslinking is initiated immediately upon fibril