Since consumer satisfaction when eating meat (especially beef) is mainly driven by tenderness, a great deal of research has been done on muscle biochemistry and meat cooking. Skeletal muscles are made up of several cell types and an extracellular matrix, the characteristics of which differ across and within muscles. These differences induce variability in eating quality of meat either directly or indirectly by affecting meat ageing. The latter is well known to butchers as a major way of increasing tenderness, but it is a complex biochemical post-mortem process.

Cooking is also a major factor affecting tenderness. Indeed, heat during cooking induces contraction of the muscle structure and a progressive denaturation of proteins and the extracellular matrix, to an extent that depends on cooking temperature. Grading schemes to predict eating quality, such as that of Meat Standards Australia, have started to include many of these factors from the production side to the consumer end. A complementary approach is to optimize cooking equipment and procedures.

Eating quality of meat, and therefore satisfaction of consumers, is mainly driven by tenderness and flavour. Consumers know by experience that problems of tenderness are mainly associated with red meat, and that meat obtained from older animals is generally tougher than meat from younger animals (Geay et al., 2001). They are also aware that meat cuts differ in their tenderness and therefore implicitly in biochemical characteristics (Listrat et al., 2016), which explains some differences in price between them. Consumers are also concerned by the juiciness of white meat and often find poultry meat, chosen as being lean meat, too dry.

An abnormal presence of juice in the packaging, excessive cooking losses, or tougher meat may be interpreted as being the result of intensive genetic selection, poor management, stress during slaughter, or even the effect of hormone injections into the animal (this is strictly forbidden in Europe). The direct association by consumers of tough meat with problems connected with animal husbandry or slaughter is often due to their poor knowledge of the effect of meat ageing and cooking on meat tenderness. In fact, tenderness of cooked meat is the result of many factors involved during animal production, slaughtering, meat chilling, storage, and cooking (Figure 59.1). This chapter will explore what is scientifically known about the evolution of meat tenderness through all these different steps.

**FIGURE 59.1 Main factors affecting meat sensory traits for consumers.**
of sarcomeres. Muscle fibres are characterized by their contractile (slow or fast) and metabolic (oxidative or glycolytic) properties. Three main fibre types can be distinguished: slow oxidative (type I), fast oxido-glycolytic (type IIa), and fast glycolytic (types IIb and IIx).

Connective tissue has three levels of scale: the endomysium, which surrounds each muscle fibre; the perimysium, which groups muscle fibres in fibre bundles; and finally the epimysium, which is the external envelope of the whole muscle. The extracellular matrix is made of a complex network of collagen fibres in which other cells are embedded. The characteristics of collagen, including its solubility, are the main determinants of toughness. Briefly, muscles with less collagen or younger collagen are more tender. Indeed, collagen fibres are increasingly stabilized with intramolecular or intermolecular bonds, known as cross-links, with increasing age, resulting in greater toughness as animals get older (Lepetit and Culioli, 1994). Mechanical properties of the muscle are also affected by the ratio of the volume occupied by the fibres relative to the volume of the perimysium. Early researchers reported that meat toughness, especially in beef meat, was influenced by the dimensions of the main bundles that are separated by the perimysium and by the thickness of this perimysium (Purslow, 2005). This “meat grain” is still often taken into account by chefs or butchers when they try to visually assess the tenderness of meat.

Among the other cell types present in the extracellular matrix, intramuscular adipocytes determine the intramuscular fat content. The beef industry prefers working on “marbling”, which refers to visible white flecks or streaks of intramuscular fat between bundles of muscle fibres. Intramuscular fat or marbling has been the subject of active research (Hocquette et al., 2010) due to its positive influence on beef eating quality (flavour, juiciness, and tenderness). The genetic determinism of intramuscular fat seems specific compared with other fat deposits (Bernard et al., 2009). The more intramuscular fat, the better the beef sensory quality.

Connective tissue is relatively stable after an animal’s death. Thus, post-mortem tenderization of meat, called ageing or maturation, results mainly from a softening of the myofibrillar structure after rigor mortis by protein degradation due to a variety of endogenous proteases and peptidases acting at different pH values (Ouali et al., 2006). Protein degradation is also associated with glycogen degradation; muscle glycogen is converted into lactate, leading to a progressive acidification of the muscle tissue (for a review on ageing tenderization, see Listrat et al., 2016).

Any perturbation in this process may hamper tenderness. For instance, in animals under stress during transportation to the abattoir, glycogen is depleted before slaughter, and due to a lack of lactate produced from glycogen, the resulting pH in the meat is too high, causing deficits in meat quality. The variability of ageing effects on meat quality is also largely affected by the type of animal, the type of muscle, and chilling and storage conditions. The speed of contraction of muscle fibres determines the ageing rate after the animal’s death, with ageing of fast fibres being more rapid, which explains why ageing is faster in pigs and poultry compared with cattle (the maturation difference between “red” and “white” meats known from experience by meat experts). In beef, relationships between fibre characteristics differ according to animal sex, age, and breed and also according to the cut (Listrat et al., 2016). Abnormal ageing development can be connected to genetics, as for pale soft exudative (PSE) pork meat, or to slaughtering stress, as for dark firm and dry (DFD) young bull meat. Ageing and meat tenderization are favoured by slow chilling and higher temperatures; rapid chilling of the carcass can stop the normal maturation and lead to very tough beef meat due to a non-reversible contraction of the myofibres named “cold shortening”. Abnormal development of biochemical reactions is generally associated with variations in the decrease of meat pH, while cold shortening is characterized by shorter sarcomere length (Lepetit et al., 2000).

### Evolution of Meat Structure during Cooking

Meat cuts can be cooked in many different ways: immersion in liquid (boiling, deep-frying, etc.), heating by contact (grilling, pan-frying, searing, etc.), and/or convection, radiation (infrared or microwaving), phase changes (steaming, etc.), or induction (ohmic heating). Differences in the cooking technique, combined with variations in the shape and size of the meat cut, lead to differences in the local variations of temperature and water concentration in the cuts.

For example, the following experimental results were obtained under laboratory-controlled heating conditions. Myofibrillar proteins (myosin and actin) and proteins of intramuscular connective tissues are the major compounds involved in the variation of meat tenderness during cooking. Mechanical measurements mimicking meat cutting by consumer teeth (Warner–Bratzler tests) have proven that meat toughness increases with cooking, with a first phase of increase between 40 and 50 °C, followed by either a plateau or a decrease between 50 and 60 °C, and then by a second phase of increase above 65 °C (Purslow, 2005). An intermediate plateau of the shearing stress is commonly observed between 50 and 60 °C for beef muscle, while a sharp decrease in the stress has been observed for rabbit muscle (Combes et al., 2003).

Heat contraction of the proteins leads to a three-dimensional contraction of the whole muscle structure, which can be observed by magnetic resonance imaging (MRI) (Bouhrara et al., 2011). Muscle contractions begin at 38 °C but become very important between 54 and 70 °C (Bouhrara et al., 2012). Shearing stress of muscle myofibres generally increases up to 90 °C, this increase being related at low temperatures to the denaturation of myosin and then to the denaturation of actin, which is more thermally stable (Purslow, 2005). Direct measurements on perimysium isolated from beef meat show that its strength increases in meat cooked up to 50 °C and then decreases (Lewis and Purslow, 1990), leading to a major contribution to toughness by the connective tissues in the range 20–50 °C and by the myofibrillar proteins above 60 °C (Purslow, 2005). Connective tissue still has a predominant effect on muscle contraction between 55 °C and 65 °C (Lepetit et al., 2000).

In fact, the exact role of the denaturation of the different proteins in muscle contraction remains under debate, because the intramuscular connective tissue, which is made up of a
Meat: Meat Tenderness

Is it Possible to Totally Control the Tenderness of Cooked Meat?

Consumers still experience problems of meat tenderness, mainly for “red meats”, or juiciness, mainly for “white meats”. This is also true for trained cooks or butchers, who know how to select meat from different animals, breeds, and muscles. In practice, even top chefs can have some difficulties in obtaining the same cooked meat quality when they change their heating equipment or try to adapt a recipe or develop a new one.

The first reason for this problem is connected with the variability of the mechanical properties of the raw meat, because of the biological and biochemical differences due to animal genetics or bad control of the ageing process.

The second reason is connected with the fact that most heating equipment leads to important gradients of temperature and water concentration in the meat cuts. Cooked meat quality is judged, after all, averagely, and the perception of its tenderness is largely influenced by its other sensory qualities (juiciness, odour, and taste). This mainly explains why changes of equipment or of recipe are often difficult. A traditional way of avoiding heating problems for collagen-rich muscles is to apply slow cooking. This mainly explains why changes of equipment or of recipe are often difficult. A traditional way of avoiding heating problems for collagen-rich muscles is to apply slow cooking. However, this does not address the whole problem, since it is important not to consider tenderness alone, but also safety and the nutritional traits of meat. The design of new cooking equipment based on the theoretical knowledge obtained from the prediction of the different quality traits of meat during cooking is a promising solution (Kondjoyan et al., 2013; Kondjoyan et al., 2014; Kondjoyan et al., 2018).

It is important to control all these steps to increase consumer satisfaction, since meat tenderness is the result of many factors that take place from animal selection, production, and slaughter to meat maturation and cooking (Figure 59.1). Attempts have been made to grade beef carcasses by including some indicators associated with eating quality, such as ultimate pH of meat and marbling score, or others such as carcass fatness, which is positively correlated with marbling. The most advanced grading scheme is the Meat Standards Australia grading scheme, which includes, among others, indicators of growth rate, animal sex, and physiological maturity, which all affect the muscle characteristics mentioned earlier (Thompson, 2002). The MSA system goes further by including ageing time and the average effects of some cooking methods. This system has been proved to detect variability in quality across and within muscles, depending on their biochemical characteristics. It works to predict eating quality not only in Australia but also in many other countries (reviewed by Hocquette et al., 2014).

Conclusion

Meat tenderness, as it is perceived by consumers, results from a combination of complex mechanisms associated with animal species, muscle structure, slaughtering procedures, chilling, meat ageing, and cooking processes. How to control all the parameters through these steps remains a challenge. This often results in consumer dissatisfaction, especially for beef consumption. Grading schemes like that of Meat Standards Australia are aimed at integrating all factors, from animal production to cooking methods, in order to predict the eating quality of lamb and beef for each combination of cut and cooking method, and offering a solution for improving consumer satisfaction, not only with meat tenderness but also with flavour and juiciness. A complementary strategy is to improve the design of the equipment and methods used to cook these different combinations.

REFERENCES


