MONITORING RIGOR PROCESS IN MUSCLE USING OPTICAL SCATTERING

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Introduction

Tenderness is the most important attribute of eating quality in beef. Studies have shown that consumers are willing to pay more for products with guaranteed tenderness. Therefore beef producers can gain significant incentives if their products can be sorted into different tenderness categories. Tenderness is affected by multiple factors such as genetic type, chronological age, animal handling, and the processing of meat during and after slaughter. Among many technologies emerged, optical based methods have the potential for online application because they are rapid, non-destructive and inexpensive.

We recently developed a method to characterize muscle quality using optical scattering. Our studies (Xia et al. 2006) have shown that extracted optical scattering properties were correlated with muscle sarcomere structures, and may provide a good indicator of meat tenderness (Xia et al. 2007). In this study we investigated the feasibility of optical characterization of rigor process by comparing optical scattering changes with pH and muscle tension changes in prerigor muscles. We found that the temporal changes of optical scattering during proceeding rigor closely reflected the changes of pH and muscle tension.

Materials and Methods

Bovine and porcine *Sternomandibularis* muscle strips on the left and right side of neck were extracted from the animal after exsanguination. Muscle samples were fixed on ends to keep the length of muscle unchanged during rigor process. In the experiment, one strip was used for optical scattering and pH measurement. The other was used to study the passive tension development during rigor. The experiment was conducted in room temperature. During the whole experiment, samples were covered by plastic film to avoid moisture change.

A probe was inserted into the muscle to measure pH value continuously. Simultaneously, optical reduced scattering coefficient was measured on the same sample. The experimental setup for optical measurement has been described in detail previously (Xia et al., 2006; 2007). Briefly, a 20W broadband halogen light (HL-2000-FHSA-HP, Ocean Optics Inc., Dunedin, Florida) was used as the light source. An optical fiber (400 mm) delivered light to the sample at an oblique incident angle of 40°. Diffuse reflectance was collected by a second 400 mm fiber that was mounted at 90° to the sample surface and connected to a spectrometer (USB4000, Ocean Optics Inc.). A mechanical stage translated the collection fiber above the sample surface to measure the spatially resolved reflectance from twelve positions. Acquired spectra were processed using a personal computer to extract optical scattering properties.

During the tension measurement, the muscle strip was fixed on one end; and the other end was attached to a force transducer. Muscle was stretched with constant speed to a fixed distance (3% of the total sample length) and released back immediately every time. The force sensor recorded the force value at each point during the stretching and release procedure. The force at the maximum stretch was converted to a tension by dividing the cross section area of the sample. The whole procedure was controlled by a Labview program.

Results and Discussion

Figure1 shows the change of the reduced scattering coefficients and pH value during rigor process in porcine and bovine *M. sternomandibularis*. Measurements in multiple animals showed similar trends. As indicated in previous studies, the reduced scattering coefficient of beef muscle decreased with time and slowly reached a steady state. However, it started to increase at about 10 hours after slaughter. The temporal change of pH was very consistent: it decreased rapidly at the beginning, and then transited to a flat stage. Similar results were obtained in porcine *M. sternomandibularis* muscles although the optical scattering change with time was a little different. The reduced scattering coefficient decreased from the beginning, started to increase at relative shorter time after slaughter compared with beef muscle. The time of increase started at about 3~6 hours depending on individual animal.

It is generally accepted that during development of rigor mortis, temporary cross-bridges form and "break" (due to ATP hydrolysis and subsequent ATP binding) between the actin and myosin filaments in the overlap area. Upon rigor completion, cross-bridges become stably and irreversibly formed due to the depletion of ATP. Previous studies (Baskin et al., 1986) have revealed that rigor induced sarcomere changes lead to a reduced refractive index difference between A-band and I-band, which results in a smaller scattering efficiency. The

increase of optical scattering after certain times was due to the fiber separations as confirmed by microscopic studies.

The temporal courses of the passive tension development during rigor for pork and beef muscles were shown in Figure 2. The passive tension of the muscle did not change at the beginning, indicating that actin-myosin could still slide against each other freely by the stretching. As time went on, the passive tension started to increase, which implied that some actin and myosin proteins started to bond together permanently. Once the tension started to increase, it developed very rapidly. In other words, the permanent binding formed rapidly in many actin-myosin interactions. After all actin and myosin were bonded together, the tension reached a steady state. The temporal development of scattering and passive tension was very consistent. Specifically the optical scattering increased consistently with the passive tension and both approached the steady state simultaneously.

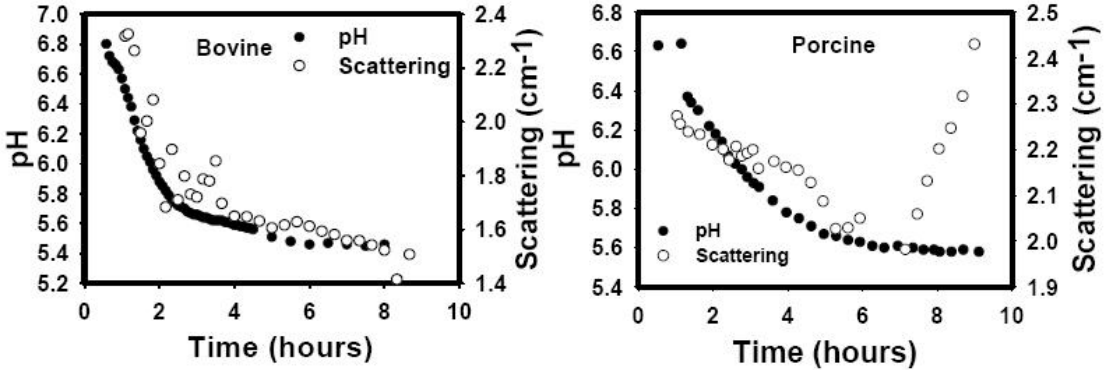

Figure 1. The pH value and reduced scattering coefficient change with time during rigor development in bovine and porcine *M. sternomandibularis*.

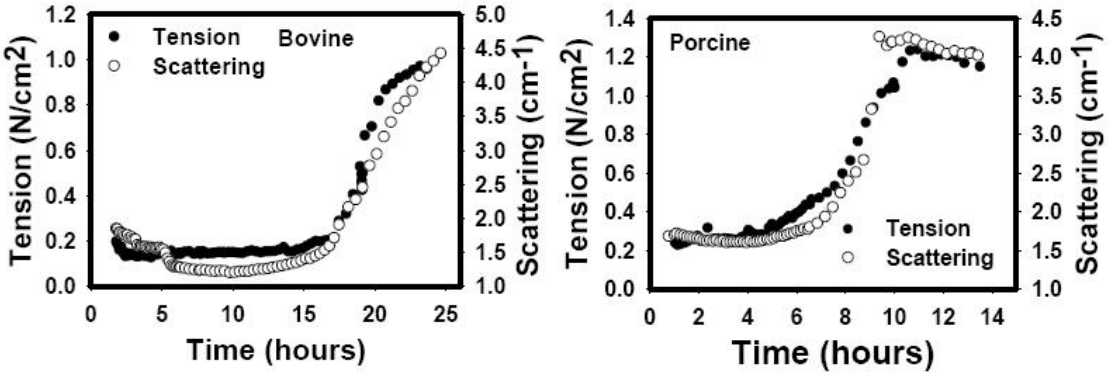

Figure 2. The temporal profiles of passive tension and optical scattering during the rigor process in bovine and porcine *M. sternomandibularis*.

Conclusions

The optical scattering changes during early rigor process reflected the metabolism-related functional and structural changes, especially the status of actin-myosin binding and releasing cycling. As a traditional monitoring means, the pH values decreased first and eventually reached a steady state. At the same time, tension started to develop because of the permanent binding between actin and myosin. Our results indicated that the change of optical scattering during this process matched well with the temporal courses of the tension development and pH. Therefore optical scattering has the potential to be used as an indicator for monitoring muscle rigor process.

References

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