

Project Summary

Fiber-Optic Characterization of the Tenderness of Low Marbled Beef Steaks

**Principal Investigator: G. Yao, Ph.D. and E. Berg, Ph.D.,
University of Missouri**

**Study Completed
May 2008**



Funded by The Beef Checkoff

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Background

There is a one in four chance of obtaining a tough steak from a USDA Select grade beef carcass and a one in five chance for low Choice (George et al., 1999). An instrument that identifies tender steaks independent of marbling would be beneficial to the industry. The ability to identify the one in four tough steaks in the Select population and one in five tough steaks in the low Choice population could allow for increased price incentives at the retail level and an increased potential for repeat customers. The objective of this project was to identify tender steaks within the USDA quality grades of Select and low Choice using fiber-optic analysis of light absorption and scattering.

Methodology

A total of 97 *Longissimus thoracis* samples obtained adjacent the 12th rib location on beef carcasses obtained from a commercial beef slaughter facility from beef animals harvested on the same day to reduce the day-to-day influence on the physio-chemical factors associated with the conversion of muscle to meat. Care was taken in selection to ensure steaks were obtained from young, A-maturity carcasses with similar lean color scores. Only one steak was removed from each carcass. A range of ribeye size and carcass muscularity was utilized in an attempt to maximize the potential for a wide range of Warner-Bratzler shear force variability. All samples were transported and wet aged fresh (never frozen) at 3°C for 14 days postmortem. After aging, samples were removed from vacuum packaging and were cut to an approximate volume of 5.5 cm long × 3.5 cm wide × 3 cm thick prior to optical measurements.

A 20W broadband halogen light was used as the light source. The light was incident upon the sample through an incident optical fiber at an oblique angle. A second fiber, connected to spectrometer to the sample surface to collect the backscattered light from meat. The collection fiber was positioned for scanning via a translation stage so that reflectance could be measured at different positions along the scanning plane. The scanning plane of the collection plane was parallel to the plane of incidence, but was offset by a small distance of 1.5 mm to avoid collision with the incident fiber. The spectra were then acquired and processed by a personal computer. All optical fibers used in the experiments had core diameters of 400 μm. The measurement window was constructed by cutting a small window (1 × 4 cm²) through a black metal plate. A micro cover glass was used to cover this sample window.

A layer of water was added on top of sample for refractive index match. Absorption and scattering coefficients represent the probabilities of a photon being absorbed and scattered inside the sample. For simplicity, a scattering coefficient was used to refer to reduced scattering coefficient. Absorption and scattering coefficients of a sample are independent of each other.

The measurements for optical properties of beef samples were conducted in a cold storage room with temperature 2 to 5°C. Spatial resolved reflectance spectra were collected by collection fiber from thirteen positions; from 9.0mm to 6.5mm on the left side of the incident fiber and 4.0mm to 7.0mm on the right side of the incident fiber at an interval of 0.5mm. At each position, the raw reflectance spectrum from 450nm to 950nm was recorded. The measured raw spectra were normalized to remove the effects of the light source spectrum, the fiber attenuation and the detector response.

The measured spectra at different locations were also fitted with diffuse equations for the derivation of the absorption and scattering coefficients at each wavelength by using equations. The system was verified by using scattering phantoms made of Intralipid of known concentrations. Intralipid is a fat emulsion that is used clinically as an intravenously administered nutrient. It is commonly used as a scattering component in tissue phantoms for light transport research. The measurement error in this experiment was less than 10% compared with theoretical predictions. After recording optical measurements, samples were cooked for Warner-Bratzler shear force analysis.

Findings

The reflectance measured at the sample surface was the result of both scattering and absorption processes involved in light-muscle interactions. The measured diffuse reflectance reflects those photons that have survived absorption and been scattered diffusely in meat and eventually escaped from the meat surface. Hence, the conventional absorbance is the combined result of the absorbing and scattering effects and is different from the derived absorption coefficient, which is independent of scattering. The absorbance calculated from reflectance depended on the measurement position; while the absorption coefficients represent the samples absorbing characteristics and are solely determined by the sample itself.

In the experiments, light signal is low at wavelengths below 600 nm due to the high absorption of myoglobin derivatives and the low source of light produced in this bandwidth. The absorbance spectrum and the absorption coefficient spectrum are similar, especially for the bandwidth from 600nm to 950nm. This implied that the absorption characteristics associated with sample chemical composition are major components affecting the absorbance features of the sample. In the bandwidth from 600 nm to 760 nm, *Psoas major* muscle had higher absorption coefficients; but with lower scattering coefficients, compared to the *Semimembranosus* muscle. The absorbance spectrum, which depended on both the absorption and scattering coefficients, showed higher absorbance values for the *Psoas major* sample in the bandwidth from 600 nm to 760 nm. In the bandwidth from 760 nm to 950 nm, the absorption coefficients of *Psoas major* were slightly lower than the *Semimembranosus* muscle. Further, the scattering coefficients of the *Psoas major* sample were significantly lower than the *Semimembranosus*. However, such combination of scattering coefficients and absorption coefficients resulted in equal absorbance values in this bandwidth for these two samples.

The absorbance spectrum in a sample is dynamically determined by the combination effects of the scattering and absorption coefficients. Therefore the direct use of absorbance spectra to differentiate the microstructure dependent beef tenderness is subject to the interference of the variations in chemical composition.

Although the correlation was significant between optical scattering and Warner-Bratzler shear force, the coefficient of determination is low. The correlation results indicated that Warner-Bratzler shear force increased with the scattering coefficient. The scattering coefficient in *Psoas major* muscle has the highest value among the muscles studied (*Psoas major*, *Semitendinosus*, *Semimembranosus*, and *Longissimus*). *Semitendinosus* and *Semimembranosus* muscles have similar scattering distributions in quantity. They are slightly smaller than *Longissimus* muscle in scattering quantity.

The above studies indicate that optical scattering coefficient does reflect the tenderness-related muscle structural properties such as sarcomere length and collagen content. It seems the correlation

observed is mainly induced by variations in collagen content. However, the variations in sarcomere length and proteolysis also play important roles in determining the correlation between scattering coefficients and Warner-Bratzler shear force. Because optical scattering and absorption properties completely describe the light propagation processes in tissue, these findings are also helpful in explaining those inconsistent results obtained previously using various other optic-based techniques. If the contributions from these different muscle components can be differentiated, the accuracy of tenderness prediction will be greatly improved.

Implications

Results from this study revealed that optical scattering coefficient measured from whole intact muscle can reflect those tenderness-related muscle structure properties. However, multiple competing factors are mingled in measured optical signals and may lead to variations in the derived structural sensitive meat scattering coefficients.

For more information contact:

National Cattlemen's Beef Association
9110 East Nichols Avenue
Centennial, Colorado 80112-3450
(303) 694-0305