자기공명영상을 이용한 소고기의 내부 구조 분석
Determination of Internal Structure of Beef using Magnetic Resonance Imaging

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1. Introduction

Most important factors that food retailers and consumers concern are price and quality of food. Retailers select product to stock and consumers also select to purchase in both quality and cost concerns. Many factors can affect the quality of meat. Those are breeding, production management, preslaughter handling, slaughter hygiene, preparation methods and technology, and product distribution. The quality traits of fresh and cooked meat are not identical. For economic reasons, fresh meat quality is of more concern at the industrial and retail level than processed meat. The quality of cooked meat, however, must also be evaluated terms of its organoleptic properties. The groups of meat quality characteristics are presented in the Table 1.(1)

Now the most remarkable reasons of choosing meat products are price of the product and healthiness which is directly related to the fat content of meat. Of the both reasons, Health consciousness has been changing mostly and affecting the quality of meat product. Now the desirable characteristics of meat are that meat should be healthy, low fat, tender and juicy, have a good flavor and must have an appropriate price.(2) In those terms consumers want to see the appropriate labeling to figure out which is the good quality meat. To put an appropriate label to the meat product, the objective and accurate methods to evaluate meat quality are needed.

In order to measure quality of meat, many conventional methods have been used, such as sensory evaluation, chemical methods, and mechanical methods. In spite of the effort expended on various methods, to date none of the methods appear to be satisfactory measure of meat quality under practical conditions.

The significant advantage of Nuclear Magnetic Resonance (NMR) spectroscopy is that it is a nondestructive and noninvasive method. A variety of NMR techniques exist which can provide structural information. High resolution NMR spectroscopy is a basic tool for biologists and chemists. This technique is often used to measure distances between atoms. Magnetic resonance imaging (MRI), an extension of 2-D NMR spectroscopy was initially developed as a medical diagnostic tool. MRI is successful in the medical field and has been recently applied in the biological and agricultural area due to the advance of computer technology and the potential for low-cost system manufacture. MRI provides the macroscopic spatial distribution of information based on the chemical and electronic environment of nuclei within a sample.

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Table 1. Meat quality characteristics

Nutritional factors		**Technological factors**
Proteins and their composition		Water holding capacity
Fats and their composition		Protein content and its status
Vitamins		Fat content and its status
Minerals		Connective tissue content
Digestibility		Tenderness
		PH-value
		Color
Hygienic factors		**Sensory factors**
Microorganisms	PH value	Color, hue
Factors of shelf life	A_w value	Color brightness
	Degree of heating	Marbling
	Temperature of storage	Odor
Residues	Nitrosamines	Flavor
	Antibiotics	Juiciness
	Hormones	Consistency
	Other pharmaceuticals	Tenderness
Contaminants	Pesticides	
	Mycotoxins	
	Heavy metal	
	Nuclides	

Chen *et al.* (1989) demonstrated that MRI could be used for evaluation of various internal quality factors of fresh fruits and vegetables.[3] NMR is not harmful to products and does not damage product quality, and used in examining food stability and structure, moisture migration, rheology, phase changes, etc.[4]. There are some papers related to magnetic resonance characteristics of meat. The multi-exponential decay of the T_2 of water protons in pork muscle has been reported in the literature.(Tornberg *et al.* 1993) The major fraction ($\approx$ 80% of total water) of muscle water has a T_2 between 35-50 ms, whereas the rest of the water relaxes in the range of 100-150 ms.

The objectives of this study are to measure basic NMR parameters of meat such as T_1, T_2 using various part of beef (rib, tail, top round etc.) and also to find optimal MR imaging parameters such as TE, TR for determining fat distribution, water distribution, foreign materials existence from MR images. Based on the basic results, to acquire quantitative information of meat quality from MR images is the ultimate objective of this study.

2. Materials and Methods

The different parts of beef –short rib, ox tail and top round – were purchased from the local food retailer and used for this study. Each part had four replications. Those three parts were used within a week after purchasing.

A 2 Tesla NMR spectrometer (General Electric CSI-2) operating at a proton resonant frequency of 85.5 MHz was used for this study. A commercial birdcage coil (15cm diameter, 34 cm long) and a spin-echo pulse sequence were used to acquire two-dimensional images. The slice thickness was 5 mm or 10 mm and the echo delay (TE) was 15 ms. The 180° pulse length was 86 ㎲, and the number of data pints in a projection was 128. The field of view in the frequency-encoding direction (FOV_{fe}) and that in the phase-encoding direction (FOV_{pe}) were approximately 90 mm. Two acquisitions were acquired for each image to enhance signal-to-noise ratio.

T_1 and T_2 measurements by magnetic resonance spectroscopy (MRS) were performed with beef short ribs. T_1 measurements were done by inversion recovery pulse sequence using a commercial imaging coil. Inversion delay times of 4 ms, 10 ms, 60 ms, 100 ms, 200 ms, 500 ms, 800 ms, 1.5 s, 2 s, 3 s, and 4.9 s were used. T_2 measurements were done by spin echo pulse sequence (refer to Figure 1) using also a commercial imaging coil. Used echo times were 4 ms, 10 ms, 20 ms, 30 ms, 60 ms, 80 ms, 120 ms, 160 ms, 200 ms, 300 ms, and 600 ms. Relaxation time constants of the whole samples were measured by magnetic resonance spectroscopy.

T_1 and T_2 of short rib (# 4) were estimated by a magnetic resonance imaging (MRI) method. T_1 was measured by setting TE to 15 ms, and changing inversion delay by 150 ms, 300 ms, 700 ms, 1.2 s, 1.9 s, 3 s, and 4.9 s. T_2 was also measured by setting TR to 700 ms, and changing TE by 15 ms, 30 ms, 50 ms, 80 ms, and 120 ms. Relaxation time constants T_1 and T_2 of localized region of images were estimated. MATLAB program was used to process magnetic resonance data and to estimate relaxation time constants.

3. Results and Discussion

T_1 and T_2 measurements by MRS

T_1 and T_2 of short rib samples were measured by MRS and it is tabulated in Table 2. The maximum T_1 of sample # 1 of short rib is 902 ms and the sample # 1 contained most muscle part and less other parts such as fat and bone. And this first sample also had longest T_2 that is 44 ms. In contrast, the sample of #3 and #4 showed relatively lower T_1 and T_2 (refer Figure 1). These two samples contained less muscle and higher portion of fat and bone. T_1 and T_2 were related to the ratio of each part of samples and this implied that MRS can be used as a method to estimate the meat quality in terms of the ratio of different parts.

T_2 measurements by MRI

After acquiring image of the short rib samples with the # 4 the T_2 estimation was done using localization. It created the T_2 s of three components; muscle, fat, and inner bone. Five points were chosen for each component and T_2 was estimated and averaged. T_2 of various parts of #4 of short rib samples were estimated by MRI and it is tabulated in Table 3. Muscle part showed longer T_2 and inner bone showed shortest T_2. It indicated that muscle part contains more water than any other parts and also inner bone contains more water than fat. However T_2 of fat part and that of bone part were relatively similar than that of muscle.

Table 2. Measured T_1 and T_2 of short rib by MRS.

Sample no.	T_1 (ms)	T_2 (ms)
#1	902.0	44.0
#2	875.0	39.5
#3	744.1	37.5
#4	781.5	34.7
Maximum	902.0	44.0
Minimum	744.1	34.7
Average	825.7	38.9
S.D.	75.0	3.9

Table 3. Estimated T_2 of various parts of #4 of short rib samples by MRI

Repetition	Muscle(ms)	Fat(ms)	Inner bone(ms)
#1	45.0	22.0	26.0
#2	43.0	25.0	29.0
#3	42.0	25.0	27.0
#4	47.0	24.0	26.0
#5	47.0	24.0	30.0
Maximum	47.0	25.0	30.0
Minimum	42.0	21.0	26.0
Average	44.8	23.4	27.6
S.D.	2.3	1.8	1.8

Determination of structure by MRI

MRI technique was used to investigate the internal structure of the three kinds of meat samples, and it was very successful (refer Figure 1 and Figure 2). Optimal MRI parameters to get best contrast between

different parts of beef were TR=700 ms, TE=15ms and slice thickness=5mm in this study. The inner parts of the three samples, short rib, round top and ox tail, were clearly seen by the image. The intensity of magnetic resonance images acquired by a spin echo pulse sequence related with T_2 values of materials (McCarthy, 1994). The muscle part generated strongest signal (darker part in the image) and the fat part generated weakest signal (whiter part in the image) as expected. It is possible to investigate the structure by naked eyes and evaluate the quality factors such as marbling, vague amount of fat and muscle. That means this method can be used for quality evaluation in terms of eye investigation.

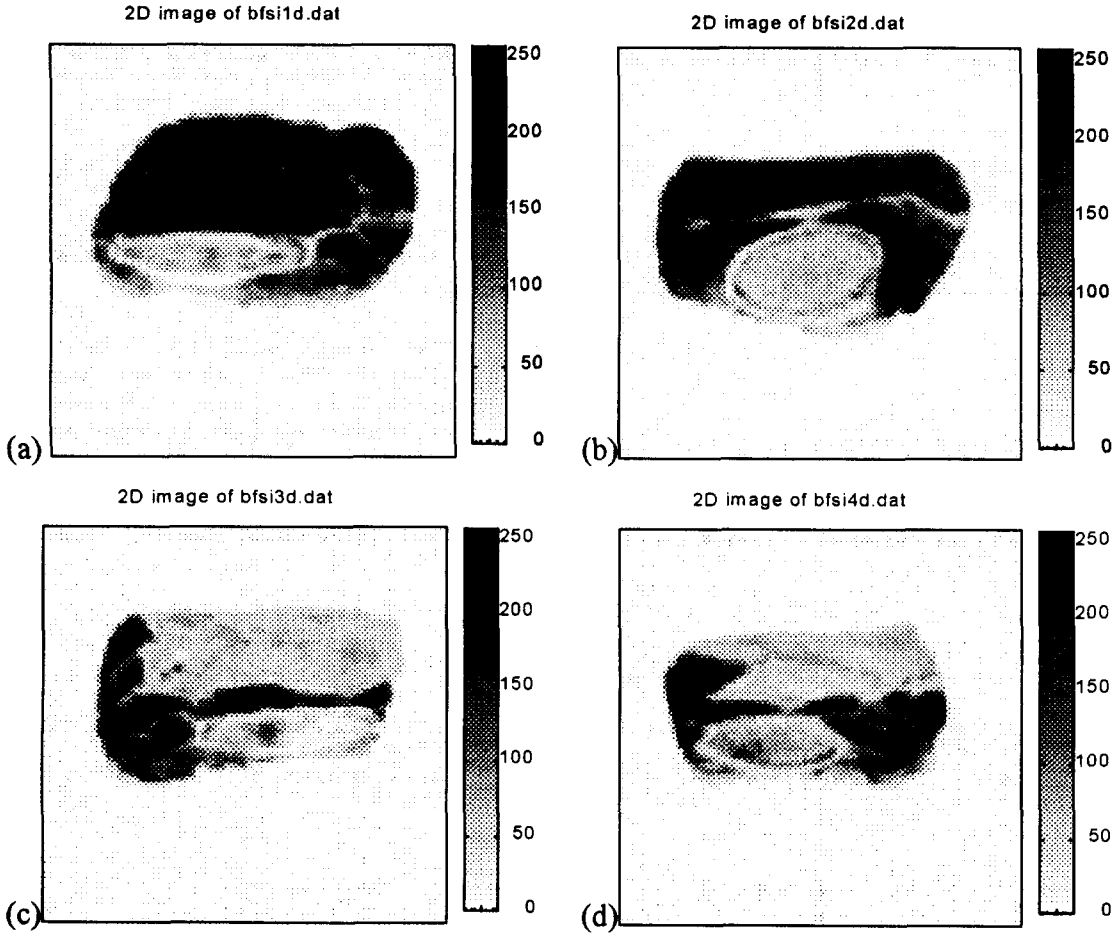

Figure 1. Magnetic resonance images of four different kinds of rib, (a) #1 (b) #2 (c) #3 (d) #4. MRI parameter TR=700 ms, TE=15ms and slice thickness=5mm.

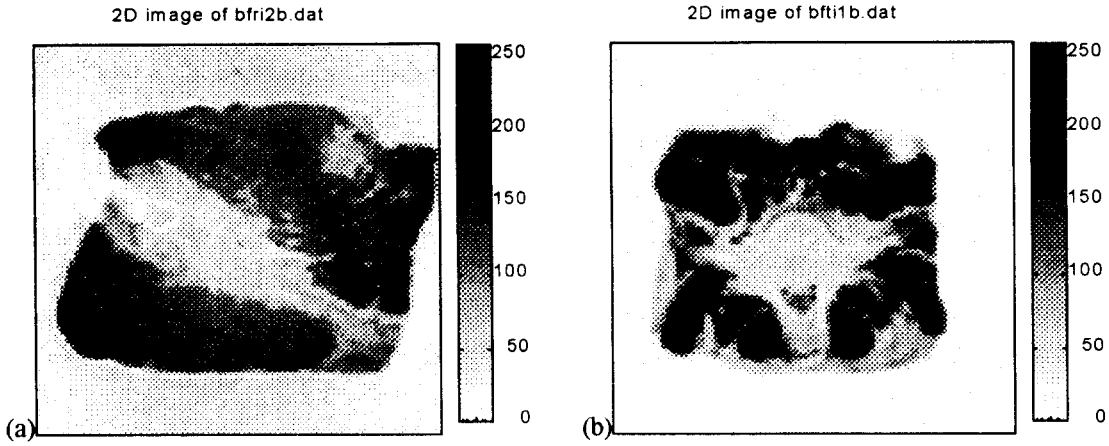

Figure 2. Magnetic resonance images of (a) top round (b) ox tail. MRI parameter TR=700 ms, TE=15ms and slice thickness=5mm.

4. Conclusions

Magnetic resonance techniques, magnetic resonance spectroscopy and magnetic resonance imaging, were successfully used to determine the structure of beef. The results of this study summarized as follows:

1. Relaxation time constant T_1 and T_2 were related to the ratio of each part of samples and this implied that magnetic resonance spectroscopy can be used as a method to estimate the meat quality in terms of the ratio of different parts.
2. Muscle part showed longer T_2 and inner bone showed shortest T_2. It indicated that muscle part contains more water than any other parts and also inner bone contains more water than fat. However T_2 of fat part and that of bone part were relatively similar than that of muscle.
3. Optimal MRI parameters to get best contrast between different parts of beef were TR=700 ms , TE=15ms and slice thickness=5mm in this study. The muscle part generated strongest signal and the fat part generated weakest signal as expected. It is possible to investigate the structure by naked eyes and evaluate the quality factors such as marbling, vague amount of fat and muscle. That means this method can be used for quality evaluation in terms of eye investigation.

More studies are needed to determine the water distribution and to determine meat quality factors such as marbling, fat content, tenderness, water holding capacity *etc.*

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6. References

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