한국농업기계학회지 제24권 제6호. pp. 531~538. 1999

자기공명영상을 이용한 소고기의 내부 구조 평가+

Evaluation of Internal Structure of Beef Using Magnetic Resonance Imaging

김 성 민*
정회원
S. M. Kim

적 요

비파괴 품질 평가 기술인 핵 자기공명 분광법과 자기공명영상을 이용하여 소고기의 내부 구조를 분석하였다. 이완 상수 T_1과 T_2가 육류의 내부 구조와 관계가 있음을 보였다. 근육부분의 면적 비율이 증가할수록 T_1이 증가했다. 지방 부분의 T_2는 뼈 내부 부분의 T_2와 비슷한 값을 보였다. 자기공명 영상을 이용하여 육류의 원하는 부위의 T_2를 측정할 수 있는 방법을 구하였다. 근육 부분의 T_2가 길었으며 지방 부분의 T_2가 짧았다. 부위별로 최적의 신호를 얻을 수 있는 자기공명영상 인자 TR과 TE를 구하였다. 자기공명영상을 이용하여 근육, 지방 그리고 뼈 성분에 따른 육류의 품질을 비파괴적으로 평가할 수 있는 가능성을 보여주었다.

주요용어(Key Words) : 핵 자기공명 분광법 (Nuclear Magnetic Resonance Spectroscopy), 자기공명영상 (Magnetic Resonance Imaging), 품질 (Quality), 소고기 (Beef), 비파괴 (Nondestructive)

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 quality. The quality of cooked meat, however, must also be evaluated in terms of its organoleptic properties. The groups of meat quality characteristics are categorized into nutritional, technological, hygienic, and sensory factors. Nutritional factors are proteins and their composition, fats and their composition, vitamins, minerals and digestibility. Technological factors are

+ 이 연구는 전북대학교 신입교수 연구비의 지원을 받아 수행되었음.

* 전북대학교 농과대학 생물자원시스템공학부 생물자원기계공학전공 (농업과학기술연구소)

water holding capacity, protein content and its status, fat content and its status, connective tissue content, tenderness. pH-value, and color. Hygienic factors are microorganisms. factors of shelf life. residues, and contaminants. Sensory factors are color hue, color brightness, marbling, odor, flavor, juiciness. consistency, and tenderness (Honikel, 1993).

Now the most remarkable factors of choosing meat products are both price of the product and healthiness that is directly related to the fat content of meat. Of the two factors, health consciousness has been changing mostly and affecting the quality of meat product. Good quality meat should be healthy, low fat, tender and juicy. It should have a good flavor and an appropriate price (Judith and Verner, 1990). In those terms consumers want to see the appropriate labeling to figure out which the good quality meat is. To put the appropriate label to the meat product, objective and accurate methods to evaluate the meat quality are needed.

In order to measure quality of meat, many conventional methods such as sensory evaluation, chemical methods, and mechanical methods have been used. The developed methods hardly appear to be satisfactory measure of the meat quality for practical applications.

The significant advantage of Nuclear Magnetic Resonance (NMR) spectroscopy is that it is nondestructive and noninvasive. 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 has been successful in the medical field and recently applied in biological and agricultural areas 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.

Chen *et al.* (1989) demonstrated that MRI could be used for evaluation of various internal quality factors of fresh fruits and vegetables. 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. (McCarthy, 1994). There are some research papers related to magnetic resonance characteristics of meat. Renou et al. (1985) used a low resolution NMR for determining fat content in meat products. The multi-exponential decay of the T_2 of water protons in pork muscle has been reported (Tornberg *et al.*, 1993). The major fraction ($\approx$ 80% of total water) of muscle water had a T_2 between 35-50 ms, whereas the rest of the water relaxed in the range of 100-150 ms. Foucat et al. (1997) designed an on-line low field NMR spectrometer to estimate fat content in ground beef and showed this method was excellent (R^2=0.992) compared to Soxhlet reference method.

The objectives of this study are to measure basic NMR parameters of meat such as T_1, and T_2 of beef short rib using NMR spectroscopy, to find a method estimating T_2 by MRI, and also to find optimal MR imaging parameters such as echo time (TE), and repetition time (TR) for determining fat distribution, water distribution, foreign materials existence. The ultimate objective of this study is to acquire quantitative information for meat quality from MR images.

2. Materials and Methods

The different parts of beef - short rib, ox tail and top round - were purchased from a local food retailer and used for this study. Each part had four replications. Samples were stored at a commercial refrigerator after purchasing and put them to temperature controlled room at 17℃ for 6 hours before the experiment. 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 sequences were used to acquire two-dimensional images. The slice thickness was 5 mm or 10 mm and the TE was 15 ms. The 180° pulse length was 86 ms, and the number of data points 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 the beef short ribs. T_1 measurements were done by inversion recovery pulse sequence using the 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 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.

T_2 of short rib (sample # 4) were estimated by a magnetic resonance imaging (MRI) method. Series of five images were acquired from the sample with fixed TR and varying TEs. T_2 was 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_2 of localized region of T_2 weighted images were estimated using a following relationship (refer McCarthy, 1994).

$$S(t) \infty \sum_{i} \rho_i \exp(-TE/T_{2i})$$

where S(t) is gray level of image, ρ is proton density and index i=1.

MATLAB (version 5.0, MathWorks Inc., Natick, Mass. USA) 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

Table 1 shows the area ratio of muscle, fat and bone parts of each rib sample from images of fig. 1. T_1s and T_2s of the four short rib samples were measured by MRS and they are tabulated in table 2. The short rib sample # 1 had longest T_1 of 902 ms and it had a largest portion of muscle part (refer table 1 and table 2). And the short rib sample #3 had shortest T_1 of 744.1 ms and it had a smallest portion of muscle

Table 1 Area ratio of muscle, fat and bone parts of each rib sample (%)

Sample no.	Muscle	Fat	Bone
#1	77.0	4.1	18.9
#2	60.2	11.1	28.7
#3	31.8	49.5	18.7
#4	36.0	41.5	22.5

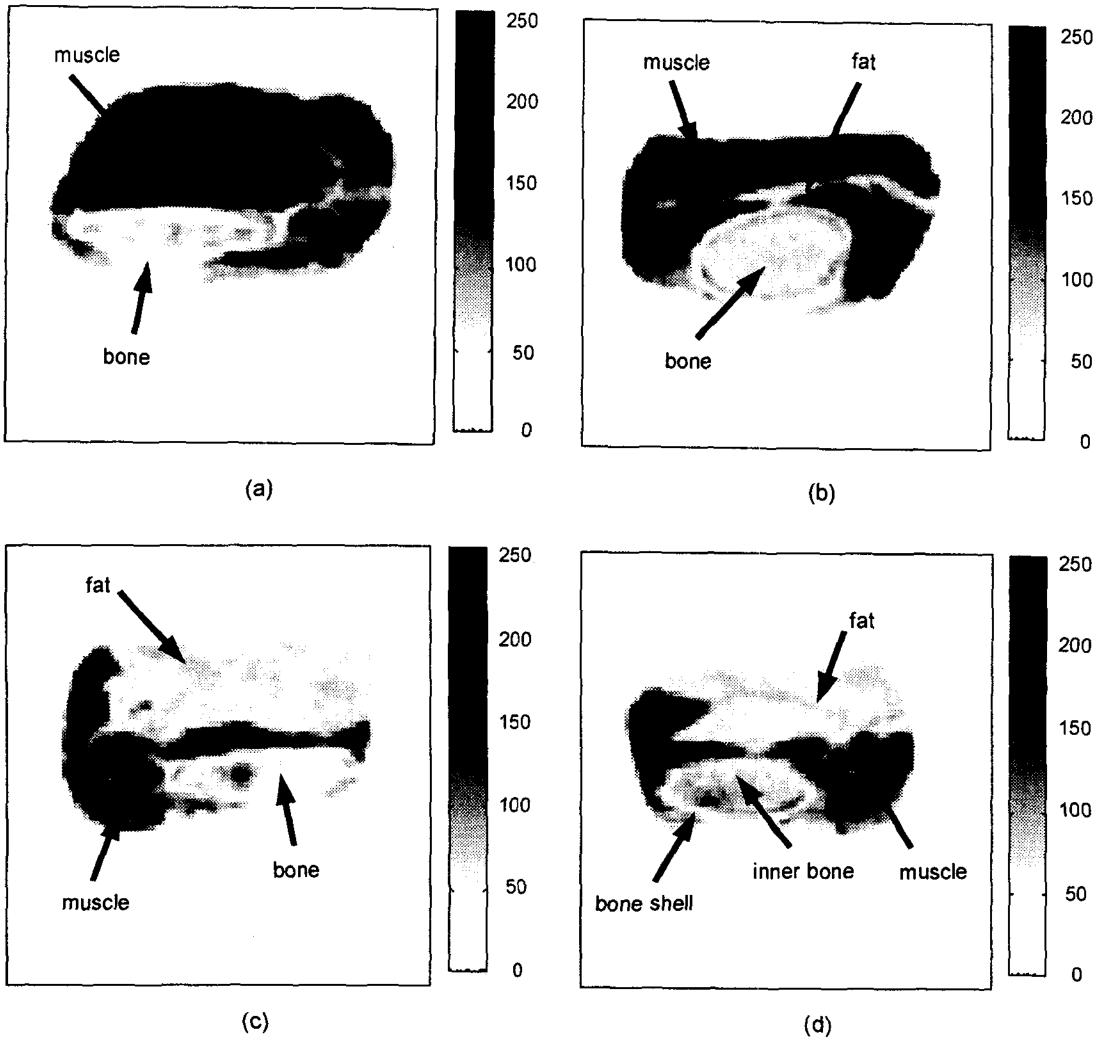

Fig. 1 Magnetic resonance images of four different samples of rib, (a) sample #1 (b) sample #2 (c) sample #3 and (d) sample #4. MRI parameters: TR=700 ms, TE=50 ms and slice thickness=5 mm. Bars on right side of images shows the gray level of images.

Table 2 Measured T_1 and T_2 of the short rib samples 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
Average	825.7	38.9
S.D.	75.0	3.9

part. Comparing the area ratio of muscle part to T_1 value of each sample they were proportional to each other. The short rib sample #1 also had longest T_2 of 44 ms and the short rib sample #4 had shortest T_2 of 34.7 ms. Apparently T_2 is not directly proportional to the area ratio of muscle part from the presented data. The sample #3 and #4 showed relatively lower T_1 and T_2. These two samples contained less muscle and higher portion of fat and bone parts than sample #1 and sample #2. T_1 and T_2 were apparently related to the composition ratio of muscle, fat bone. This implied that MRS could be used to estimate the meat quality in terms of the composition ratio of muscle, fat and bone.

T_2 measurements by MRI

After acquiring five images with different TEs of the short rib sample #4 the T_2 was estimated using localization. It created the T_2s of three components; muscle, fat, and inner bone (refer fig. 1(d)). Five data points were chosen for each component and T_2 was estimated and averaged. T_2s of various parts of short rib sample #4 were estimated by MRI and are tabulated in table 3. Calculated T_2 value of short rib sample #4 using averaged T_2s of muscle, fat and inner bone from table 3, and area ratios of them from table 1 was 32.1 ms. This calculated value from MRI was close to the T_2 (34.7 ms) measured by MRS. This showed MRI could be useful for determining relaxation time constants of localized area of interest and of whole sample. Muscle part showed long T_2 and fat showed short T_2. It implied that muscle part contained more mobile water than any other parts and also inner bone contained more mobile water than fat. However T_2 of fat part and that of bone part were relatively close compared to the T_2 of muscle part. Fig. 1 shows the result of developed program showing the process of estimating T_2 of muscle part of short rib sample #4. When TE=120 ms the signals generated from the sample almost died out and diappeared.

Table 3 Estimated T_2 of various parts of short rib sample #4 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
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 three kinds of meat samples, and it was feasible. 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 structures of the three samples (short rib, round top and ox tail) were clearly seen by the images (refer fig. 1 and fig. 3). 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 was possible to investigate the inner structure by naked eyes and to evaluate the quality factors such as marbling, vague amount of fat and muscle. That means this method can be used for quality evaluation of internal structure of meat products in terms of eye investigation.

4. Conclusions

Magnetic resonance techniques, magnetic resonance spectroscopy and magnetic resonance imaging, were feasible to determine the structure of beef. The results

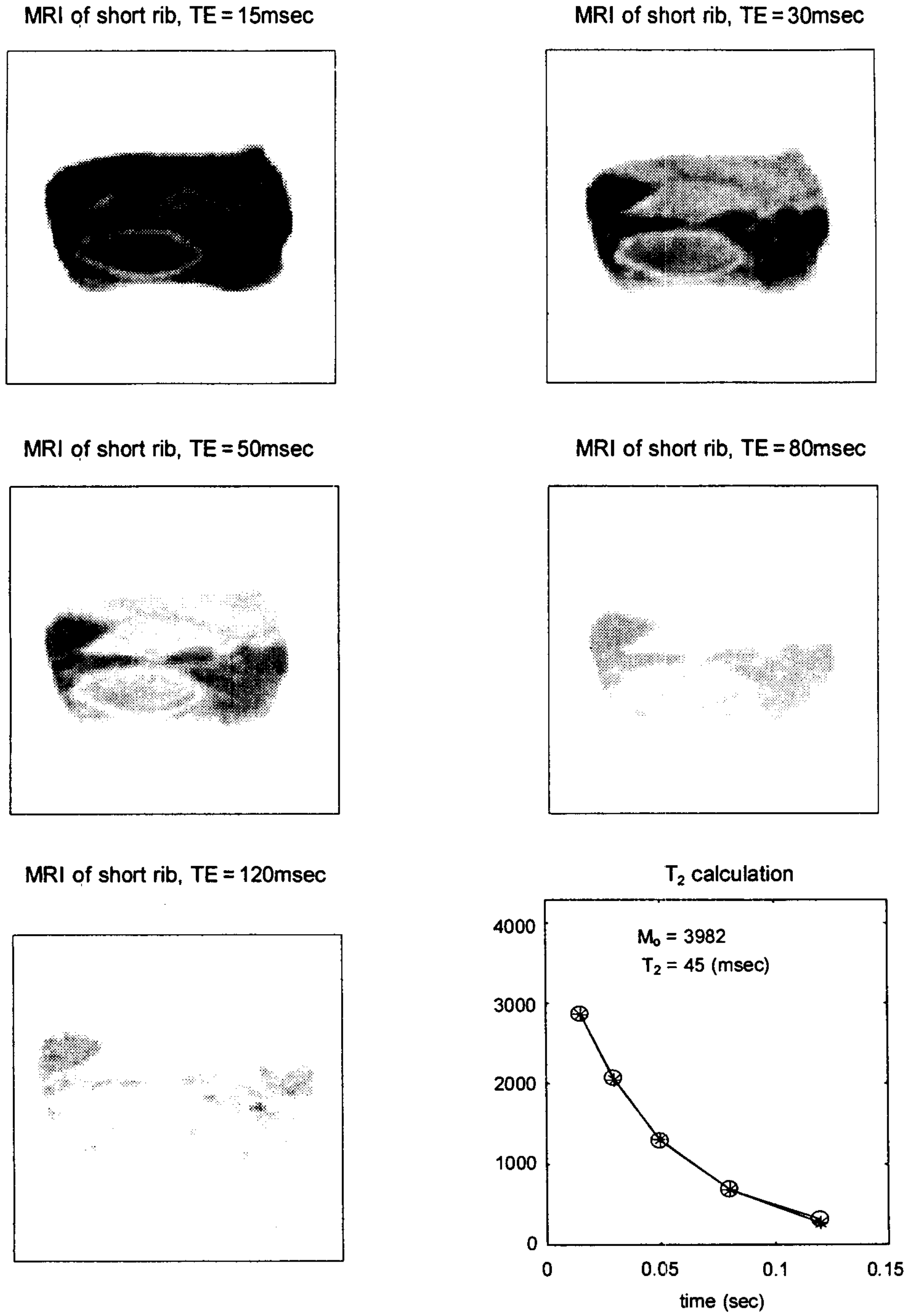

Fig. 2 Five magnetic resonance images of short rib sample #4 with TR = 700 ms and different TEs and graph of T_2 estimation. 'o' indicates original data and '*' indicates estimated data in the graph.

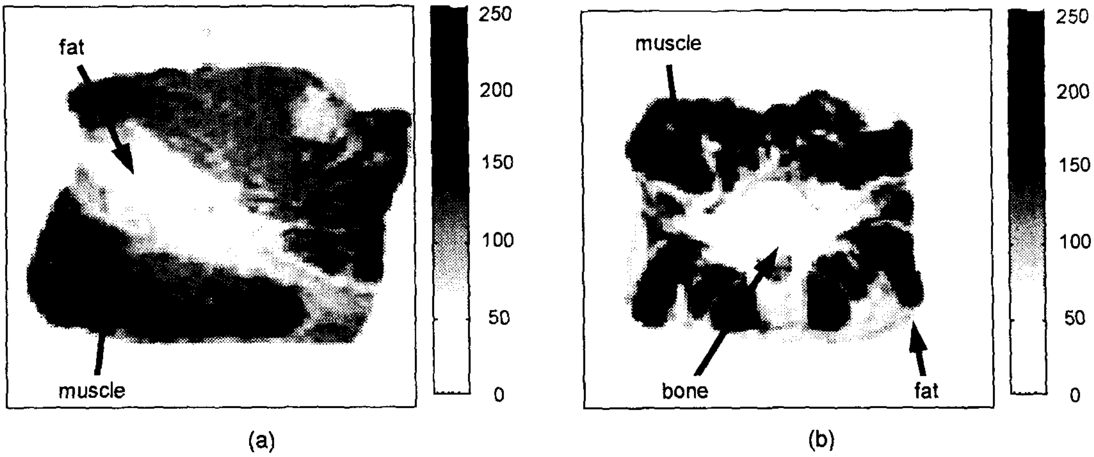

Fig. 3 Magnetic resonance images of (a) top round and (b) ox tail. MRI parameters: TR=700 ms, TE=15ms and slice thickness=5mm. Bars on right side of images shows the gray level of images.

of this study summarized as follows:

(1) Relaxation time constants of T_1 and T_2 were related to the composition ratio of muscle, fat and bone. This implied that magnetic resonance spectroscopy could be used to estimate the meat quality in terms of the composition ratio.

(2) MRI could be useful for determining relaxation time constants of localized area of interest and of whole sample.

(3) T_2 of muscle part was relatively long and T_2 of fat was short. It indicated that muscle part contained more mobile water than any other parts and also inner bone contained more water than fat. However, T_2 of fat part and that of bone part were close compared to the T_2 of muscle part.

(4) 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 was feasible to investigate the inner structure and to evaluate the quality factors such as marbling, vague amount of fat and muscle. That implied this method could 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, and water holding capacity.

5. Acknowledgement

Special thanks to Prof. M. J. McCarthy, Prof. P. Chen, Y. J. Choi, S. Y. Lee, and Y. S. Lee at the University of California, Davis for their encouragement and assistance in performing this experiment.

References

1. Chen, P., M. J. McCarthy and R. Kauten. 1989. NMR for Quality Evaluation of Fruits and

Vegetables. Transactions of the ASAE. 32(5):1747-1753.

2. Foucat, L., J. P. Donnat, F. Humbert, G. Martin and J. P. Renou. 1997. On-line determination of fat content in ground beef. J. of Magnetic Resonance Analysis. Vol. 3:108-112.
3. Honikel, K. O. 1993. Quality of Fresh Pork: Review, Pork Quality: Genetic and Metabolic Factors, C.A.B. International, Wallingford, p. 203-216.
4. Judith, W. and W. Verner. 1990. Consumer Attitudes to Fat, Meat in Reducing Fat in Meat Animals, Elsevier Applied Science. P. 66-100.
5. McCarthy, M. J. 1994. Magnetic Resonance Imaging in Foods. Chapman & Hall. New York, NY.
6. Renou, J. P., J. Kopp and C. Valin. 1985. Use of low resolution NMR for determining fat content in meat products. J. Food Technology. Vol. (20):23-9.
7. Tornberg, E., A. Andersson, Å. Göransson and G. Von Seth. 1993. Water and Fat Distribution in Pork in Relation to Sensory Properties, Pork Quality: Genetic and Metabolic Factors, C.A.B. International, Wallingford. p. 239-258.