Evaluation on Availability of MTF Measurement Using the ACR Phantom in MRI

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Abstract

Background/Objectives: The aim of this study is to evaluate the availability of MTF measurement as a quantitative method of MRI spatial resolution evaluation using the ACR phantom that is internationally used for MRI quality control.

Methods/Statistical analysis: Images were obtained using both 1.5T MRI and 3.0T MRI and by changing slice thickness, ETL, and matrix size in the default image parameter which is involved in spatial resolution to assess if spatial resolution change in MRI is reflected in MTF measurement. The plot profile measured through ImageJ was expressed as MTF curves using Origin Pro through the Differential-Fast Fourier transform-Smooth-Normalization process. Findings: We observed that 10% MTF values of ETL 10 and ETL 40 measured using 1.5T MRI and 3.0T MRI were higher for ETL 10 and 1.5T MRI was shown to have a higher magnetic field strength than 3.0T MRI. On 10% MTF values comparison of slice thickness 2 mm and slice thickness 8 mm, both 1.5T MRI and 3.0T MRI were shown to have a higher value for slice thickness 2 mm and 3.0T MRI had a higher value than 1.5T MRI. On comparison of matrix sizes 128*128, 256*256, and 512*512, with the increase in matrix size, 10% MTF values were increased for both 1.5T MRI and 3.0T MRI and 3.0T MRI was found to have a higher value than 1.5T MRI. Improvements/Applications: The MTF technique could accurately distinguish between low spatial resolution and high spatial resolution and it can be considered to be useful in the quality control of MRI spatial resolution.

Keywords: IJST, MTF, MRI, Quality Control, Quantitative Measurement, Spatial Resolution

1. Introduction

The first practical Nuclear Magnetic Resonance (NMR) image was obtained using gradient field and back projection by Paul Lauterbur (1929–2007) at the State University of New York in 1973, and since that time, today’s Magnetic Resonance Imaging (MRI) using phase encoding and Fourier transform was developed. The concept of T1 and T2 relaxation times, which are the major factors in deciding contrast of MRI images, was defined by Felix Bloch (1905–1983) in the Bloch equation in 1946.

Recently in MRI, various clinical techniques are being developed with the development of hardware and software technologies and it has become a very important imaging device in the diagnostic field such as in diseases of the brain-nervous system, musculo-skeletal system, digestive system and reproductive system. In addition, importance of MRI quality control for medical imaging quality improvement and public health enhancement has been emphasized, and since 2005, according to the Special Medical Equipment Quality Control Act of the Korean Institute for Accreditation of Medical Image (KIAMI), regular medical imaging quality control is being conducted.

Phantom imaging tests managed by the KIAMI regulate the inspection with the American College of Radiology (ACR)-PH1 MRI phantom and others certified to be equivalent, and there are seven inspection items including geometric accuracy, high contrast spatial resolution, slice thickness accuracy, slice position accuracy, image intensity uniformity, percent signal ghosting, and low contrast object detect ability. Scan sequence uses Spin Echo standard T1 and T2 sequences, and if inadequate,
hospital specific T1 and T2 sequences can be used. Among the inspection items, high contrast spatial resolution is visually evaluated if dots located close to each other in a 4×4 form a group under 1 mm can be distinguished. However, because it is evaluated visually, the accuracy of inspection can be low and subjective judgment of evaluator may be involved.

Performance of imaging systems used in medical environments is expressed by various complex factors (spatial resolution, sharpness, SNR; signal-to-noise ratio) and spatial resolution of medical imaging systems has the ability to distinguish anatomical images of the tissue in the imaging subject. To evaluate the spatial resolution, Modulation Transfer Function (MTF) is widely used in an x-ray system. MTF represents the ratio of the output spatial frequency component to the input spatial frequency component, and mathematically, MTF is a system frequency response on point spread function input and the resulting image can be obtained using Fourier transform. With respect to the methods to express spatial resolution for MTF measurement, in an x-ray system, there are methods such as using the bar pattern, slit, and edge phantom, and among them, the evaluation method using edge is mainly used due to the accuracy, precision, and ease and convenience of the measurement method.

Therefore, the purpose of this study is to use the ACR-PH1 MRI phantom that is internationally used for MRI precision management in order to evaluate the ease of MTF measurement as a quantitative method of MRI spatial resolution evaluation.

2. Materials and Methods

2.1 MRI Scan Parameters

The scan utilized a 8-channel phased-array head coil, Signa Excite HDxt 1.5 Tesla (T) MRI (GE Healthcare, Milwaukee, WI, USA), and Discovery MR750 3.0T MRI (GE Healthcare, Milwaukee, WI, USA) manufactured by GE, and the image was obtained using the ACR-PH1 MRI phantom. Fast spin echo T2 was used for pulse sequence and the default image parameters were TR; 4000 ms, TE; 100 ms, FOV; 200×200 mm, slice thickness 5 mm, Echo Train Length (ETL); 20, matrix size; 256×256.

2.2 Image Acquisition and Analysis

Images were obtained using both 1.5T MRI and 3.0T MRI and by changing slice thickness, ETL, and matrix size in default image parameter which is involved in spatial resolution to assess if spatial resolution change in MRI is reflected in MTF measurement.

The changed spatial resolution elements were set by stages such as slice thickness; 2 mm and 8 mm, ETL; 10 and 40, and matrix size; 128×128, 256×256, and 512×512.

For the ACR-PH1 MRI phantom, the ramp bar which measures the accuracy of slice thickness was raised perpendicularly and as a method suggested by Fujita et al., it was rotated around 2° to the right and 6 slices showed by the ramp bar were set as the measurement subjects as shown in Figure 1.

With respect to the measurement of images, after setting all 6 ROIs on images acquired through Image J (version. 1.50j, Wayne Rasband, the National Institutes of Health, USA), plot profile was measured.

2.3 Measurement of Modulation Transfer Function

The plot profile measured through ImageJ was expressed as MTF curves using OriginPro (version 2016, OriginLab Corp, Northampton, MA, USA) through the Differential-Fast Fourier transform-Smooth-Normalization process. MTF is a frequency transfer function that faithfully expresses origin information when the detector input signal is transformed into the output signal through the system which is a method to evaluate the sharpness and spatial resolution of images. Sharpness is the ability to clearly delineate the borders of images and spatial resolution is defined as the ability to distinguish objects positioned close to one another. Spatial resolution is expressed as spatial frequency and is represented in lp/mm units. It was considered that spatial resolution in the Figure 1. ACR-PH1 MRI phantom images.
final measured MTF curve was a value corresponding to 10% of the MTF curve.

2.4 Statistical Analysis
Statistical analysis results were presented as average±standard deviation using SPSS (version 24.0, SPSS, Chicago, IL, USA) and statistical significance of the MTF value was analyzed using independent t-test or one-way ANOVA with Tukey’s Honestly Significant Difference (HSD) post hoc test. A significance level less than 0.05 were regarded as statistically significant.

3. Results
3.1 Echo Train Length
10% MTF values measured using 1.5T MRI were 0.5663±0.0033 and 0.5254±0.0052 for ETL 10 and ETL 40, respectively, and this showed that ETL 10 images had a higher spatial resolution and there was a statistically significant difference (t=8.433, p<0.001). 10% MTF values measured using 3.0T MRI were 0.5558±0.0024 and 0.5219±0.0092 for ETL 10 and ETL 40, respectively, and this showed that ETL 10 images had a higher spatial resolution and there was a statistically significant difference (t=8.705, p<0.001).

On comparison between 1.5T MRI and 3.0T MRI, ETL 10 showed a statistically significant difference (t=-6.429, p<0.001), but ETL 40 did not show a statistically significant difference (t=-0.812, p>0.05), as seen in Table 1.

3.2 Slice Thickness
10% MTF values measured using 1.5T MRI were 0.5899±0.0041 and 0.5215±0.0056 for slice thickness 2 mm and slice thickness 8 mm, respectively, and this showed that slice thickness 2 mm images had a higher spatial resolution and there was a statistically significant difference (t=24.058, p<0.001). 10% MTF values measured using 3.0T MRI were 0.5926±0.0032 and 0.5308±0.0067 for slice thickness 2 mm and slice thickness 8 mm, respectively, and this showed that slice thickness 2 mm images had a higher spatial resolution and there was a statistically significant difference (t=20.823, p<0.001).

On comparison between 1.5T MRI and 3.0T MRI, slice thickness 2 mm did not show a statistically significant difference, but slice thickness 8 mm showed a significant difference (t=2.583, p<0.05), as seen in Table 2.

3.2 Matrix Size
10% MTF values measured using 1.5T were 0.4663±0.0085, 0.5541±0.0054, and 0.8990±0.0086 for matrix sizes 128*128, 256*256, and 512*512, respectively, and this showed that matrix size 512*512 had the highest spatial resolution and the matrix size 128*128 image showed the lowest value, and there was a statistically significant difference (f=1171.337, p<0.001).

On comparison between 1.5T and 3.0T, all matrix sizes 128*128 (t=18.709, p<0.001), 256*256 (t=2.625, p<0.05 Ed: A p value of 0.025 has been presented in Table 3), and 512*512 (t=5.812, p<0.01) showed statistically significant differences, as seen in Table 3.

4. Discussion
With the development of modern medical technology, medical imaging tests are being widely used for diagnosis and treatment of disease, and for providing accurate imaging information. However, because old medical devices can show false lesions and cause the possibility of misdiagnosis and medical errors through inadequate imaging, regular management of medical imaging devices is necessary. For this purpose, the KIAMI, based on rules regarding the installation and operation of special medical equipment, has designated MRI as special medical

Table 1. 10% MTF values due to change echo train length

|       | 1.5T MRI | 3.0T MRI | t     | p   |
|-------|----------|----------|-------|-----|
| Mean  | 0.5663   | 0.5558   | -6.429| <0.001|
| SD    | 0.0033   | 0.0024   |       |      |
| ETL 10| 0.5254   | 0.5219   | -0.812| 0.436|
| SD    | 0.0052   | 0.0092   |       |      |
| t & p | t=8.433, p<0.001 | t=8.705, p<0.001 |       |      |
spatial frequency value of the 10% point of the measured MTF curve was defined as system resolution. With respect to the MTF value, after obtaining the image, ESF data in which image noise was reduced using ImageJ was obtained, and by using OriginPro to process differentiation and Fourier transform, the MTF measurement was conducted.

In the measurement results, 10% MTF values of ETL 10 and ETL 40 measured using 1.5T MRI and 3.0T MRI were higher for ETL 10 and 1.5T MRI was shown to have a higher magnetic field strength than 3.0T MRI. This result is in agreement with the study results of Gordon Sze et al. which show that image blurring increases with ETL and an increase in image blurring has an effect on the resolution of images. The increase in image blurring in 3.0T MRI compared to 1.5T MRI can be explained by the theory stated by Choi et al. which states that compared to low magnetic field, in high magnetic field, there can be an increase in distortion of images due to in homogeneity in artifacts and magnetic field.

Among the seven items of MRI phantom imaging inspection, high contrast spatial resolution involves the visual inspection of the degree of distinction between closely located dots by a radiology specialist for line resolution and column resolution. For the diameter of dots, it is arranged in the order of 1.1 mm, 1.0 mm, and 0.9 mm from the left and the acceptance criterion is the distinction in a dot group under 1.0 mm for both line resolution and column resolution. However, because during visual evaluation, there may be not only involvement of subjective judgment but also evaluator dependency according to the experience and expertise of the evaluator, there is a need to develop an objective and quantitative evaluation method.

The MTF technique was used to test the performance of ordinary cameras or spatial resolution and sharpness evaluation on input and output of photons in an x-ray system. Although MTF can be obtained through programming such as C-language and Matlab, due to high price and necessity for expert knowledge on programming, the MTF measurement method suggested by Woo et al. was utilized. In terms of spatial resolution, the spatial frequency value of the 10% point of the measured MTF curve was defined as system resolution. With respect to the MTF value, after obtaining the image, ESF data in which image noise was reduced using ImageJ was obtained, and by using OriginPro to process differentiation and Fourier transform, the MTF measurement was conducted.

In the measurement results, 10% MTF values of ETL 10 and ETL 40 measured using 1.5T MRI and 3.0T MRI were higher for ETL 10 and 1.5T MRI was shown to have a higher magnetic field strength than 3.0T MRI. This result is in agreement with the study results of Gordon Sze et al. which show that image blurring increases with ETL and an increase in image blurring has an effect on the resolution of images. The increase in image blurring in 3.0T MRI compared to 1.5T MRI can be explained by the theory stated by Choi et al. which states that compared to low magnetic field, in high magnetic field, there can be an increase in distortion of images due to in homogeneity in artifacts and magnetic field. Also on 10% MTF values comparison of slice thickness 2 mm and 8 mm, both 1.5T MRI and 3.0T MRI were shown to have a higher value for slice thickness 2 mm and 3.0T MRI had a higher value than 1.5T MRI. In terms of image parameter, the voxel size decreases with reduced slice thickness and increased matrix size, and this improves the spatial resolution of equipment like Computed Tomography (CT) and mammography in 2005 and it is managing them through one-year cycle document inspection and three-year cycle precision inspection.

### Table 2. 10% MTF values due to change slice thickness

|            | 1.5T MRI |            | 3.0T MRI |            | t     | p     |
|------------|----------|------------|----------|------------|-------|-------|
|            | Mean     | SD         | Mean     | SD         |       |       |
| Slice thickness 2mm | 0.5899   | 0.0041     | 0.5926   | 0.0032     | 1.290 | 0.226 |
| Slice thickness 8mm | 0.5215   | 0.0056     | 0.5308   | 0.0067     | 2.583 | 0.027 |
| t & p      | t=24.058, p<0.001 | t=20.823, p<0.001 | |

### Table 3. 10% MTF values due to change matrix size

|            | 1.5T |            | 3.0T |            | t     | p     |
|------------|------|------------|------|------------|-------|-------|
|            | Mean | SD         | Mean | SD         |       |       |
| Matrix size 128*128 | 0.4663c  | 0.0085 | 0.5357c  | 0.0032 | 18.709 | <0.001 |
| Matrix size 256*256 | 0.5541b  | 0.0054 | 0.5636b  | 0.0070 | 2.625  | 0.025  |
| Matrix size 512*512 | 0.8990a  | 0.0086 | 0.9845a  | 0.0302 | 5.812  | 0.001  |
| t & p      | f=547.590, p<0.001 | f=1171.337, p<0.001 | (a>b>c) | (a>b>c) | |
images. On comparison of matrix sizes 128×128, 256×256, and 512×512, with the increase in matrix size, 10% MTF values were increased for both 1.5T MRI and 3.0T MRI and 3.0T MRI was found to have a higher value than 1.5T MRI.

5. Conclusion

The MTF technique, according to the changes in ETL, slice thickness, and matrix size, which are the mediating variables directly related to spatial resolution of magnetic resonance imaging, could accurately distinguish between low spatial resolution and high spatial resolution and it can be considered to be useful as a quantitative and standardized measurement method in the quality control of MRI spatial resolution.

The MTF technique confirmed in this study can be utilized as basic data for quantitative evaluation of spatial resolution in the MRI field in the future, and if data is accumulated through further research, it is considered that accurate management of comparison of image quality and quality control will be conducted by hospitals, equipment, and each parameter, and furthermore, it is considered that it will contribute to enhancement of public health.

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7. References

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