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Correlation of Image Quality according to the Distance of the Magnetic Isocenter

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In an MRI scan, the larger the patient's body, the farther away the test target area is from the center. Therefore, this study aims to measure the changes in image quality according to distance from the center of the MRI machine's bore and provide a reference distance that does not cause image degradation during actual examinations. The data from a total of nine points at 5 cm, 10 cm, 15 cm, and 20 cm away from the center of the MRI bore in both directions were obtained and compared with the measurement data of the isocenter. As for the experimental equipment, the 3.0 Tesla MRI device and the 16-channel GEM Flex Suite (small) were used to acquire the TI and T2 images of the old Phantom. Furthermore, the Image J program analyzed the mean difference between SNR and CNR. As a result of the statistical analysis, The one-way batch ANOVA and Duncan's posthoc test results showed no statistically significant difference between the measurements from the center at 5cm, 10cm, and 15cm positions ($p < 0.001$). However, at the 20cm position, the standard deviation of the noise increased by more than 10%, for the values of SNR and CNR to decrease rapidly.

Keywords : isocenter center, magnetic field, uniformity, surface coil

1. Introduction

The efficient use of advanced medical equipment has made it possible to observe the inside of the human body more precisely. As one of the imaging diagnostic equipment, the MRI scanner is a device that acquires biomedical images by using the magnetic resonance phenomenon of the hydrogen nucleus, which occupies most of the human body, differs according to tissue, and provides medical images with excellent diagnostic value [1].

Magnetic Resonance Imaging (MRI) is a diagnostic imaging tool that displays anatomical or pathological information inside the human body in a non-invasive method. Moreover, it can acquire biochemical and functional image data of tissues and take three-dimensional images at any angle. It is an imaging technology that is very useful for diagnosing and monitoring diseases due to its excellent resolution [2].

When the body is placed in the strong magnetic field for an MRI exam, the magnetic vector of the hydrogen atoms in the body is aligned with the Z-axis, which is the direction of the magnetic field, before it starts the precession at the Larmore frequency. Subsequently, when a radio frequency (RF) such as the Larmore frequency is externally applied, a resonance occurs, and this resonance moves the magnetization vector of the hydrogen atom from the Z-axis to the X-Y plane. When the receiver coil is placed on the X-Y plane, the magnetization vector of the hydrogen atom forms an induced electromotive force in the coil, and the magnitude of this induced electromotive force is shown as the size of the MRI signal [3].

In MRI, the RF coil is vital in increasing spatial resolution. The susceptibility of the RF coil affects the signal-to-noise ratio, and the sensitivity of the coil varies depending on the shape and size of the coil [4]. Moreover, the strength of the magnetic resonance signal is more significant the closer it is to the coil. In addition, the loops of the coil must be increased, and the coil must be made greater than the sample to make the magnetic field generated by the RF coil uniform to the entire sample [5]. However, the signal-to-noise ratio drops when the filling factor, the proportion of the sample in the coil, becomes smaller. In the end, the optimal coil must be made in consideration of the size and shape of the sample to obtain an appropriate signal-to-noise ratio. Furthermore,

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the surface coil is used as the coil mainly used on arms, legs, and shoulder areas to obtain high-resolution diagnostic images within the area of diagnosis [6].

However, if the target area to be imaged cannot be located in the center of the coil, the signal strength of the image, including core lesions, cannot be maintained at the maximum. In other words, to maintain the image's maximum signal strength, including the core lesion during MRI exams, the target area to be imaged must be placed in the center of the coil. However, the target area will likely be distanced from the center of the coil due to various causes, such as the size and shape of the target area, the lack of skills or carelessness of the examiner, the surrounding environment, and the patient's condition.

If the exam is performed while the center of the coil and the target area to be imaged are distanced apart, the signal strength declines. This is because it follows the characteristics of the MRI coil, in which the signal strength increases when the distance between the subject and coil is close and decreases when the distance is far [7].

The decline in MRI signal intensity blurs the location and boundaries of the core lesion, making it unclear the exact location of the lesion and adversely affecting the diagnosis, treatment, and disease prognosis [8]. However, due to the lack of studies on whether the signal strength declines below the diagnostic quality if the target site is not positioned in the center of the coil, most of these tests are being overlooked, and the seriousness of the diagnostic problems that may occur due to the decrease in signal strength is not recognized.

The tests performed with a surface coil applied to different parts of the body in the MRI laboratory often depend on the technical factors of the examiner, which can reduce the quality of MRI images and the advantages of MRI as a medical diagnostic image.

As of 2023, the utilization of MRI diagnostic devices has advanced to the level of hybrid devices that combine linear accelerators for radiation therapy, and the accuracy of the alignment of the isocenter of the device is closely related to the success of the treatment. For example, it requires precision in diagnostic and therapeutic imaging, such as detecting anatomical changes during patient care, real-time motion management, gates, or follow-up treatments, and expects an accurate level of care that does not allow image distortion in the radiotherapy plan [9].

Accordingly, the authors hypothesized that if the distance of the material to be imaged from the center of the coil within the coil constantly increased or decreased, the signal strength would also decrease or increase accordingly. Hence, if the signal strength when the material to be imaged is located in the center of the coil and the signal strength for each distance when it is moved, and statistically find and present the same distance as the signal strength of the coil center, it is judged that the seriousness of the problem of signal strength deterioration can be recognized if the target part is not located in the center of the coil due to various causes. To this end, if the target part cannot be located in the center of the coil due to various irresistible causes, statistically, the distance of the same signal strength as the center of the coil is analyzed, and how many 10 % is reduced, or the reference distance, that is, the reference distance (guideline), was presented to find a way to maintain the optimal signal strength.

2. Experimental Procedure

2.1. Subject and Method of Research

As shown in Figs. 1 and 2, the experimental device for obtaining T1 and T2 weights was a 3.0 T (GE Discovery MR 750, GE Health Care, USA) and a 16-channel GE GEM Flex Coil 16-S Array Small suite (3T Receiver only GE Health Care, USA) was used. Image of an old Phantom (MRS 4.38 Sphere with Solution Phantom).

The conditions of T1 Weighted Imaging (T1WI) were TR 500 ms, TE 20 ms, Slice thickness 5 mm, Slice gap 5

Fig. 1. (Color online) 16-channel GE GEM flex coil 16-S array compact product line for analysis of image quality according to distance from MRI bore center.

Fig. 2. (Color online) MRI-specific phantom for image quality evaluation (including MRS 4.38 Sphere solution phantom).

Table 1. Scan parameters of images of T1WI and T2WI.

	T1WI	T2WI
TR (Repetition ime)	500 ms	3000 ms
TE (Echo time)	20 ms	80 ms
Slice thickness	5 mm	5 mm
Slice gap	5 mm	5 mm
FA (Flip angle)	90°	120°
NEX (Number of excitations)	1	1
FOV (Field of view)	250×250 mm	250×250 mm

mm, Flip angle 90 degrees, and the Number of excitations (NEX) was 1, and the conditions of T2 Weighted Imaging (T2WI) were TR 3000 ms, TE 80 ms, Slice thickness 5 mm, slice gap 5 mm, Flip angle 120 degrees, and NEX 1, as displayed in Table 1, with each position being measured 50 times.

The 5 cm points, 10 cm points, 15 cm points, 20 cm points to both the right and left of the isocenter on the inside of the MRI device's bore were positioned as shown in Fig. 3. In addition, surface coil was wrapped around the old Phantom to obtain the measurement data of the nine points, and the measurement data at the isocenter in the center of the bore were compared and evaluated with the measurement point outside the center of the bore.

2.2. Image Evaluation

As the image evaluation method, the Region of Interest (ROI) of the acquired image was set using the Image J program (National Institute of Health) as the quantitative analysis method, and the measurements of right point 5 cm, right point 10 cm, right point 15 cm, and right point 20 cm, as well as left point 5 cm, left point 10 cm, left point 15 cm, and left point 20 cm were used to measure the strength and standard deviation of signal and noise.

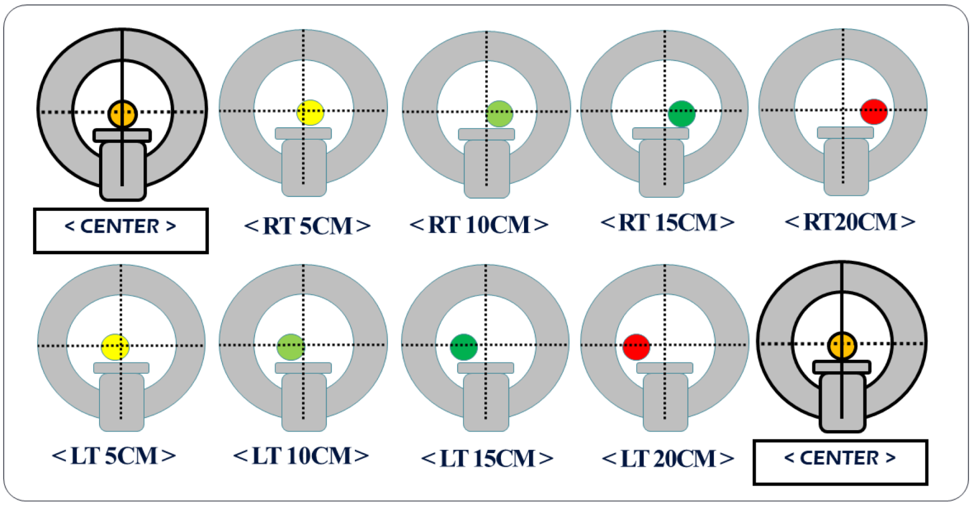

Fig. 3. (Color online) Location of a spherical phantom for measuring image quality by distance from the center of the MRI bore.

Fig. 4. (Color online) Arrangement of spherical phantom, fixed frame (A), and coil with surface coil wound (top view B, front view C).

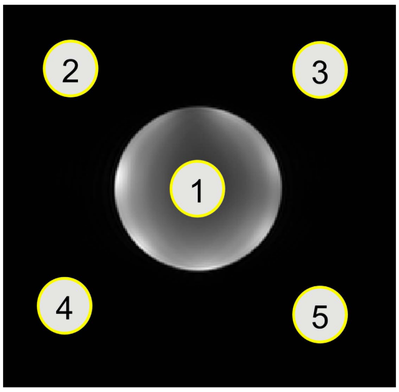

Fig. 5. (Color online) Area setting image of 5 points in the region of interest and background for SNR and CNR analysis of MRI phantom (spherical) scan image using Image J program.

As for the measured image, the circular ROI of 70 mm^2 in the isocenter of the old Phantom was set as shown in Fig. 5, and the background noise was measured by setting 70 mm^2 in four places diagonally around the Phantom.

The measured data was applied to the formulas of Eq. (1) and Eq. (2) to calculate and compare the SNR (Signal to Noise Ratio) of the image. The mean values of the Signal-to-Noise, Contrast to Noise, and the 95 % confidence interval value, as well as the mean difference between SNR and CNR were analyzed.

2.3. Statistical Analysis

The quantitative evaluation of the difference in image quality between the two groups was performed using SPSS Ver. 26.0 one-way batch ANOVA and Duncan's post-hoc analysis to determine whether the measurements at the right point 5 cm, 10 cm, 15 cm, and 20 cm, as well as the left points 5 cm, 10 cm, 15 cm, and 20 cm on the X-axis were statistically significantly different from the isocenter (0 cm).

3. Results

3.1. T1 Weighted Image Evaluation

The SNR value set the isocenter at the standard value (100 %), and the highest value (1240.07 ± 37.21) was found in the isocenter, while the lowest value (1046.42 ± 36.02) was found at the left 20 cm point, as shown on Table 2. Based on the maximum value of the center of the circular Phantom, the SNR value showed the largest decrease (84.38 %) at the left point 20 cm, and the second largest decrease (84.45 %) at the right point 20 cm. The CNR value also showed the same pattern as the SNR value. The highest value (1228.77 ± 36.87) was found at the isocenter of the circular Phantom, while the lowest value (1032.36 ± 35.68) was found at left point 20 cm. Based on the maximum value of the center point, the decrease in the CNR value showed the largest decrease (84.01 %) at the left point 20 cm, and the second highest decrease (84.11 %) at the right point 20 cm.

3.1.1. Results of One-way ANOVA for T1 Weighted Image (SNR)

As shown on Table 3, the difference in the SNR value according to the distance from the isocenter of the circular phantom shows that there is an SNR value at a point where there is at least one other significant difference in the group ($p<0.001$).

3.1.2. Results of Duncan's post-hoc analysis for T1 Weighted Image (SNR)

Although there were two subgroups for the significance level of 0.05, in the case of right point 5 cm, left point 5 cm, right point 10 cm, left point 10 cm, right point 15 cm, and left point 15 cm, there was no significant difference from the isocenter representing the maximum SNR value statistically (Sig. 0.162) for them to have the equal SNR value.

Table 2. Mean SNR and CNR values of T1-weighted images according to measurement location.

Position	SNR (Relative ratio)	CNR (Relative ratio)
Right point 20 cm	1047.27 ± 42.03 (84.45 %)	1033.56 ± 41.67 (84.11 %)
Right point 15 cm	1223.98 ± 56.12 (98.70 %)	1209.53 ± 55.56 (98.43 %)
Right point 10 cm	1236.55 ± 39.68 (99.71 %)	1223.75 ± 39.17 (99.59 %)
Right point 5 cm	1236.96 ± 29.09 (99.74 %)	1224.64 ± 28.79 (99.66 %)
Center	1240.07 ± 37.21 (100 %)	1228.77 ± 36.87 (100 %)
Left point 5 cm	1237.57 ± 33.30 (99.79 %)	1225.35 ± 33.00 (99.72 %)
Left point 10 cm	1237.03 ± 57.55 (99.75 %)	1224.39 ± 56.97 (99.64 %)
Left point 15 cm	1221.88 ± 45.57 (98.53 %)	1207.71 ± 45.10 (98.28 %)
Left point 20 cm	1046.42 ± 36.02 (84.38 %)	1032.36 ± 35.68 (84.01 %)

Table 3. Post-analysis of T1-weighted image SNR according to the position of the surface coil spherical phantom.

Position	Subset for alpha = 0.05	
	1	2
Left point 20 cm	1046.42	
Right point 20 cm	1047.27	
Left point 15 cm		1221.88
Right point 15 cm		1223.98
Right point 10 cm		1236.55
Right point 5 cm		1236.96
Left point 10 cm		1237.03
Left point 5 cm		1237.57
Center		1240.07
Sig.	.938	.162

Table 4. Post-analysis of T1-weighted image CNR according to the position of the surface coil spherical phantom.

Position	Subset for alpha = 0.05	
	1	2
Left point 20 cm	1032.36	
Right point 20 cm	1033.56	
Left point 15 cm		1207.71
Right point 15 cm		1209.53
Right point 10 cm		1223.75
Left point 10 cm		1224.39
Right point 5 cm		1224.64
Left point 5 cm		1225.35
Center		1228.77
Sig.	.913	.100

3.1.3. Results of One-way ANOVA for T1 Weighted Image (CNR)

The difference in CNR value according to the distance from the center of the circular Phantom indicates that there is a CNR value at a point where there is at least one significant difference in the population ($p<0.001$).

3.1.4. Results of Duncan's post-hoc analysis for T1 Weighted Image (CNR)

As shown in Table 4, there were two subgroups for a significance level of 0.05, but in the case of right point 5 cm, Left point 5 cm, Right point 10 cm, Left point 10 cm, Right point 15 cm, Left point 15 cm, It can be seen that there is no significant difference from the center representing the maximum CNR value statistically (Sig. 0.100) and represents the same CNR value.

3.2. Evaluation of T2 Weighted Image

The SNR value was set to the standard value (100 %) at the center of the circular phantom, and the highest value was found in the isocenter as shown in Table 5, and the lowest value was found at the right point 20 cm. The decrease in SNR value based on the maximum center showed the largest decrease (84.28 %) at the right point 20 cm and the second largest decrease (84.74 %) at the left point 20 cm.

The CNR value also showed the same pattern as the SNR value. The highest value was found at the isocenter, and the lowest value was found at 20 cm from the right point. Based on the maximum center value of the circular phantom, the decrease in CNR value was the largest decrease (83.65 %) at the right point 20 cm and the second largest decrease (84.01 %) at the left point 20 cm

3.2.1. Results of One-way ANOVA for T2 Weighted Image (SNR)

The difference in the SNR value according to the distance from the isocenter of the circular phantom shows that there is an SNR value at a point where there is at least one other significant difference in the population. (p

Table 5. Mean SNR and CNR values of T2-weighted images according to measurement location.

Position	SNR (Relative ratio)	CNR (Relative ratio)
Right point 20 cm	232.93 ± 5.57 (84.28 %)	224.62 ± 5.41 (83.65 %)
Right point 15 cm	273.45 ± 9.39 (98.95 %)	264.18 ± 9.11 (98.38 %)
Right point 10 cm	273.98 ± 10.26 (99.14 %)	265.08 ± 9.99 (98.71 %)
Right point 5 cm	275.43 ± 6.73 (99.66 %)	267.52 ± 6.56 (99.62 %)
Center (0 cm)	276.35 ± 8.22 (100 %)	268.52 ± 7.99 (100 %)
Left point 5 cm	274.51 ± 5.79 (99.33 %)	266.49 ± 5.65 (99.24 %)
Left point 10 cm	274.49 ± 8.23 (99.32 %)	265.99 ± 8.02 (99.05 %)
Left point 15 cm	273.44 ± 8.94 (98.94 %)	264.27 ± 8.65 (98.41 %)
Left point 20 cm	234.19 ± 6.67 (84.74 %)	225.59 ± 6.51 (84.01 %)

Table 6. Post-analysis of T2-weighted image SNR according to the position of the surface coil spherical phantom.

Position	Subset for alpha = 0.05	
	1	2
Right point 20 cm	232.936	
Left point 20 cm	234.190	
Left point 15 cm		273.441
Right point 15 cm		273.452
Right point 10 cm		273.985
Left point 10 cm		274.493
Left point 5 cm		274.510
Right point 5 cm		275.438
Center		276.356
Sig.	.540	.227

< 0.001).

3.2.2. Results of Duncan's post-hoc analysis for T1 Weighted Image (SNR)

As shown in Table 6, there are two subgroups for a significance level of 0.05, but in the case of right point 5 cm, Left point 5 cm, Right point 10 cm, Right point 10 cm, Right point 15 cm, and Left point 15 cm, there was no significant difference from the isocenter representing the maximum SNR value statistically (Sig. 0.227) for them to have the equal SNR value.

3.2.3. Results of One-way ANOVA for T2 Weighted Image (CNR)

The difference in the CNR value according to the distance from the center of the circular phantom indicates that there is a CNR value at a point where there is at least one significant difference in the population ($p < 0.001$).

Table 7. Post-analysis of T2-weighted image CNR according to the position of the surface coil spherical phantom.

Position	Subset for alpha = 0.05	
	1	2
Right point 20 cm	224.625	
Left point 20 cm	225.594	
Right point 15 cm		264.182
Left point 15 cm		264.277
Right point 10 cm		265.082
Left point 10 cm		265.997
Left point 5 cm		266.497
Right point 5 cm		267.529
Center		268.525
Sig.	.626	.059

3.2.4. Results of Duncan's post-hoc analysis for T2 Weighted Image (CNR)

As shown in Table 7, there are two subgroups for a significance level of 0.05, but in the case of right point 5 cm, Left point 5 cm, Right point 10 cm, Right point 10 cm, Right point 15 cm, and Left point 15 cm, there is no significant difference from the center representing the maximum CNR value statistically (Sig. 0.059) and represents the same CNR value.

4. Discussion

Since MRI is a non-invasive, cost-effective, and diagnostic imaging procedure using ionizing radiation, it is a clinical tool that can provide anatomical, functional, and metabolic information inside the human body without the injection of radioisotopes and has significant advantages over other diagnostic equipment [10]. In recent years, PET-MRI has been installed that combines PET (Positron emission tomography) and MRI, and it is a fusion molecular imaging system that combines PET of ultra-sensitive molecular imaging and MRI capable of high-resolution functional imaging [11]. It is a high-frequency coil for reception only. Surface coils are small and should be placed anatomically near the surface of the human body, which is flexibly shaped to produce an image to increase the area of contact with the human body surface as much as possible [12]. In essence, surface coils have a good signal-to-noise ratio with respect to the tissues adjacent to the coil. It also allows for smaller voxel sizes, which improves image resolution. However, as the distance from the coil increases, the signal strength of the image decreases significantly. Therefore, the surface coil is constrained by the distance from the center of the runner field. When using the surface coil in an MRI examination, it is possible to obtain an excellent or bad image signal due to the examiner's understanding and attention to the surface coil.

Therefore, the placement and selection of the surface coil depends on the type of imaging required and is particularly useful for localized body parts where anatomy is studied in relative proximity to the skin, such as the temporomandibular joint and the spine. During MRI examination, the surface coil is an RF coil specially designed to be placed close to the surface of the imaging object, increasing the SNR of the area close to the coil and the resolution. However, it has the disadvantage of being limited in its position with the runner field and the shooting area.

This study can be clinically significant in suggesting that the image quality deteriorates rapidly when it is far from the center of the magnetic field to a certain extent. It also suggests the reference distance.

When selecting a measurement object, using a bolus similar to the human body or acquiring and executing an image on the human body may be authoritative as a convincing study to apply to clinical patients. However, it is not easy to establish a standard because the physique conditions of the chest and abdomen are different for each patient. It is challenging to apply the exact distance from the isocenter of the runner's field.

This suggests that the susceptibility of the main magnetic field can occur not only in the x-axis but also in the y-axis and z-axis. For this reason, there is a need to measure the strength of the main magnetic field in the y-axis and z-axis with respect to the center of the main magnetic field in future research.

Due to practical problems such as the acquisition and storage of living organisms, it was not possible to conduct experiments with organisms such as animal legs, and it was not possible to further subdivide the location away from the center. In addition, when the surface coil was positioned, the measurement at a distance accessible to the patient was right and left, and the measurement of the up and down (three-dimensional) axis of the Y and Z axes remained a limitation.

This paper's significance is that the image's signal degradation is presented. However, the change in image quality according to the distance from the center of the magnetic field is quantitatively presented, and the reference distance at which the image quality is statistically rapidly deteriorated.

In future research, experiments should be conducted on changes in image quality according to frequency characteristics such as MTF (Modulation Transfer Function) in addition to SNR and CNR using the ACR MRI Phantom.

The key to MRI is how much high-resolution signal strength can be obtained quickly. Several studies have been conducted to increase this signal strength. According to Choi *et al*. [13], the signal strength can be increased by increasing the filling factor in the coil. Seo *et al*. [14]. stated that the signal strength could be increased by reducing the susceptibility difference by adding human tissue equivalent materials to the coil. Nakada [15] and others have introduced methods to increase the signal strength while increasing the main magnetic field.

However, increasing the strength of the magnetic field, changing the parameters of the image, and increasing the signal strength by increasing the magnetic field without the surface coil being located in the center of the isocenter will only result in overloading the device and increasing the risk of the patient's high magnetic field.

Accordingly, the author recognizes the seriousness of the problem that the signal strength is lowered mainly when the surface coil is applied to the target site to be imaged, and statistically the surface coil is located more than a few centimeters in the isocenter of the magnetic field.

As can be seen from the results, both SNR and CNR in T1 and T2 images show a statistically significant difference between 15 cm on the right and 15 cm on the left of the X axis, and the signal strength decreases rapidly below 80 % at 15 cm or more on the right and left of the X-axis.

In conclusion, if it is difficult to position the target part of the upper and lower limbs in the isocenter due to the patient's torso if the target part is located within 15 cm of the left point on the right side of the X-axis from the center of the magnetic field as much as possible.

5. Conclusion

Through this study, it was discovered that when a surface coil is applied to an MRI device, there are points where it is not located at the center (Isocenter) of the main magnetic field and the signal strength deteriorates.

When performing an MRI examination of an area located on one side, such as the elbow or wrist, if the distance from the center of the magnetic field does not exceed 15 cm, the optimal signal strength can be maintained even if the patient's physique is large without correction for image quality compensation.

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