Adaptability of needle electrodes used for neurophysiological monitoring to intraoperative MRI

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Purpose

Image-guided techniques using preoperative computed tomography and magnetic resonance images, beginning with microscopy techniques have led to a radical development in the technical assistances available for brain tumor surgery. Intraoperative magnetic resonance imaging (iMRI) has been drawing attention since it was first introduced by Black et al. [1] and Wirtz et al. [2] in the 1990s. The main roles of iMRI are: (1) controlling the resection of brain tumors; (2) updating the data-sets for navigational systems; and (3) confirming the presence or absence of fatal bleeding. In [3], it is claimed that a number of new technological methods such as iMRI can improve patients' prognoses.

In iMRI, low-field magnetic resonance scanners are often introduced because of their advantages in terms of safety, introducing and running costs and so on. One of its greatest benefits is that the region of the 5 gauss line is narrow enough to allow iMR scanner to be introduced into an operating room, and ordinary surgical instruments to be used. Conversely, it also has demerits, one of which is a lower signal-to-noise ratio (SNR) than that of a high-field MR scanner. In addition, operative settings (e.g., craniotomy) and the operation of medical electronics, such as anesthesia apparatus, are considered to cause a decline in the SNR of iMR images. We are concerned that iMR images occasionally become noisy for unknown reason. Therefore, we were apprehensive that an object not typically used in an MRI suite may affect the quality of iMR images. One of them is a needle electrode used for the neurophysiological monitoring of motor evoked potentials (MEP) or somatosensory evoked potentials (SEP). These electrodes are made of ferromagnetic material and attached to the patient's temple, scalp, etc. Metallic objects in the gantry of an MR scanner can cause artifacts on MR images.

In this paper, we evaluated the influence of a needle electrode used for neurophysiological monitoring on iMR images, and then examined whether using electrodes in iMRI caused the decline in SNR, which occasionally occurs in clinical iMRI.
Methods and Materials

We used a cylindrical phantom made of acrylic resin, a stainless steel needle electrode, a 0.4T MR scanner (APERTO Inspire, Hitachi Medical Co., Chiba, Japan) and a solenoid coil with a Sugita head frame (Fig. 1 on page 5). The cylindrical phantom had an internal diameter of 200 mm, height of 30 mm, and acrylic resin thickness of 3 mm. We filled it with a solution of 300 g of powdered gelatin dissolved in 700 mL normal saline (hereafter "gelatin"). The gelatin had T1 and T2 values of 690 and 135, respectively, which were similar to that of cerebral parenchyma [4]. When the phantom was pierced by the electrode, it was held in place by the gelatin in the same way metallic materials had been fixed in agar [5,6]. To pierce the phantom with the electrode, 5 small holes were made in the phantom as shown in Fig. 1 on page 5(a). The needle electrodes used for neurophysiological monitoring are 1.45 mm long and have a diameter of 0.22 mm.

We scanned the phantom with the electrode and evaluated its influence on MR images, in 3 of the following experimental terms. The imaging conditions for each of those 3 experimental terms were as follows: 3-dimensional (3D) gradient-echo (GRE) in T1-weighted images (T1WI) (repetition time 21 ms, echo time 9 ms, slice thickness 2 mm, matrix size 256 × 160, and flip angle 40°) and the 3D fast-spin-echo (FSE) in T2-weighted images (T2WI) (repetition time 1100 ms, echo time 144 ms, slice thickness 3 mm, and matrix size 256 × 192). Each scan was performed 5 times.

A. Comparison of metallic artifacts at different angles

We measured the metallic artifact diameter when piercing the phantom with the electrode at each of the following angles with respect to the direction of frequency encoding: 0°, 30°, 60°, 90°, 120°, and 150° (Fig. 2 on page 5). First, we set the phantom with the electrode at 0° in the center of gantry [Fig. 1 on page 5(c)] and performed 5 times MR scans. Next, the phantom was rotated 30° and scanned. Scanning was repeated in this manner the angle was 150°. To calculate the artifact diameter, we plotted the artifact profile at the electrode’s position and measured the half-value width of the profile [Fig. 3 on page 6 and Fig. 4 on page 7(c)]. We plotted the profile so the half-value width was at a maximum in each of 2 directions: the direction parallel to and perpendicular to the needle, which are referred to "the major axis" and "the minor axis," respectively.

B. Comparison of metallic artifact at different locations

We measured the artifact diameter at ±0, ±25, ±50, ±75 mm from the center of the phantom to each direction of the frequency and phase encoding with the electrode parallel to the slice encoding direction [Fig. 4 on page 7(a)]. First, we set the phantom pierced by the electrode at the center of the phantom in the center of the gantry and performed 5 times MR scans. Then, the electrode was replaced and re-scanned, and the process
repeated. To calculate the artifact diameter, we plotted the artifact profile at the electrode position and measured the half-value width of the profile [Fig. 4 on page 7(c)]. We plotted the profile at the electrode.

C. Variation in SNR

We evaluated the variation in SNR at each of 4 locations around the electrode, which had been inserted in the center of the phantom. First, we set the phantom in the center of gantry and performed 5 times MR scans. Next, the phantom were pierced with the electrode at the center, and also scanned 5 times. To calculate the SNR, we selected the image slice in which the artifact was the largest, and set a region of interest (ROI) with a diameter of 20 mm at each of 4 locations as shown in Fig. 5 on page 8. The SNR was calculated as:

\[
\text{SNR} = \frac{S_p}{\left( \frac{N_s}{\sqrt{2}} \right)}
\]

Fig. 11

References: [7], [8], [9]

where \( S_p \) is the mean of signal intensity in the ROI and \( N_s \) is the standard deviation in the ROI on the subtraction image between an interest image and another image.
Fig. 1: (a) The cylindrical phantom made of acrylic resin filled with a solution of 300 g powdered gelatin dissolved in 700 mL normal saline. It has 5 small holes which have a diameter of 1.5 mm. One of them is located on the lateral side of the phantom. Another is located in the center of the circle and the others were located at 25 mm intervals from the center. (b) The needle electrode made of stainless steel. (c) The 0.4T MR scanner in the operating room. The phantom and the solenoid coil are located in the center of the gantry.

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**Fig. 2:** (a) Each angle of the electrode as described in Experiment A. (b) An example of measuring the artifact diameter at 90°. Red and blue arrows mean the artifact's major and minor axis lengths, respectively.

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Fig. 3: (a) (b) The profiles of the phantom without the electrode. (c) (d) The case where the electrode is pierced the phantom at 90° on the major axis. The major axis artifact lengths calculated half-value width is shown by yellow and red arrows.

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**Fig. 4:** (a) The arrangement of electrodes used to pierce the phantom in Experiment B. (b) A example of measuring the artifact diameter. Yellow and blue arrows show the artifact diameter in the direction of phase encoding and frequency encoding, respectively. (c) An example of the phantom profile through the artifact. The red arrow shows the half-value width of the profile. The half-value is the halfway between the lowest signal intensity at the artifact and the mean signal intensity of the phantom around the artifact.

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Fig. 5: (a) An interest image for calculation of SNR showing 4 ROIs in the phantom. In the ROI, the mean of the signal intensity $S_p$ of the SNR is measured at each of the 4 locations. (b) Another image of interest for image subtraction to estimate the noise. (c) The subtraction image between (a) and (b) is shown. The standard deviation of the value in the ROI of (c) as $N_s$ is measured at each of the 4 locations.

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Fig. 6: (a) (c) The artifact at each angle in T1WI and T2WI is shown, respectively. They were composite images, which show the artifact at all angles. (b) (d) The result of measuring the artifact lengths is shown.

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Fig. 7: (a) (b) The artifact at each location in T1WI and T2WI is shown, respectively. They are composite images which show the artifact at all locations.

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Fig. 8: The artifact diameter at each location and in each direction as follows: (a) comparing the artifact diameter in the direction of frequency encoding and disposition in the direction of frequency encoding; (b) comparing the artifact diameter in the direction of phase encoding and disposition in the direction of frequency encoding; (c) comparing the artifact diameter in the direction of frequency encoding and disposition in the direction of phase encoding; and (d) comparing the artifact diameter in the direction of phase encoding and disposition in the direction of phase encoding.
Fig. 9: To calculate the artifact diameter in both high and low intensity region, the half-value width is corrected such as in the example in Fig 9. In the example of the profile, the half-value of the left side is halfway between the highest value of the high signal intensity artifact and the mean value signal intensity of the phantom around the artifact.
Fig. 10: In GRE T1WI and FSE T2WI using a 0.4T MR scanner, the phantom size in the frequency direction (the direction parallel to the magnetostatic field) was accurate (a), but in the phase direction (perpendicular to the magnetostatic field), it was not accurate (b). Therefore, it seems that the artifact diameter in marginal regions such as (b) is shorter than those at the center such as (c) because of the shift.

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\[ \text{SNR} = \frac{S_p}{(N_s / \sqrt{2})} \]

Fig. 11

© [7], [8], [9]
Results

To evaluate and compare artifacts, we selected the slices where the metallic artifacts appeared largest. Fig. 6 on page 17 and Fig. 7 on page 18 show the artifacts in Experiments A and B, respectively. The region around a stainless steel needle electrode causes a loss in signal because ferromagnetic substances disturb the magnetostatic field. In addition, there were also high signal intensity artifacts in the T2WI. In that case, to evaluate regions of both high and low signal intensity artifacts, the calculation of the artifact diameter was corrected as shown in Fig. 9 on page 20.

A. Comparison of metallic artifact at different angle

The minor axis artifact length was highest when the angle of the needle was 90° to the direction of frequency encoding for both T1WI and T2WI (Fig. 6 on page 17). The minor axis lengths were approximately 12 and 7 mm in T1WI and T2WI, respectively. In T2WI, a wraparound artifact at 0° was shown, so that the artifact size was an overestimation. There was not much difference in the major axis of the artifact on T1WI. On the other hands, on T2WI, the artifact's major axis length became longer as the angle was increased. The most commonly expressed reasoning for this phenomena was the shift in frequency encoding direction. The frequency shift made the length shorter and longer at near 0° and near 150°, respectively.

B. Comparison of metallic artifact at different locations

Fig. 8 on page 19 shows the artifact diameter at each location on T1WI and T2WI with the electrode direction parallel with the slice encoding. It seems that there was not much difference in most of the case even when the location was changed. However, the artifact diameter became smaller as the distance from the center of phantom (located in the center of MR gantry) became greater. The reason was the shift in the marginal region in the phase encoding direction. The phantom diameter in the phase encoding direction was shorter than due to the frequency because of it (Fig. 10 on page 21). Therefore, the effect of phase encoding was underestimated and the artifact diameter in marginal regions was also underestimated. It was not important because both the real spatial coordinates and the artifact were similarly distorted. Hence, the artifact diameter in real spatial coordinates was not dependent on the location where the electrode pierced the phantom. In this experimental term, it was important that the metallic artifacts diameter at any locations on T1WI and T2WI were at most 12 and 10 mm, respectively.

C. Variation in SNR

Table 1 on page 17 showed the SNR of the phantom with and without the electrode on both T1WI and T2WI. The mean (SD) of the phantom's SNR at each of 4 locations...
around the electrode on T1WI was 10.9 (0.51), 12.4 (0.43), 11.7 (1.03) and 11.9 (0.95), respectively and without it, the mean (SD) was 11.1 (0.72), 12.7 (0.54), 11.4 (0.40) and 12.6 (0.70). There was no significant difference each location for both T1WI and T2WI (paired t-test, p > 0.05). Therefore, the influence of the electrode on MR images appeared to be in only the local region around the electrode.
### Table 1: Variation of SNR with and without the needle electrode

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<th>NO.</th>
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<th>T1WI without electrode</th>
<th>NO.</th>
<th>T2WI with electrode</th>
<th>T2WI without electrode</th>
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</tr>
<tr>
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<td>0.36</td>
<td>0.58</td>
<td>0.21</td>
<td>0.22</td>
</tr>
</tbody>
</table>
Fig. 6: (a) (c) The artifact at each angle in T1WI and T2WI is shown, respectively. They were composite images, which show the artifact at all angles. (b) (d) The result of measuring the artifact lengths is shown.

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Conclusion

There was no significant difference in the phantom's SNR around the electrode either with or without an electrode present. Therefore, it is considered that any influence on iMR images caused by needle electrodes used for neurophysiological monitoring appear only in the local region around the needle, and that these electrodes do not cause the SNR degradation, which occasionally occurs in clinical iMRI. The metallic artifacts extended to a radius of at most approximately 6 mm and 5 mm on T1WI and T2WI, respectively. These artifacts do not depend on the location where the electrode pierced the phantom. Therefore, the metallic artifacts in clinical iMR images where the patient was pierced with the electrode also extended to a radius of approximately 6 and 5 mm on T1WI and T2WI, respectively. When the electrode pierces the patient's scalp or earlobe, it is believed that the artifact is not large enough to reach the region of cerebral parenchyma. Hence, needle electrodes do not result in adverse clinical effects on iMR images.
Personal Information

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