Development and Validity of Experimental Phantoms to Examine Metallic Artifacts on MRI
- The Effect of Agar on MRI -

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ABSTRACT

The presence of magnetic substances within magnetic resonance imaging (MRI) machines, which possess a uniform magnetostatic field, cause metallic artifacts to appear. In the stomatognathic system, metallic prosthetic devices in the mouth are a source of metallic artifacts and may affect diagnosis. In order to assess the impact of dental alloys on MRI, we devised and manufactured an experimental phantom made of acrylic resin and examined the appearance of metallic artifacts caused by dental alloys. Dental gold alloy objects (cubes and spheres) of equivalent volumes were manufactured and fixed within the phantom with agar dissolved in normal saline solution in order to facilitate detection of metallic artifacts and prevent movement of the objects. This experiment was a preliminary study to determine the impact of agar on MRI. No significant difference in pixel value by the signal intensity of agar was found between the center and peripheral areas for the highest and lowest pixel values by MRI. These results clearly demonstrate that the pixel value based on signal intensity was uniform for the center and peripheral areas in MRI of agar, and suggest that agar dissolved in normal saline solution does not impact MRI.

INTRODUCTION

In magnetic resonance imaging (MRI) machines, which have a uniform magnetostatic field, the presence of magnetic bodies can throw off the uniformity of the magnetic field, leading to artifacts which affect signal intensity [1,2,3,4]. In MRI tests of the stomatognathic region in particular, metallic prosthetics in the mouth can cause the appearance of metallic artifacts. In daily clinical practice, these...
artifacts often make diagnosis difficult or impossible [5,6,7,8,9]. However, only a few studies have addressed the impact that metallic prosthetics have on MRI findings [6,7,10].

In order to understand the impact of dental alloys on MR images, we designed and manufactured experimental phantoms filled with agar dissolved in normal saline. We fixed a metallic object in place inside the phantom to carry out our studies. This current study was a preliminary experiment to determine the validity of the methodology, and in particular, the effect of agar dissolved in normal saline solution on MR imaging and dental alloys.

MATERIALS and METHODS

1 Phantom Production

A 5 mm-thick acrylic resin was used for phantom production. We manufactured a cylindrical 50 mm-high removable, fixed internal phantom with an internal diameter of 90 mm (hereafter “internal phantom”), and a rectangular external phantom (200 mm long, 150 mm wide, and 160 mm tall), that was used to fix the internal phantom in place. (Photograph 1) A 50 mm-high fixed base was installed for the external phantom.

( ) shows the direction in MRI
① Internal phantom
② External phantom

Photograph 1 Experimental Phantom

2 Production and Composition of Dental Alloys Used in Experiment

The metal used in this experiment was the gold metallic alloy used most frequently in dentistry (KIK, produced by Ishifuku Metal Industry, Co. Ltd, Tokyo, Japan). Its composition is as follows: Au 85.5%, Ag 0.5%, Pt 4.0%, Pd 8.0%, other (total of Ir, In, Sn) 2.0%. Information on trace metals contained is not made public for industry reasons.

The alloy is manufactured using a casting method similar to that used in making crown prostheses (the lost-wax casting method) by a single engineer [11]. To avoid mixing foreign substances into the alloy, a vacuum pressure casting machine is used (KDF-Super Cuscom, Denken Corp, Kyoto, Japan). Failed casting attempts were discarded because of the possibility that the alloy composition had changed during the casting.

For the dental alloys, we manufactured 5 cubes and 5 spheres. The cubes were 5 mm long on each side, and the spheres had diameters of 6.204 mm. Both objects had the same volume.

We tested the volume and mass accuracy of the alloys. Three individuals measured the length, width, and height of each alloy cube 5 times each using a digital caliper (Shinwa Rules Co, Ltd, Japan). The averages of these measurements were used to calculate the cube volume. Three researchers measured the diameter of the spheres 5 times each and the sphere volumes were calculated using the average of the diameters measured.

The mass was measured using a LIBORIS EB-330D-A Electronic Balance (Shimadzu Corporation, Japan).

3 MRI Machine and Imaging Conditions

We used a GE Horizon Echo Speed 1.5T MRI machine. For imaging conditions, we selected the Fast Spin Echo method (FSE); T2W1 (TR/TE=4000/102, ETL=20, number of acquisitions=4) from the pulse sequence program, which we use in daily clinical practice.

Imaging is carried out by having a person lie face-up, with the left-right direction fixed within the gantry as the x-axis, the ceiling-floor direction as the y-axis, and the cranial-caudal line as the z-axis. The magnetostatic field direction is the z-axis, the slice gradient magnetic field direction is the y-axis, the frequency encoded magnetic field direction is the z-axis, and the phase encoded gradient magnetic field direction is the x-axis. Imaging in this experiment was of the x-z plane, which clinically is the coronal section when imaging the stomatognathic region. (Table 1)

Ten image slices were taken each time the agar was imaged. We hypothesized that the dental alloy was embedded and fixed in the center of the internal phantom, and we aligned the center of this with
Table 1 MRI Used and Imaging Conditions

<table>
<thead>
<tr>
<th>MRI Machine Used</th>
<th>GE Horizon Echo Speed 1.5T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse sequence</td>
<td>TR</td>
</tr>
<tr>
<td>Fast Spin Echo T2 Weighted Image</td>
<td>4000</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>20.83 kHZ</td>
</tr>
<tr>
<td>Field of View</td>
<td>16 x 16 cm</td>
</tr>
<tr>
<td>Slice thickness/direction</td>
<td>2.0 mm/X-Z plane</td>
</tr>
<tr>
<td>Spacing</td>
<td>0 mm (gapless)</td>
</tr>
<tr>
<td>Matrix size</td>
<td>256 x 256</td>
</tr>
<tr>
<td>Magnetostatic field direction</td>
<td>Z axis dir.</td>
</tr>
<tr>
<td>Slice gradient magnetic field</td>
<td>Y axis dir.</td>
</tr>
<tr>
<td>Frequency encoded gradient magnetic field</td>
<td>Z axis dir.</td>
</tr>
<tr>
<td>Phase encoded gradient magnetic field</td>
<td>X axis dir.</td>
</tr>
<tr>
<td>Head coil used</td>
<td>GE Quadrature type</td>
</tr>
</tbody>
</table>

the center of the slice. In other words, we aligned the core of the internal phantom (22.5 mm from the bottom) with the center of the slice when imaging.

Agar Adjustment and Phantom Placement

In order to fix the alloy within the internal phantom, we used agar dissolved in normal saline solution. We filled the internal phantom with 4.0 g of powdered agar dissolved in 650 ml of normal saline solution, and set it within the external phantom. The external phantom's major axis was made to conform to the MRI machine's z-axis, the minor axis with the machine's x-axis, and the height with the machine's y-axis. In order to ensure that the isocenter matched the internal phantom's center, the phantom was also fixed to the headrest using a Velcro belt during imaging.

5 Method of Processing MRI of Agar

The method used to process the MRI of agar is shown in Figure 1. Agar MRI were transferred to the image server and saved. Next the images were

![Diagram](image)

Figure 1 Agar MR Image Processing Method
processed by the AMIN Work Station, converted to bmp files, and saved in DVD-RAM. Saved images were then converted to TIFF files using Adobe Photoshop 5.0.2 (Adobe Systems, Tokyo, Japan) installed on an iMac.

6 Analysis of Agar MRI

The pixel value of the agar signal intensity in the agar MRI converted to TIFF file format was measured using NIH image version 1.62 (U.S. National Institutes of Health).

Each pixel of MRI that appeared to be uniform when checked visually had different pixel values. Therefore, we studied differences in signal intensity of various regions of the agar. Of the ten agar MRI taken, we used the fifth image, for which it was possible to assume with certainty that the alloy was included. The radius of the agar was 45 mm, and we treated the area in a radius half that size (22.5 mm) as the center and the region outside of that as the periphery for measuring the signal intensity pixel value. To measure the signal intensity pixel values, we set up a square-shaped area of interest 5 mm on one side, the same as the cross-sectional area of the cube alloy. In both the center and the periphery, 25 places were selected randomly (the largest number that could be identified without overlapping the areas of interest), and the signal intensity pixel value was measured (Photograph 2). The highest pixel value in the area of interest (the whitest image) and the lowest pixel value (the blackest image) were calculated, and comparing these made it possible to display the MRI's uniformity as a numerical value. By doing so, we obtained the largest and smallest pixel values in the center and periphery.

We then studied whether or not it was possible to uniformly detect images of just the agar using the MRI pixel value. If it was possible to measure the pixel value of agar MRI and uniformly identify the agar portion, it would be possible to capture metallic artifacts caused by the alloy.

In images that we hypothesized contained the alloy, 50 places (the largest number that could be identified without overlapping the area of interest in the periphery) of the agar portion in the periphery outside the 22.5 mm center radius were randomly selected and the pixel values were measured. The average of the largest pixel values measured and the average of the smallest pixel values measured were calculated (both rounded up after the decimal point) and the signal intensity pixel value included in this range was set as the agar signal intensity pixel value. Images with pixel values greater than the highest agar pixel value and lower than the lowest agar pixel value were detected, allowing detection of the agar portion.

7 Statistical Analysis

We used the Student's t-test (p<0.05) to analyze the comparison of the dental alloy volumes and masses, and the comparison of the signal intensities of the MRI of agar.

RESULTS

1 Dental Alloy Volume and Mass (Tables 2 and 3)

The average volume of the cubes manufactured was $125.11\pm0.317 \text{ mm}^3$ and the average mass was $2.20\pm0.040 \text{ g}$. The average volume of the spheres was $124.97\pm0.370 \text{ mm}^3$ and the average mass was $2.21\pm0.044 \text{ g}$. No significant difference was ob-

Table 2 Dental Alloy Volume

<table>
<thead>
<tr>
<th>Tester</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cube 1</td>
<td>125.00±0.000</td>
<td>125.18±0.440</td>
<td>124.99±0.043</td>
</tr>
<tr>
<td>Cube 2</td>
<td>125.14±0.474</td>
<td>125.13±0.328</td>
<td>125.14±0.474</td>
</tr>
<tr>
<td>Cube 3</td>
<td>125.34±0.471</td>
<td>125.14±0.322</td>
<td>125.00±0.000</td>
</tr>
<tr>
<td>Cube 4</td>
<td>125.00±0.177</td>
<td>125.14±0.321</td>
<td>125.19±0.313</td>
</tr>
<tr>
<td>Cube 5</td>
<td>124.99±0.022</td>
<td>125.19±0.312</td>
<td>125.05±0.112</td>
</tr>
</tbody>
</table>

(mean ± S.D. n=5)

Table 3 Dental Alloy Mass

<table>
<thead>
<tr>
<th>Alloy</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>mean ± S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cube</td>
<td>2.27</td>
<td>2.17</td>
<td>2.21</td>
<td>2.19</td>
<td>2.18</td>
<td>2.20±0.040</td>
</tr>
<tr>
<td>Sphere</td>
<td>2.28</td>
<td>2.23</td>
<td>2.21</td>
<td>2.18</td>
<td>2.17</td>
<td>2.21±0.044</td>
</tr>
</tbody>
</table>
served between the volumes of the cubes and spheres (p=0.29), or the mass of the cubes and spheres (p=0.72).

2 Pixel Value of Signal Intensity in Agar

In the agar, the lowest signal intensity pixel value was 35.7±4.00 in the center and 36.3±3.37 in the periphery, with no significant difference between them (p=0.57; Figure 2). The agar’s highest signal intensity pixel value was 60.4±3.40 in the center and 60.8±4.07 in the periphery, with no significant difference between them (p=0.68; Figure 2).

The above results suggest that the agar’s signal intensity pixel value in MR images was uniform in the center and periphery.

In addition, the lowest pixel value in the periphery was 36.0±3.67, and the highest value was 60.6±3.72. This clearly showed that it was possible to detect images uniformly when analyzing MRI of agar based on pixel value (Photograph 3-1, 2).

DISCUSSION

As there was no significant difference in volume or mass of the dental alloy objects used in this experiment (5 cubes and 5 spheres), we concluded that it is valid to compare the metallic artifacts created using these objects.

Phantoms are used to evaluate image quality of MRI machines. An important condition of phantoms is that they do not affect MRI. Materials that generate a uniform signal, such as acrylics, are used for phantoms [4]. Therefore, we manufactured and used acrylic phantoms for the present study. Solutions used to fill the inside of phantoms include cupric sulphate, manganese chloride, Ni (NO₃)₂, and agar [6,12,13]. Hayes et al. employed a method in which NaCl is dissolved in solution in order to obtain electrical conductivity equivalent to that of the human body [12]. Ishigami et al. previously reported that because the agar that fills the phantom is uniform, even slight changes in the image can be read as artifacts [14]. Furthermore, it is impossible to fix the position of a metallic alloy in an aqueous solution. Given these reports, we used an acrylic phantom filled with agar. We used agar dissolved in normal saline solution to embed the
alloy object and study the impact the agar itself would have on MRI. To determine whether it was possible to uniformly detect the images of agar without an embedded alloy, we performed imaging under the same conditions as this experiment. We found no significant difference in the agar signal intensity pixel value between the center and periphery, and demonstrated that the MRI were uniform in these areas. Furthermore, we could detect the agar uniformly in MRI based on pixel values obtained only in the periphery. From this, we conclude that it would be possible to detect differences in the image’s signal intensity pixel value by measuring the signal strength pixel value of the agar periphery even in phantoms with an alloy object embedded within agar.

These results clarify that when imaging an alloy embedded in agar, the agar itself has no effect on the MRI. Thus, we think that the research method used in this study is valid.

**CONCLUSIONS**

In order to study the appearance of MRI metallic artifacts caused by dental alloys experimentally, we designed an experiment to investigate the appearance of metallic artifacts by embedding an alloy object in agar dissolved in normal saline. Prior to this experiment, we conducted a preliminary experiment to study the precision of alloy objects and the effect of the agar itself, which would be used to embed an alloy object when dissolved in saline solution, on MRI. We obtained the following results:

1. There was no significant difference in volume or mass between the alloy cubes and spheres.
2. The agar dissolved in normal saline solution had no impact on MR images.

Based on these results, we can conclude that the use of dental alloys or agar dissolved in normal saline solution is not problematic for fixing the position of dental alloys within a phantom.

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**REFERENCES**


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