An Experimental Study of the Appearance of Metallic Artifacts on MRI
-Artifacts Caused by Dental Alloys-

Hiroshi TAKEISHI¹, Masashi SHIMAHARA² and Yasunori ARIYOSHI²

1 Division of Dentistry and Oral Surgery, Hirakata Municipal Hospital,
Hirakata-city, Osaka 573-1013, Japan
2 Department of Dentistry and Oral Surgery,
Division of Medicine for Function and Morphology of Sensory Organs,
Osaka Medical College, Takatsuki-city, Osaka 569-8686, Japan

Key words: MRI, metallic artifacts, dental alloys, image processing,
metallic artifact surface area

ABSTRACT

Cubes and spheres made from dental alloys and an experimental phantom were used to assess
the impact of dental alloys on MRI and to examine the appearance of metallic artifacts on MRI. Prior
to MRI, dental alloy objects were fixed in place within the experimental phantom using agar.
Through MRI, we visually evaluated metallic artifacts prior to image processing, quantitatively
evaluated metallic artifacts after image processing, and compared the surface area of metallic arti-
facts before and after image processing. When evaluated visually and after image processing, dif-
ferent alloy shapes resulted in different artifact shapes; however, the area of artifact appearance was
similar regardless of alloy shape. No significant difference was found in the surface area of metallic
artifacts identified visually, regardless of differences in the shape of alloy objects. After image pro-
cessing, the surface area of metallic artifacts caused by cubes was found to be significantly larger
than that caused by spheres. When surface area was compared before and after image processing,
metallic artifacts were significantly larger after image processing. These results suggest that with
MRI, signal intensity is affected by metallic artifacts even when they cannot be visually identified.

INTRODUCTION

From a previous investigation which examined the possibility of using magnetic resonance imaging
(MRI) to detect squamous cell carcinoma of the tongue, we reported that dental prostheses or fill-
ings might cause metallic artifacts that could be mistaken for lesions in T1 weighted MRI [1]. To test
this, we studied the appearance of dental metal arti-
facts using panoramic images from MRI taken
during the course of clinical practice. This con-
firmed that the effect of metallic artifacts on imag-
ing differs based on the quantity, shape, and point of attachment of metal prostheses [2].

To investigate the impact of dental metals on MRI in more detail, we manufactured dental alloys and studied the appearance of metallic artifacts.

MATERIALS and METHODS

1 Experimental Phantoms and Dental Alloy Objects

We used acrylic resin to manufacture a rectangular external phantom and a cylindrical internal phantom for use in the imaging studies. We used dental alloys to manufacture 5 cubes and 5 spheres, all with the same volume. The cubes were 5 mm long on each side and the spheres had diameters of 6.204 mm [3].

2 Method of Fixing the Position of Dental Alloys

We filled the internal phantom with a solution of 4.0 g powdered agar dissolved in 650 ml normal saline (hereafter “agar”) and embedded the dental alloy object in the center. The position of the alloy object was fixed by filling the internal phantom with agar to a height of 22.5 mm and allowing it to harden, setting the alloy object in the center, and then filling the remainder of the internal phantom with agar. For the alloy cubes, the internal phantom was placed within the external phantom in such a way that the sides of the cubes were parallel to the sides, top and bottom of the external phantom. Once the internal phantom with the alloy object was fixed within the external phantom, we placed them within the MRI machine in the same way as in the preliminary experiment and ensured that the isocenter matched the center of the alloy object [3].

3 MRI Machine and Imaging Conditions

The same MRI machine and imaging conditions used for the preliminary experiment were used here. Briefly, we used a GE Horizon Echo Speed 1.5T MRI machine for the imaging studies. For imaging conditions, we used the Fast Spin Echo method (FSE):T2W1 (TR/TE=4000/102, ETL=20, number of additions=4) from the pulse sequence program [3].

Ten image slices were taken each time the phantom was imaged. We aligned the center of the slice with the center of the alloy object. Thus, slices 4, 5, 6, and 7 would include the alloy object (Figure 1). Each alloy object was scanned three times.

4 Method of Image Processing

MR images were processed according to the methodology used in the preliminary experiment [3]. MR images as DICOM data were converted to TIFF files with AMIN Work Station (M900/TXA, Ziosoft Inc., Tokyo, Japan) and iMac (Mac OS9.2, Apple).

CATEGORIES for OBSERVATION

1 Visual Evaluation of Metallic Artifacts Prior to Image Processing

For visual evaluation of the images, the MRI were displayed on a monitor (EIZO, 18.1 inch, resolution: SXGA, pixel count: 1280×1024 dpi, Ishikawa Prefecture, Japan) connected to the Work Station. In the MRI displayed on the monitor, the area surrounding the alloy object clearly had a different signal intensity from that of uniform agar and was considered to be a metallic artifact. Visual evaluation was performed independently by 3 people (each with at least five years of clinical experience as an oral surgeon), and we deemed the findings valid when the evaluations of at least 2 researchers matched.

We used freehand tools to extract the metallic artifacts found in MRI processed using NIH image version 1.62 with the Work Station. We calculated the surface area of the visually-identified metallic artifacts and compared the surface areas of artifacts between the cubes and spheres.

We calculated the surface area three times for each image, and the average of these was used as the surface area of each metallic artifact.

2 Quantitative Analysis of Metallic Artifacts after Image Processing

Metallic artifacts in MR images occur as dis-
torted images or abnormal signals as the magnetic field space becomes warped [4]. A few studies have reported distorted image size and shape [5-9]. Yet, no studies have conducted digital image processing of digitized MRI and carried out quantitative evaluation of abnormal signals. By identifying the pixel values of digitized MRI displaying normal signal intensities, it was possible to detect the pixel values of images exhibiting abnormal signals. Therefore, this study identified abnormal signals by conducting digital image processing of the MRI. The method is outlined below.

For the MR imaging, we established a 5 mm x 5 mm square area of interest in the outermost portion of the image, which corresponds to the portion of agar that does not contain the alloy object, and for which no artifacts were identified visually (hereafter “images of the agar portion”). We randomly extracted 50 places, and measured the signal intensity pixel values for the images of the agar portion using NIH image software. The signal intensity pixel values of the agar portion included all pixel values measured in these 50 squares that fell between the highest pixel value (the image portion appearing whitest) and the lowest pixel value (the image portion appearing blackest). In addition, we identified areas of the image corresponding to the alloy object and its surroundings that were clearly different from images of the agar. These areas had signal intensity pixel values above or below that of the agar portion, and both were deemed metallic artifacts. We then examined differences between the shapes of metallic artifacts arising from the cubes compared to the spheres. Identification of metallic artifacts was performed 3 times for each image. We measured the surface area of each metallic artifact three times in the same image and used the average as the surface area of the metallic artifact for that image. Using these results, we then compared the surface areas of metallic artifacts between cubes and spheres.

3 Comparison of the Surface Areas of Metallic Artifacts Prior to and After Image Processing

We compared the surface areas of metallic artifacts identified visually in MRI prior to image processing with the surface areas of metallic artifacts found in MRI after image processing. In other words, we compared the surface areas of the metallic artifacts identified in Category for Observation 1 and Category for Observation 2.

4 Method of Statistical Analysis

We used the Student’s t-test for statistical analysis of the surface areas of metallic artifacts identified visually. We used the unpaired t-test (Welch’s t-test) for statistical analysis of the surface areas of metallic artifacts after image processing. We used Mann-Whitney’s U-test to compare the metallic artifacts prior to and after image processing. P<0.05 was set as the level of significance for all tests.

RESULTS

The pattern of metallic artifact appearance was the same for all five dental alloy cubes and five dental alloy spheres. Furthermore, after image processing, the metallic artifact appeared larger in the fifth of the 10 image slices than in any other slice for both cubes and spheres (Figure 2). Therefore,

![Figure 2](image_url)  
**Figure 2** Comparison of All Metallic Artifact Surface Areas After Image Processing

*Bulletin of the Osaka Medical College* 55 (1) : 45-54, 2009
when we compared the metallic artifacts, we compared the fifth slices, where the surface areas of the metallic artifacts appeared largest.

1 Visual Evaluation of Metallic Artifacts Prior to Image Processing

The appearance of metallic artifacts displayed on monitors connected to the Work Station showed a uniform pattern for all alloy objects. Every metallic artifact displayed a low-signal domain for the alloy object, high-signal and low-signal domains in the frequency direction centered around the alloy, and a low-signal domain in the phase direction. The shape of the metallic artifact differed between cubes and spheres; the metallic artifact was square in the alloy portion for cubes and triangular in the alloy portion for spheres. Yet, when the metallic artifact was extracted visually using the freehand tools of NIH image, the area in which the metallic artifact appeared was similar for both cubes and spheres (Photograph 1). Thus, it was clear that while the shape of the metallic artifact prior to image processing was affected by differences in the shape of the alloy object, the area of where the artifact appeared was not. The average surface area of metallic artifacts prior to image processing was 136±6.82 mm² for cubes and 135.3±7.49 mm² for spheres. Although the artifacts appeared larger with cubes, we found no statistically significant difference in the size of metallic artifacts between cubes and spheres (Student's t-test p=0.60; Figure 3).

2 Quantitative Analysis of Metallic Artifacts after Image Processing

Using NIH image, we detected metallic artifacts in the alloy area and in the agar portion surrounding the alloy with signal intensity pixel values outside the range of the uniform agar. After image processing, the shape of the metallic artifacts for the alloy cubes exhibited large protruding areas compared to the shape for alloy spheres (Photograph 2). However, the area of artifact appearance spreading out around the alloy object was similar in both cubes and spheres. As with the shape of metallic artifacts prior to image processing, the shape of metallic artifacts after image processing was affected by differences in the shape of the alloy objects, but we observed no difference in the area of appearance of the metallic artifacts.

The average surface area of metallic artifacts after image processing was 213.0±34.42 mm² for cubes and 190.4±19.49 mm² for spheres, and thus the surface area of metallic artifacts appeared larger for cubes. We found that the metallic artifacts were significantly larger in cubes relative to those in spheres using the unpaired t-test (Welch's

For both cubes and spheres, the portion with the alloy object had a low signal, with high- and low-signal areas spreading out from the alloy object in the frequency direction and low-signal areas in the phase direction.

The shape of the metallic artifact in the alloy portion of the image was square for cubes and triangular for spheres, but appeared in similar areas for both when extracted) using the freehand tools in NIH image (black line).

Photograph 1 Metallic Artifact Shapes from Cubes and Spheres Before Image Processing
An experimental study of the appearance of metallic artifacts on MRI

Figure 3  Comparison of the Average Surface Areas of Metallic Artifacts from Cubes and Spheres Identified Visually Before Image Processing

Compared to metallic artifacts in spheres, the shape of metallic artifacts in cubes was larger and had protruding areas (arrow). The area of the metallic artifact spreading out from around the alloy object was similar in cubes and spheres.

Photograph 2  Metallic Artifact Shapes from Cubes and Spheres After Image Processing

3 Comparison of Metallic Artifact Surface Area Before and After Image Processing

We compared the surface areas of the metallic artifacts identified visually with that of the metallic artifacts measured quantitatively and found that the metallic artifact found through image processing appeared larger in both cubes and spheres. The average surface area of the metallic artifacts in cubes was $136.6 \pm 6.82 \text{ mm}^2$ prior to image processing and $213.0 \pm 34.42 \text{ mm}^2$ after image processing. The average surface area of the metallic artifacts in spheres before image processing was $135.3 \pm 7.49 \text{ mm}^2$, while after image processing the average surface area of the metallic artifact was...
190.4 ± 19.49 mm$^2$. These differences were significant (Mann-Whitney’s U-test, p<0.05) for both cubes and spheres, and thus the surface area of metallic artifacts after image processing was significantly larger. In short, even in the area where metallic artifacts could not be observed visually on the MRI, metallic artifacts were affecting the signal intensity (Figure 5).

**DISCUSSION**

It has been previously reported that dental alloys, which contain ferromagnetic material, can cause metallic artifacts on MRI [10, 11]. Hinshaw et al. have reported that metallic artifacts caused by stainless steel are strongest [5] while Keyvan et al. reported that dental gold alloys caused the largest artifacts among all metals used in dentistry [6]. In
short, various reports exist on the relationship between the type of metal and MRI artifacts.

Generally, metallic artifacts are said to appear because the existence of magnetic material disrupts the magnetic field inside the MRI machine [6, 12]. Among the basic properties of metals are electric properties and magnetic properties [13, 14]. When MR imaging begins, the gradient magnetic field is alternated at high speed in order to form the image. If metals, which are good electrical conductors, are present during imaging, eddy currents are created that distort the local magnetic field and cause artifacts [15, 16]. Furthermore, when magnetic objects (including metals) are present within the magnetic field, magnetic flux changes occur [17] which can result in the appearance of artifacts. Alloys are metallic and because they are magnetic, they have both electrical and magnetic properties. Even the dental gold alloys used in this experiment (which do not contain ferromagnetic material) caused eddy currents and magnetic flux changes, which in turn caused a distortion of the local magnetic field. Although there were some differences in shape and size, metallic artifacts occurred in every case.

1 Visual Changes in Metallic Artifacts Prior to Image Processing

While there have been reports concerning metallic artifacts in low-field MRI machines and high-field MRI machines using the Spin Echo (SE) method, there have been very few comparative studies of metallic artifacts appearing in high-field MRI machines using the FSE method [18, 19]. Because the images obtained from an MRI machine differ based on the scanning method and parameters, as well as the intensity of the magnetostatic field, comparing different machines is thought to be very difficult [20, 21]. Therefore, this experiment used just one MRI machine.

Metallic artifacts are reported to appear as a decline in signal around the magnetic object due to the non-uniformity of the local magnetic field, as well as increased signal intensity and image distortion observed in the boundary area [21-23]. In this study, the metallic artifacts for both cubes and spheres appeared prior to image processing as a decrease in signal (low-signal area) and increase in signal (high-signal area) in the frequency direction centered around the alloy, and a decrease in signal in the phase direction. Thus, the results were similar to previous reports. However, we observed differences in the shapes of the metallic artifacts as a result of differences in the shapes of the alloy objects. This clearly demonstrates that alloys are magnetic substances, and for magnetic substances, magnetization differs depending on shape and size [24]. Because the conditions for magnetization varies between cubes and spheres, we think that this also gave rise to differences in the shapes of metallic artifacts. With alloys that contain ferromagnetic substances, extensive metallic artifacts appear, and thus the degree of correlation between ferromagnetic substances and MRI metallic artifacts is thought to be high [10, 25]. We did not observe widespread metallic artifacts in this study because we used gold alloys that did not contain ferromagnetic substances.

2 Comparison of Metallic Artifacts after Image Processing

Signal intensity is of great importance when making diagnoses based on MRI [26]. In terms of foundational studies, the capacity to see minute changes in signal intensity by carrying out image processing is considered significant. Therefore, we attempted to view metallic artifacts not simply as distortions, but also use image processing to study differences in signal intensity. The MRI used in this study were stored on the server as digital graphic information. By performing image analysis on the MRIs and measuring the pixel values, we were able to quantitatively identify pixel values associated with abnormal signals. In other words, image processing made it possible to identify the minute details of metallic artifacts.

In a preliminary experiment processing MR images of agar alone (no alloy objects embedded) we were able to detect the agar portion uniformly [3]. Therefore, we concluded that it would be valid to use the same image processing method to identify and study metallic artifacts in MRI of alloy objects embedded in agar.

There have been reports that the gold alloys used in this experiment rarely cause metallic artifacts, or that the artifacts cannot be seen [10, 22, 25, 27]. However, our results differed from these reports, as we did observe metallic artifacts. The differences may be due to both the use of agar to fix the alloy objects in place and the image processing method. It has been reported that phatoms using agar make it possible to detect even small distortions of the image as artifacts and allow analysis in great detail [28]. Furthermore, as phatoms using agar fix the alloy object in place, it is possible to prevent artifacts caused by slight movements. This makes it possible to identify only the artifacts caused by the alloy object. Therefore, we think that we were able to detect metallic artifacts by using agar to perceive even small changes in the image.
and to prevent the alloy object's movement. In addition, we not only considered image distortions as metallic artifacts, but also comprehensively studied decreases and increases in signal intensity in the image around the alloy object. We think that conducting image processing of the MRI made it possible to detect even slight changes in signal intensity around the alloy object. We found differences when comparing the shapes of metallic artifacts of alloy cubes with those of spheres after image processing. As magnetization of the same metal differs according to shape, it has been reported that there are various ways that metallic artifacts might appear [7, 23, 24, 29, 30]. We think that differences in the shape of the alloy objects changed the magnetization, resulting in differences in the shape of metallic artifacts identified in detail after image processing.

3 Consideration of the Size of Metallic Artifacts

We found very little difference in the size of metallic artifacts identified visually between cubes and spheres prior to image processing. We think that this is because the specimens were alloys that did not contain ferromagnetic material, and thus large distortions of the image were not observed. Thus, differences in the shape of the alloy objects had little impact on the size of the metallic artifacts when observed visually. In contrast, we did find a difference in the size of metallic artifacts in MRIs after image processing when the shape of the alloy differed. We think that image processing made it possible to perceive small changes in the pattern of magnetization due to differences in the shape of the alloy objects. The surface area of metallic artifacts for cubes probably appeared larger than that for spheres due to a large disturbance in the magnetic field at the cubes' corners.

When comparing metallic artifacts before and after image processing, we found that the surface areas of the metallic artifacts were significantly larger after image processing for both cubes and spheres. We think that this is because there is a threshold below which changes cannot be perceived visually. Thus, even though changes in the magnetic field large enough to affect the appearance of the artifact may not have occurred, image processing may reveal that visually unperceivable changes in the magnetic field actually occurred.

From these results, it is clear that while the presence of alloy objects only causes slight distortions in MRI that can be detected visually, the signal intensity of images studied closely can be affected significantly. Our study also shows that differences in the shape of alloy objects impact the shape of metallic artifacts. Therefore, one must always keep in mind the presence of metal prostheses in the mouth that cause metallic artifacts in the interpretation and diagnoses of MRIs of the stomatognathic region.

CONCLUSION

1 Observation of Metallic Artifacts Prior to Image Processing

The portion of the image containing the alloy object had a low signal, with high-signal and low-signal areas spreading out from the alloy object in the frequency direction, and low-signal areas in the phase direction. The appearance of metallic artifacts was affected by the shape of the alloy object.

2 Observation of Metallic Artifacts after Image Processing

The area of appearance of metallic artifacts caused by cubes and spheres was similar, but we observed differences in the shapes of the artifacts. Metallic artifacts in cubes had protruding areas and were larger than the metallic artifacts caused by spheres.

3 Comparison of Metallic Artifact Surface Area

During visual observation prior to image processing, there was no significant difference in how the shape of the alloy object affected the surface area of metallic artifacts. During quantitative observation following image processing, we observed a difference in how the shape of alloy objects affected the shape and surface area of metallic artifacts. Furthermore, we observed a statistically significant difference between the size of metallic artifacts before and after image processing. In short, metallic artifacts are identified in greater detail by performing image processing, revealing that metallic artifacts are detected in areas that are not visually perceptible.

ACKNOWLEDGEMENTS

We thank many Radiologists at the Osaka Medical College Department of Radiology for their assistance.

REFERENCES


Bulletin of the Osaka Medical College 55 (1) : 45-54, 2009
cancer: comparison of lesion detectability between magnetic resonance imaging and computed tomography. JSOMS 1999;45:482-90.


28. Ishigami T, Naitoh M, Tanaka Y, Miyata H,


Received December 1, 2008
Accepted December 22, 2008