Magnetic resonance imaging and aneurysm clips

Magnetic properties and image artifacts

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The magnetic properties of 12 different types of aneurysm clip were investigated in order to identify which clips allow postoperative magnetic resonance (MR) imaging without risk. Clip-induced MR artifacts were also quantitatively studied using a geometrical phantom. Nonferromagnetic aneurysm clips like the Yasargil Phynox, Sugita Eligloy, and Vari-Angle McFadden clips do not appear to contraindicate MR studies performed with a FONAR β-3000M imager. There is no clip movement upon introduction of the phantom into the MR imager, and the image artifacts caused by the clips are so limited that patients harboring such clips may well be considered for MR imaging. This examination may reveal information not obtainable by any other radiological modality.

KEY WORDS □ aneurysm clip □ microvascular clip □ metallic composition □ magnetic field □ magnetic resonance imaging □ image artifacts

MODERN aneurysm surgery almost invariably involves occlusion of the neck of the ruptured aneurysm by a metal clip. In the postoperative course, computerized tomography (CT) is frequently performed. However, CT may provide insufficient information on more subtle white matter lesions of the brain, and metal clips cause pronounced beam-hardening artifacts. In the last decade, magnetic resonance (MR) imaging has been heralded as one of the greatest neurodiagnostic advances because of its ability to visualize white matter abnormalities. At some centers, liability concerns dictate the policy that patients with a history of cerebral aneurysm surgery should be excluded from consideration for MR imaging. In 1983, New and coworkers presented a study on potential hazards and artifacts of ferromagnetic and nonferromagnetic aneurysm clips in MR imaging. The present study was undertaken to investigate the magnetic properties of different aneurysm clips so as to identify which clips allow postoperative MR investigation without risk. In addition, clip-induced MR artifacts were quantitatively studied using a geometrical phantom.

Historical Background and Metallurgical Considerations

Aneurysm Clip Development

In 1910, Harvey Cushing added immeasurably to brain-tumor surgery when he introduced the silver clip "for the occlusion of vessels inaccessible to the ligature." Twenty-seven years later Walter Dandy was able to clip the neck of an internal carotid artery aneurysm using a modification of the original Cushing clip described by McKenzie. In 1966, Scoville described his miniature torsion bar spring aneurysm clip made of stainless steel, and 5 years later Mayfield and Kees described a clip for permanent occlusion of aneurysms. Today, the most frequently used clips are probably those designed by Yasargil, Sugita, et al., and McFadden.

Metallurgical Considerations

Freedom from corrosion is the prime requirement for a material suitable for biological implantation. Stainless steel, characterized by its structure and its
MR imaging and aneurysm clips

TABLE 1
Composition of commonly used aneurysm clips*

<table>
<thead>
<tr>
<th>Aneurysm Clips</th>
<th>Steel Types</th>
<th>Alloy Material (%)</th>
<th>Cr</th>
<th>Ni</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Mo</th>
<th>Co</th>
<th>Fe</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake</td>
<td>301</td>
<td>16-18  6-8  0.15</td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mayfield</td>
<td>201</td>
<td>16-18  6-8  0.15</td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heifetz†</td>
<td>17-7PH</td>
<td>17     7   0.01</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
<td>rest</td>
<td>1.0 Al</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scoville</td>
<td>EN-58J</td>
<td>16-17  9-10 0.2</td>
<td>0.5</td>
<td>3</td>
<td></td>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yapargil</td>
<td>316</td>
<td>16-18  10-14 0.03</td>
<td>2.0</td>
<td>1.0</td>
<td></td>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>McFadden Vari-Angle</td>
<td>MP-35-N</td>
<td>19-21  33-37 0.025</td>
<td>0.15</td>
<td>0.15</td>
<td>9-10.5</td>
<td>rest</td>
<td>1.0 Ti</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yapargil Phynox</td>
<td>Phynox</td>
<td>18.5-21.5 15-18 &lt;0.15</td>
<td>1-2</td>
<td>6.5-7.5</td>
<td>39-42</td>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugita</td>
<td>Eligloy</td>
<td>19-21  14-16 &lt;0.15</td>
<td>1.5-2.5</td>
<td>6-8</td>
<td>39-41</td>
<td>rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Modified from the report of New, et al.† The first four clips in the column, which are ferromagnetic, contain < 10% Ni and approximately 70% Fe. The last three clips in the column contain > 15% Ni and 35% to 40% Co and are nonferromagnetic. The Vari-Angle McFadden clip also contains 1% Ti.
† The Heifetz clip, which is composed of Elgiloy steel, was not investigated.

magnetic properties, is classified into martensitic (ferromagnetic) or austenitic (nonferromagnetic) types. The fraction of martensite in a given implant will determine the degree of its ferromagnetism and hence the extent by which it will be affected by a magnetic field. Clips manufactured of martensitic stainless steel, such as the Mayfield and Heifetz 17-7PH alloy clips, are quite sensitive to magnetic flux, while many modern aneurysm clips are constructed of austenitic steel, resist corrosion, and are nonferromagnetic. Cobalt-based superalloys are a viable alternative to ordinary stainless steel for integral spring clips. These materials are very resistant to corrosion and are nonferromagnetic. Commonly used aneurysm clips like the Sugita Eligloy, Yapargil Phynox, and Vari-Angle McFadden models are made of such alloys. Tantalum and titanium exhibit high resistance to corrosion. Although these metals are too soft to be used in spring clips, they can be used for malleable clips. The demands upon aneurysm clips of today are not only that they must be corrosion-resistant and have a reliable holding force but also that they should be nonferromagnetic.

Materials and Methods
Investigation of Magnetic Properties

Relevant data concerning the composition, size, and weight of the clips studied are shown in Tables 1 and 2. The equipment used to measure magnetic properties (the martensitic component or the ability to be magnetized) was originally constructed to study the magnetic fields from biological samples (L Andersson, et al., unpublished data). The clips were separately put into small nonmagnetic plastic tubes and fixed in position with paraffin, then magnetized by an electromagnet with a magnetic field strength of 0.2 tesla (2000 gauss) for approximately 0.1 second. The remaining magnetization (that is, the magnetic remanence) was measured three times with a sensitive flux-gate magnetometer with de- and remagnetization before each reading. Clip movement due to magnetic forces was investigated by exposing clips, placed on a cardboard sheet, to the magnetic field of a 0.3-tesla MR imager.

Investigation of MR Image Artifacts

In order to study the image artifact caused by the clips, a geometrical phantom consisting of 25 cubic cavities with a side length of 20 mm each was used. The walls between the cavities were 8 mm thick and made of acetal plastic, which has very stable dimensions. Also, its magnetic properties are such that the MR image is not disturbed. To fix the clips in position in the phantom, a small plastic bar was fitted into one cavity. Figure 1 shows the phantom with a Drake clip in the center cavity. The phantom, which in itself does not give any MR signal, was put in a Lucite box filled with a 0.2-mM Mn++ water solution (which has relaxation times similar to brain tissue).

All MR examinations were performed on a 0.3-tesla
(3000 gauss) FONAR β-3000M imaging system* with a vertical magnetic field. Clip-induced artifacts were studied using three sequences: one spin-echo sequence with TR = 500 msec and TE = 28 msec; one gradient-echo sequence with TR = 500 msec and TE = 12 msec; and one inversion recovery sequence with TR = 700 msec, TI = 200 msec, and TE = 28 msec. Scan times were approximately 4 minutes, and for image reconstruction a two-dimensional Fourier transformation was employed. The matrix size was 256 × 256 pixels, the field of view was 256 × 256 sq mm, and the slice thickness was 5 mm. The phantom with the different clips was scanned in axial, coronal, and sagittal projections.

For comparison of image artifacts caused by different clips, we measured the effects of metal clips on an MR image at two distances. The first was the greatest distance from the edge of the clip to the rim of the distorted part of the phantom where no meaningful information was obtainable. The second distance (for ferromagnetic clips) was the greatest distance from the clip to the part of the phantom where distortion can be identified (> 2 mm).

Results

Magnetic Properties

The magnetic remanence (the remaining magnetization) in arbitrary units for each clip is given in Table 2. The values given are mean values of three measurements. The remanence was confined to the clips, since it could not be detected from tubes containing only paraffin. The four clips showing magnetic remanence exhibited considerable motion upon introduction to the magnetic field of the imager. The gold-plated Sugita clip rotated around its axis on the cardboard sheet but did not move toward the imager.

An easy way to determine whether aneurysm clips are ferromagnetic or not is to test them with a small permanent magnet. Ferromagnetic clips can be lifted or dragged, whereas nonferromagnetic ones do not react to the small magnet. The results of this simple test were in agreement with the magnetic remanence measurements.

Kelly* and Dujovny and coworkers* have pointed to the possibility that certain metal alloys may acquire ferromagnetic properties after tooling. However, we were not able to detect any increased magnetism despite intense handling and tooling of the nonferromagnetic clips.

MR Image Artifacts

The MR artifacts were slightly larger in the axial and sagittal projections, and hence the distances were determined from these projections. Images made with gradient-echo sequences contained less information than images where the signal echo was obtained with a 180°

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* FONAR β-3000M imaging system manufactured by FONAR Corp., Melville, New York.

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### TABLE 2

<table>
<thead>
<tr>
<th>Aneurysm Clips</th>
<th>Size (mm)</th>
<th>Weight (mg)</th>
<th>Magnetic Remanence (mm)</th>
<th>Image Distortion (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake DR 12</td>
<td>25 x 4</td>
<td>467</td>
<td>100 ± 1</td>
<td>52/122</td>
</tr>
<tr>
<td>Heifetz (17-7PH)</td>
<td>12 x 3</td>
<td>163</td>
<td>44 ± 1</td>
<td>66/122</td>
</tr>
<tr>
<td>Mayfield</td>
<td>15 x 3</td>
<td>166</td>
<td>74 ± 5</td>
<td>51/94</td>
</tr>
<tr>
<td>Olivecrona</td>
<td>7 x 4</td>
<td>180</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Scoville</td>
<td>16 x 4</td>
<td>206</td>
<td>64 ± 2</td>
<td>38/74</td>
</tr>
<tr>
<td>silver clip</td>
<td>7 x 2</td>
<td>138</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Sugita Elgloy</td>
<td>20 x 5</td>
<td>366</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>Sugita, with loop (gold-plated)</td>
<td>20 x 5</td>
<td>342</td>
<td>1 ± 0</td>
<td>16</td>
</tr>
<tr>
<td>McdFadden Vari-Angle</td>
<td>21 x 5</td>
<td>387</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Yaşargil 316</td>
<td>20 x 6</td>
<td>313</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Yaşargil Phynox</td>
<td>13 x 4</td>
<td>132</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Yaşargil (old)</td>
<td>18 x 5</td>
<td>324</td>
<td>1 ± 0</td>
<td>16</td>
</tr>
</tbody>
</table>

* The Drake, Heifetz, Mayfield, and Scoville clips demonstrated marked ferromagnetism whereas the rest were considered nonferromagnetic. The ferromagnetic clips showed the most pronounced image distortion in the phantom study. The distortion is quantitated in two distances: the first is the largest distance from the edge of the clip to the rim of the disturbed part of the phantom where no meaningful information is obtainable; the second (ferromagnetic clips) is the largest distance from the clip to the part of the phantom where distortion can be identified (> 2 mm).

† Magnetic remanence is given in arbitrary units ± 1 standard deviation.

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radiofrequency pulse due to dephasing of spins. Nevertheless, the total area of the phantom that was affected, either as signal misposition or loss of signal, was approximately the same for the pulse sequences investigated. The results of image distortion are presented in Table 2 and in Fig. 2.

Artifacts in MR images made with a standard spin-echo sequence or an inversion recovery sequence were identical in size and shape for each clip. With these pulse sequences, the clips caused three types of effects on the MR image. 1) A distortion effect; that is, the information was available in the image but was mispositioned. This can be seen at some distance from the clips as a slight bending of the geometrical phantom. 2) Signals from different parts of the imaged object were displayed (overwritten) within a few pixels, resulting in complete loss of information in this area. These bright signals can be seen closer to the metal object as compared to the distortion effect. 3) Close to the metal object, no protons were excited and no information could be obtained. This effect is due to off-resonance during excitation, whereas the first two types of clip-induced effects are caused by mispositioned signals. Such signals appear only in the frequency-encoding direction and were clearly seen in the geometrical phantom with the MR image distorted by a ferromagnetic clip. The edges of the square cavities were straight in one direction but appeared bent in the other.

It was found that the size and appearance of artifacts in the MR image depended not only on clip properties,
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FIG. 2. Standard spin-echo axial magnetic resonance images of the geometrical phantom with different aneurysm clips. The direction of the main magnetic field is parallel to the slices. The ferromagnetic clips show the most severe image distortion. **Upper Row** (from left to right): Sugita Elgiloy, Yaşargil Phynox, and Yari-Angle McFadden. **Center Row:** Sugita gold-plated, Yaşargil 316, and silver clip. **Lower Row:** Mayfield, Heifetz 17-7PH, and Scoville.

pulse sequences, and direction of the frequency-encoding gradient but also on the direction of the main magnetic field and the strength of the magnetic gradients. Image artifacts in the coronal plane were different from artifacts in the axial and sagittal planes. In the coronal plane the main magnetic field was perpendicular to the slice, but in the axial and sagittal planes the field was parallel to the slice. In this context it should be noted that our FONAR β-3000M system has a vertical magnetic field. Figure 3 shows the image artifacts caused by a Drake clip in the three principal projections. The size of the artifact depended on the strength of the magnetic gradients. When weaker gradients were used to increase the size of the field of view, the artifact covered a larger area of the phantom. With weaker gradients the relative magnetic disturbance by the clip was increased, and hence the artifact was enlarged. The effects from eddy currents were probably minor since hardly any artifact could be seen around the silver clips studied.

**Discussion**

Theoretically, there are two potential hazards in MR imaging of patients with intracranial clips: displacement of the clip and heating effects. According to Davis and coworkers, the latter does not appear to be clinically relevant.

The potential hazard of clip displacement arises from the longitudinal forces and torques exerted on ferromagnetic aneurysm clips. The importance of screening patients known to have metallic material implanted before they undergo MR imaging to ensure that the embedded clips are nonmagnetic is evident. This points to the necessity for careful documentation of the
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FIG. 3. Magnetic resonance images, standard spin-echo sequence, of the geometrical phantom with a Drake clip showing the artifact caused by the clip. The total artifact is due to three effects: distortion, overwritten information, and lack of excitation. In the coronal scan (left), the main magnetic field is perpendicular to the slice. In the axial (center) and sagittal (right) scans, the main magnetic field is parallel to the slices. It should be noted that the polarity of the frequency-encoding gradient is reversed between the axial and sagittal scans.

type of clip used in all relevant surgical records. Magnetic resonance investigation should be discouraged in cases where ferromagnetic clips such as Mayfield, Scoville, Heifetz 17-7PH, and Drake clips have been used. We found the Scoville clip more ferromagnetic than

FIG. 4. Magnetic resonance images showing severe artifacts caused by a Drake ferromagnetic clip.

has been reported previously. In the present study, neither the Yasargil Phynox, Sugita Elgiloy, nor Varis-Angle McFadden clips showed magnetic remanence or dislocation. Consequently, such clips do not appear to be contraindicated for MR imaging with a medium-strength magnetic field. In addition to the risk of dislocation of a ferromagnetic clip, we found MR imaging to be of no use or of very limited value since such clips caused severe artifacts (Fig. 4).

The nonferromagnetic clips that are suitable for MR imaging also cause artifacts; however, these are less pronounced and do not substantially reduce radiological information. The "blind area" caused by these clips varies from almost zero for silver clips to an area encompassing the clip and a small zone in the immediate vicinity (approximately 10 mm). Magnetic resonance imaging remains preferable to CT, not only because of less severe artifacts but also because visualization of the anatomical structures and white matter lesions is superior. However, it should be noted that,
when the clip is located outside the investigated slice, there are no artifacts on CT scans, whereas on MR images the alteration of the magnetic field extends in all directions and hence artifacts may occur on images of nearby slices.

The MR image artifacts depend on several parameters, and by alteration of some of these parameters the severity of image artifacts can be reduced. The link between gradient strength and the size of the image artifacts indicates that strong gradient should be used. However, this will increase the noise in the image, and some sort of compromise regarding the strength of the gradients has to be considered. Furthermore, the orientation of the image artifact depends on the direction of the frequency-encoding gradient, and it is therefore possible to reorientate the artifact by reversing the gradient or by interchanging it with the phase-encoding gradient. In some cases this may allow the neuroradiologist to obtain information from the vicinity of the clip that, with the standard setting on gradient directions, would have been obscured by the image artifact. Basically, there are no differences in image artifacts between T₁- and T₂-weighted MR images. However, with the FONAR MR system used in the present study, the image artifacts in T₂-weighted spin-echo images were slightly larger due to weaker gradients and a lower signal-sampling rate. Silver clips cause severe artifacts on CT scans; therefore, MR imaging appears to be the radiological method of choice in patients with such clips (Fig. 5).

Our study has demonstrated that patients harboring nonferromagnetic aneurysm clips can be examined with medium-field MR. This enabled us to conduct a study comparing MR versus CT findings in patients operated on for a ruptured aneurysm.  

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References


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