Ferromagnetism and MR Imaging:
Safety of Carotid Vascular Clamps

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Metallic extracranial carotid vascular clamps of the Selverstone, Crutchfield, Poppen-Blaylock, Salibi, Kindt, and tantalum varieties have been placed for treatment of large, giant, or inoperable intracranial aneurysms. To ascertain what adverse effect, if any, MR imaging would have on these clamps, magnetic deflection at 1.5 T was measured for various carotid clamps. Marked magnetic deflection (and torque) was displayed by stainless steel Poppen-Blaylock clamps. Relatively mild magnetic deflection was displayed by the stainless steel Selverstone, Salibi, Crutchfield, and Kindt clamps. Three patients with previously placed carotid clamps (two Selverstone, one Salibi) and one patient with a nonferromagnetic tantalum carotid clip had cranial or cervical MR studies at field strengths ranging from 0.35 to 0.60 T. No patient experienced any discomfort or neurologic sequelae as a result of MR imaging. Although the ferromagnetic clamps created severe "black-hole" artifacts and image distortion within the cervical and facial regions, no significant image degradation was apparent during spin-echo imaging of the brain. The tantalum clip created a far smaller MR artifact than did ferromagnetic clamps and allowed effective spin-echo and gradient-echo imaging in the cervical region.

Our findings indicate that most patients with carotid vascular clamps (and nonferromagnetic clips) can probably be imaged safely with MR.

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Cervical carotid artery ligation has been used since 1798 for a variety of indications, including internal carotid artery aneurysms and large or giant inoperable intracranial aneurysms [1]. Many surgeons believe that gradual occlusion is preferable to rapid closure of the carotid artery in order to reduce ischemic complications [2, 3]; and to this end, carotid vascular screw clamps have been produced that allow gradual occlusion of the cervical carotid arteries. The Dott clamp [4] was one of the first devices used for this purpose; it had to be removed after the internal carotid artery was occluded. The Poppen-Blaylock [3] and Pertuiset [5] clamps were likewise designed to be removed after carotid occlusion. The Selverstone [6], Salibi [7], Crutchfield [8], and Kindt [9] clamps were designed to be left in place once gradual occlusion of the carotid artery was achieved.

Other occlusion devices used on the carotid artery include tantalum or aluminum bands or clips [10–12] and an intraluminal balloon catheter [13].

The use of carotid vascular clamps has significantly decreased owing to the emergence of transluminal balloon embolization of large, giant, or inaccessible intracranial aneurysms [14]. However, patients will be encountered occasionally who have had previous placement of a carotid clamp and require an MR study. Consideration of the safety of MR imaging in the presence of carotid vascular clamps, therefore, becomes important, especially when considering the possible utility of MR in the follow-up evaluation of large and giant intracranial aneurysms [15, 16].

The present study evaluates in vitro the magnetic properties of a variety of carotid vascular clamps. In addition, four cases are presented in which patients

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with a previously placed carotid clamp or clip have undergone MR imaging.

Materials and Methods

Ferromagnetism of Clamps

Nine varieties of stainless steel carotid vascular clamps (Fig. 1), produced by the two primary manufacturers of such clamps (Codman & Shurtleff, Randolph, MA; and V. Mueller, Chicago, IL), were tested for magnetic deflection at the portal of a 1.5 T MR unit (Siemens; Islen, NJ) by using a method previously described by New et al. [17]. The devices were suspended by a thread at the magnetic portal, and their deflection angles from the vertical were measured and recorded. The force of deflection (F), expressed in the cgs units of dynes, is given by the formula

$$F = mg \tan \theta$$

where

m = mass of device (in grams)
g = gravitational acceleration constant (980 cm/sec^2)
θ = deflection angle from vertical

The Poppen-Blaylock clamps, because of their well-defined long axes, were evaluated for magnetic torque at the portal of the 1.5-T MR unit (Siemens) by using a previously described method [17]. The device (with mass m) was suspended from a pivot point at the magnetic portal with a lead counterweight (with mass M) attached to a point on the device most distal from the pivot.

Magnetic torque, N, expressed in dyne-cm, was given by the formula

$$N = (m + M)\, gl \sin \theta$$

where

(m + M) = combined mass of the device + lead counterweight (grams)
g = gravitational acceleration constant (980 cm/sec^2)
l = distance from pivot point to the center of mass (cm)
θ = deflection angle of the center of mass from the vertical

It should be noted that torque will be greatest where the magnetic field is maximum; that is, well inside the magnet. Therefore, measurements performed on Poppen-Blaylock clamps at the portal of a magnet will provide an underestimation of magnetic torque. The Kindt clamp (V. Mueller) has been discontinued. Also, models of the Salibi and Crutchfield clamps from one manufacturer (V. Mueller) were no longer in stock and were, thus, unavailable for evaluation.

MR Imaging in Four Patients

Case 1. A 68-year-old woman presented in 1965 with severe headaches and a visual deficit in the left eye. Cerebral arteriography diagnosed a large saccular aneurysm of the left ophthalmic artery. A Selverstone clamp was placed on the left internal carotid artery to occlude this aneurysm. A cervical MR examination was requested to evaluate neck pain. The patient was imaged on a 0.35-T MR unit (Diasonics; Milpitas, CA) with a cervical coil and spin-echo (SE) technique, 1000/40–80/2 (TR/TE range/excitations), in the sagittal plane and 500/40–80/2 in the coronal plane. Section thickness was 5 mm, and matrix size was 128 × 256 for both sequences.

Case 2. A 66-year-old woman presented in 1973 with recurrent headaches and visual loss over a period of 2½ years. Cerebral arteriography diagnosed a giant aneurysm of the superclinoid portion of the left internal carotid artery. A Salibi clamp was placed on the left internal carotid artery without neurologic consequences. The patient has since developed normal pressure hydrocephalus, which was treated with a ventriculoperitoneal shunt in 1987. A brain MR study was ordered to evaluate the patient's hydrocephalus. SE imaging (633/20/2 and 2000/120/1) was performed on a 0.5-T MR unit (Picker; Cleveland, OH), and, by use of the unit's head coil, 10-mm axial sections through the brain were obtained. Matrix size was 256.^{2}

Case 3. A 37-year-old man presented in 1985 with transient visual loss in the right eye associated with weakness of the left upper extremity. He had had similar neurologic symptoms after a severe motor vehicle accident in 1980. MR showed a pseudoaneurysm with thrombus in the right internal carotid artery at the base of the skull. Owing to the possibility of the pseudoaneurysm's being the source of emboli and the difficulty posed by its surgical resection, a Selverstone clamp was applied to the right internal carotid artery. A brain MR study was requested when the patient developed new visual symptoms. SE imaging (3000/40–80/2) with a head coil was performed and 5-mm-thick axial sections were obtained on a 0.35-T MR unit (Diasonics). Additional 5-mm-thick coronal sections were obtained within the cervical region by using SE imaging (500/30/2) and the unit's body coil. Matrix sizes were 256^2 or 128 × 256, respectively.

Case 4. A 53-year-old man presented in 1968 with right retroorbital pain of increasing intensity over a period of 1 month. A 3-mm aneurysm arising from the left posterior communicating artery was diagnosed by cerebral arteriography. A tantalum clamp was placed on the left internal carotid artery, resulting in an improvement in neurologic symptoms. Because of recurrent headaches, a brain MR study was performed on a 0.6-T unit (Technicare; Solon, OH). The study included coronal cervical imaging using SE (500/22/1) and gradient-echo (GRE) (flip angle = 20°, TR = 500, TE = 30, excitations = 4) techniques, 5-mm-thick sections, and the unit's body coil. Matrix size was 128 × 256.

Results

Magnetic deflection forces for the various clamps tested are listed in Table 1. Magnetic torque determinations for Poppen-Blaylock clamps are presented in Table 2. There is enormous magnetic deflection and torque displayed by Poppen-Blaylock clamps. The other clamps tested displayed relatively mild magnetic deflection.

During MR imaging in four patients, ferromagnetic clamps (cases 1–3) created severe metallic artifacts consisting of large rounded signal void zones bordered by relatively high signal areas. These artifacts had their major extent along the frequency-encoded direction and were accompanied by marked image distortion (Fig. 2). These "black-hole" artifacts created marked image degradation in the cervical and lower facial regions, negating the possibility of carotid MR vascular imaging in the vicinity of the clamps. In case 1, the cervical MR study was aborted because of the artifact caused by the Selverstone clamp. However, in all cases, MR images of the intracranial structures were not degraded by the presence of the clamps.

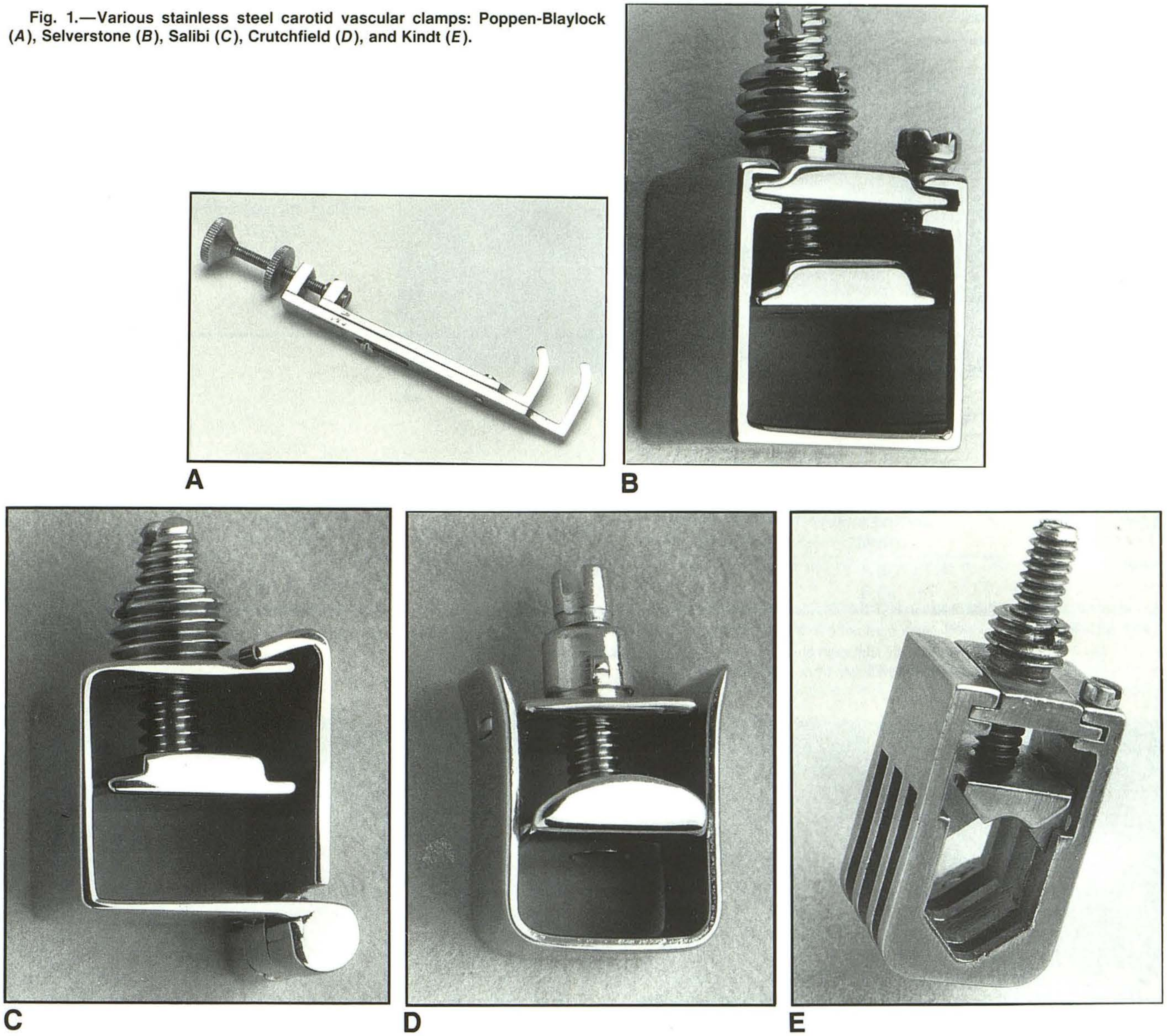


Fig. 1.—Various stainless steel carotid vascular clamps: Poppen-Blaylock (*A*), Selverstone (*B*), Salibi (*C*), Crutchfield (*D*), and Kindt (*E*).

The tantalum carotid clip created far less MR artifact than did the stainless steel clamps and allowed effective SE and GRE imaging in the cervical area (Fig. 3). Coronal GRE images demonstrated a lack of intraluminal flow signal within the internal carotid artery on the side of clip placement, suggesting occlusion of this vessel. This finding was confirmed by arteriography.

In none of the four patients was there any discomfort or neurologic symptoms as a result of MR imaging.

Discussion

A number of implanted medical devices and prostheses have been evaluated for MR imaging artifacts and safety, including neurosurgical aneurysm and hemostatic clips [17, 18, 19], cardiac pacemakers [20], cardiac valves [21], intravascular filters and stents [22–24], dental materials [17, 25], intrauterine devices [26], and metallic prostheses [27, 28]. With regard to vascular clamps and clips, MR imaging is contraindicated in cases of previous placement of a strongly ferromagnetic intracranial aneurysm clip [17]. However, it appears to be unnecessary to exclude patients from MR imaging who have nonferromagnetic or only mildly ferromagnetic aneurysm clips [29].

The weakly ferromagnetic Selverstone, Salibi, Crutchfield, and Kindt clamps that are attached to presumably occluded carotid arteries and are adjacent to muscular structures in the neck probably pose no significant hazard during MR imaging in terms of neurovascular complications or local

TABLE 1: Magnetic Deflection at 1.5 T of Various Carotid Vascular Clamps

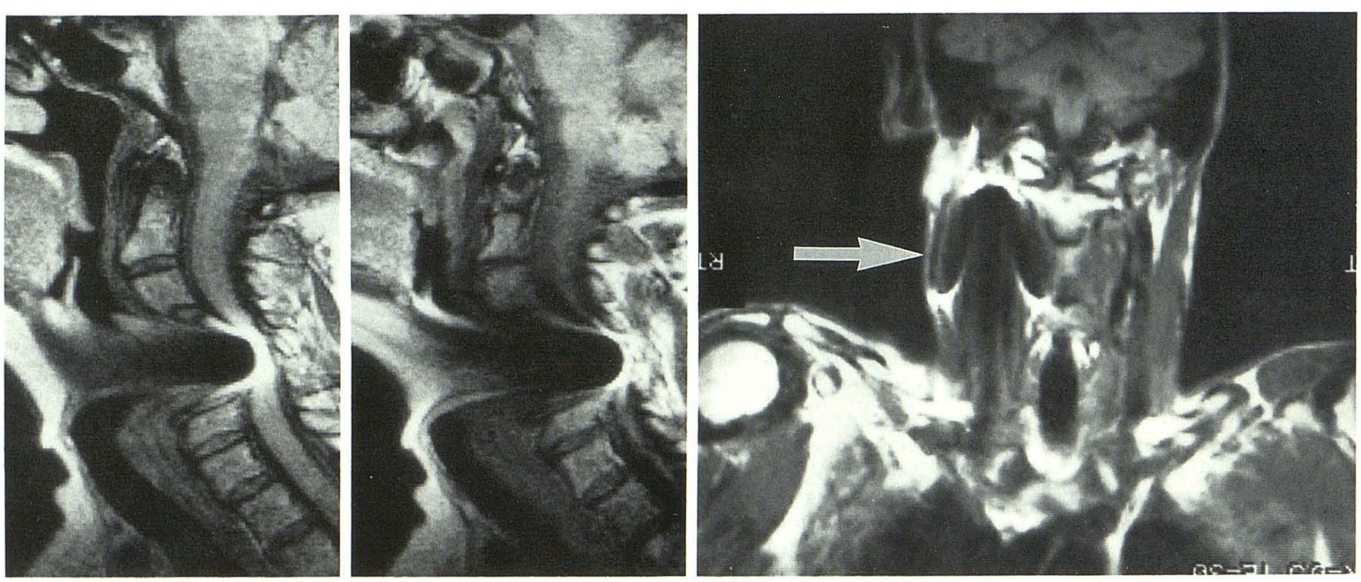
Clamp[a]	Size (mm)	Mass (g)	Deflection Angle (degrees)	Deflection Force (dynes)
Poppen-Blaylock[b]	62 (length)	13.21	>89	$>7.42 \times 10^5$
Poppen-Blaylock[b]	50 (length)	12.00	>89	$>6.74 \times 10^5$
Salibi[b]	9 × 8	3.58	17	1072.63
Kindt[c]	17 × 10	5.89	7	708.74
Selverstone[c]	10 × 6	6.41	4	439.27
Selverstone[b]	9.5 × 8.5	6.84	3	351.30
Selverstone[b]	7.5 × 6.0	3.76	4	257.67
Selverstone[c]	8 × 6	3.60	4	246.70
Crutchfield[b]	9 × 7	1.50	3	77.04
Salibi[c,d]	–	–	–	–
Crutchfield[c,d]	–	–	–	–

[a] All clamps are composed of stainless steel.
[b] Codman.
[c] V. Mueller.
[d] Not available for testing.

TABLE 2: Magnetic Torque Displayed by Poppen-Blaylock Clamps

Clamp Length (mm)	(m + M) (gm)[a]	L (cm)[b]	θ (degrees)[c]	Torque (dyne-cm)
62.5	109.18	12.0	60	1.11×10^6
50.0	107.97	11.0	55	9.53×10^5

[a] (m + M) = combined mass of clamp (m) + lead counterweight (M).
[b] L = distance between pivot point and center of mass.
[c] θ = deflection angle from vertical.



A B

Fig. 2.—*A*, Adjacent sagittal spin-echo images (1000/40/2) at 0.35 T within cervical spine in a patient with previously placed Selverstone carotid clamp. Note severe "black-hole" artifact created by clamp, the major extent of which is propagated along the frequency-encoded direction. Image distortion largely obscures disk spaces, vertebral bodies, and cervical cord. However, intracranial structures in posterior fossa are not distorted.

***B*, Coronal spin echo image (500/30/2) at 0.35 T in another patient with previously placed Selverstone carotid clamp, demonstrating similar "black-hole" artifact (*arrow*) that obscures structures in right cervical region. Imaging of intracranial structures appeared unaffected.**

tissue damage. No discomfort or neurologic sequelae was experienced by any of our four patients with a carotid clamp or clip as a result of MR imaging. No comment can be made regarding the ferromagnetism of Salibi or Crutchfield clamps from one manufacturer (V. Mueller) owing to their unavailability for testing.

Although MR imaging would appear contraindicated in the presence of the Poppen-Blaylock clamp because of the tre-

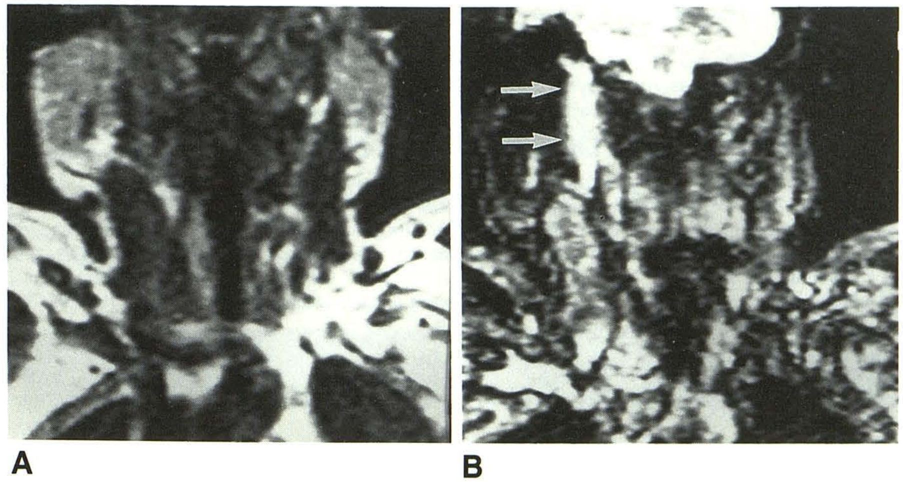


Fig. 3.—*A*, Coronal spin-echo image (500/22/1) at 0.6 T shows no significant artifact produced by previously placed left carotid artery tantalum clip.

***B*, Coronal gradient-echo image ($\alpha = 20°/500/30/4$) in same patient demonstrates patency of right internal carotid artery (*arrows*) and occlusion of left internal carotid artery as evidenced by the presence and absence, respectively, of high intraluminal flow signal. Effective gradient-echo flow imaging was possible because of the low level of artifact produced by the tantalum clip.**

mendous ferromagnetism of this device, it should be understood that this was the only such highly ferromagnetic device tested in our study, and it would be quite rare at present to encounter a patient with a temporarily placed Poppen-Blaylock clamp who would require an MR examination. Therefore, magnetic deflection and torque results for this clamp are presented more for academic interest than for practical purposes.

The MR compatibility of tantalum has been demonstrated previously [24, 30]. The expanded use of low-artifact metals, such as titanium alloys [22] and tantalum in neurosurgical implants, may allow more effective GRE, flow-sensitive imaging of treated neurovascular lesions. In case 4, the use of a tantalum carotid clip allowed the effective use of GRE imaging to determine carotid occlusion (Fig. 3).

The degree of artifact and image distortion created by a metallic device during MR imaging is directly related to its magnetic permeability, which is dependent on the device's composition, shape, and previous cold-working [17, 22, 25]. In general, the greater a device's ferromagnetism, the greater the degree of its MR artifact [22]. Devices composed of martensitic stainless steels are ferromagnetic [17]. Although austenitic steel alloys are nonmagnetic in bulk form, significant ferromagnetic domains are created during the cold-working used to fabricate austenitic stainless steel devices, resulting in the mild magnetic deflection observed with many of these devices [17, 22].

In conclusion, MR imaging is probably safe in the presence of most permanent stainless steel carotid vascular clamps. These clamps, although interfering with cervical/facial MR imaging, should not significantly degrade intracranial studies.

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REFERENCES

1. Fox JL. *Intracranial aneurysms*, Vol. II. New York: Springer-Verlag, **1983**:860–876
2. Fager CA. The effectiveness and risk of carotid ligation in the treatment of intracranial aneurysms. *Lahey Clin Bull* **1958**;10:226–233
3. Poppen JL, Fager CA. Intracranial aneurysms. Results of surgical treatment. *J Neurosurg* **1960**;17:283–296
4. Dott NM. Intracranial aneurysmal formations. *Clin Neurosurg* **1969**;16:1–15
5. Pertuiset B. La ligature progressive de la carotide interne dans le cou technique personnelle d'apres 14 cas. *Neurochirurgia* (Stuttg) **1963**;6:103–107
6. Selverstone B, White JC. A method for gradual occlusion of the internal carotid artery in the treatment of aneurysm. *Proc N Engl Cardiovasc Surg* **1952**;9 24–25
7. Raskind R. Carotid artery ligation for intracranial aneurysm. *Angiology* **1966**;17:46–55
8. Crutchfield WG. Instruments for use in the treatment of certain intracranial vascular lesions. *J Neurosurg* **1959**;16:471–475
9. Giannotta SL, McGillicuddy JE, Kindt GW. Gradual carotid artery occlusion in the treatment of inaccessible internal carotid artery aneurysm. *Neurosurgery* **1979**;5:417–421
10. Brackett CE, Jr. The complications of carotid artery ligation in the neck. *J Neurosurg* **1953**;10:91–106
11. Luessenhop AJ, Mora F, Sweet WH. Subarachnoid hemorrhage, intracranial aneurysms, and arterio-venous anomalies; treatment by cervical carotid occlusion. In: Fields WS, ed. *Pathogenesis and treatment of cerebrovascular disease*. Springfield, IL: Thomas, **1961**:516–553
12. Murphy F. Extracranial carotid ligation: technical aspects. In: Fields WS, Sahs AL, eds. *Intracranial aneurysms and subarachnoid hemorrhage*. Springfield, IL: Thomas, **1965**:315–323
13. Kessler LA, Wholey MH. Internal carotid occlusion for treatment of intracranial aneurysms. A new percutaneous technique. *Radiology* **1970**;95:581–583
14. Halbach VV, Hieshima GB, Higashida RT. Treatment of intracranial aneurysms by balloon embolization. *Semin Intervent Radiol* **1987**;4:261–268
15. Atlas SW, Grossman RI, Goldberg HI, Hackney DB, Bilaniuk LT, Zimmerman RA. Partially thrombosed giant intracranial aneurysms: correlation of MR and pathologic findings. *Radiology* **1987**;162:111–114
16. Tsuruda JS, Halbach VV, Higashida RT, Mark AS, Hieshima GB, Norman D. MR evaluation of large intracranial aneurysms using cine low flip angle gradient-refocused imaging. *AJNR* **1988**;9:415–424
17. New PFJ, Rosen BR, Brady TJ, et al. Potential hazards and artifacts of ferromagnetic and nonferromagnetic surgical and dental materials and devices in nuclear magnetic resonance imaging. *Radiology* **1983**;147:139–148
18. Dujovny M, Kossowsky N, Kossowsky R, et al. Aneurysm clip motion during magnetic resonance imaging: in vivo experimental study with metallurgical factor analysis. *Neurosurgery* **1985**;17:543–548
19. Barrafato D, Henkelman RM. Magnetic resonance imaging and surgical clips. *Can J Surg* **1984**;27:509–510
20. Pavlicek W, Geisinger M, Castle L, et al. The effects of nuclear magnetic

resonance on patients with cardiac pacemakers. *Radiology* **1983**;147:149–153
21. Soulen RL, Budinger TF, Higgins CB. Magnetic resonance imaging of prosthetic heart valves. *Radiology* **1985**;154:705–707
22. Teitelbaum GP, Bradley WG, Klein BD. MR imaging artifacts, ferromagnetism, and magnetic torque of intravascular filters, stents and coils. *Radiology* **1988**;166:657–664
23. Liebman CE, Messersmith RN, Levin DN, Lu C-T. MR imaging of inferior vena caval filters: safety and artifacts. *AJR* **1988**;150:1174–1176
24. Matsumoto AH, Teitelbaum GP, Barth KH, Carvlin MJ, Savin MA, Strecker EP. Tantalum vascular stents: in vivo evaluation with MR imaging. *Radiology* **1989**;170:753–755
25. Fache JS, Price C, Hawbolt EB, Li DKB. MR imaging artifacts produced by dental materials. *AJNR* **1987**;8:837–840
26. Mark AS, Hricak H. Intrauterine contraceptive devices: MR imaging. *Radiology* **1987**;162:311–314
27. Laakman RW, Kaufman B, Han JS, et al. MR imaging in patients with metallic implants. *Radiology* **1985**;157:711–714
28. Mechlin M, Thickman D, Kressel HY, Gefter W, Joseph P. Magnetic resonance imaging of postoperative patients with metallic implants. *AJR* **1984**;143:1281–1284
29. Becker RL, Norfray JF, Teitelbaum GP, et al. MR imaging in patients with intracranial aneurysm clips. *AJNR* **1988**;9:885–889
30. Shellock FG, Crues JV. High-field-strength MR imaging and metallic biomedical implants: an ex vivo evaluation of deflection forces. *AJR* **1988**;151:389–392