MAJOR PAPER

Artifacts of Vena Cava Filters *ex vivo* on MR Angiography

Minoru HONDA*, Masao OBUCHI, and Hideharu SUGIMOTO

Department of Radiology, Showa University Fujigaoka Hospital

1-30 Fujigaoka, Aoba-ku, Yokohama 227-8501, Japan

(Received February 7, 2003; Accepted March 26, 2003)

We evaluated magnetic susceptibility artifacts of nine types of vena cava filters in MR angiography (MRA) at 1.0T *ex vivo* in order to assess the filters' compatibility with MRA. Each filter (tulip filter, tulip MReye filter, stainless Greenfield filter, titanium Greenfield filter, TrapEase filter, Simon filter, LGM Vena-Tech filter, Antheor temporary filter, and Bird's nest filter) was inserted into an acrylic tube (20 or 25 mm in diameter, 15 or 30 cm in length). Gd-DTPA was poured into each tube at a concentration of 1/500 and each was placed in a water-filled container for imaging. We evaluated artifacts of the filters according to the following criteria: signal void beyond the tube, 3+; signal void within the tube but at more than one-half the diameter of the tube, 2+; and signal void within the tube but at less than one-half the diameter of the tube, 1+. We evaluated artifacts originating at the tip, intermediate portion, and distal end of the filters. We judged the artifacts as follows: tulip (3+, 3+, 3+); tulip MReye (2+, 1+, 1+); stainless Greenfield (2+, 1+, 2+); titanium Greenfield (1+, 1+, 1+); TrapEase (1+, 2+, 1+); Simon (2+, 2+, 1+); LGM (2+, 2+, 1+); Antheor (2+, 2+, 2+); and Bird's nest (3+, 3+, 3+). The numbers in parentheses refer to the degree of signal void at the tip, intermediate portion, and distal end of the filter, respectively. The tulip filter and Bird's nest filter made of 304 stainless steel caused extensive signal voids beyond the areas defined by the filters. The signal voids in the remaining seven filters were limited to within the tube. We concluded that seven of the nine filters were compatible with MRA *ex vivo*.

Keywords: *magnetic resonance angiography, vena cava filters, artifact*

Introduction

Currently, several types of vena cava filters are available for the prevention of pulmonary embolism. MR imaging in patients with a filter is considered to be safe when a suitable period has elapsed to ensure stable positioning of the filter.^{1,2} Since MR angiography (MRA) with use of Gd-DTPA is useful for evaluating the venous system,³ MRA may be used for follow-up study of patients with vena cava filters. Further, the number of MR studies in patients with vena cava filters is expected to increase. Finally, filter placement under MR control has already been reported.⁴⁻⁶ While ferromagnetic metals produce significant artifacts in MR images, we must use vena cava filters that do not produce severe artifacts to avoid any influence on MR images. The purpose of this study was to evaluate the extent of susceptibility artifacts caused

by the available vena cava filters in MRA at 1.0T *ex vivo* and to identify MR-compatible filters.

Materials and Methods

We evaluated nine types of the available vena cava filters. They are as follows: tulip vena cava filter (William Cook Europe A/S, Bjaeverskov, Denmark), tulip vena cava MReye filter (William Cook Europe A/S, Bjaeverskov, Denmark), over-the-wire stainless steel Greenfield filter (Boston Scientific, Natick, MA, USA), titanium Greenfield filter (Boston Scientific, Natick, MA, USA), TrapEase inferior vena cava filter (Cordis Europa, Roden, The Netherlands), Simon nitinol filter (Simon; Nitinol Medical Technologies, Boston, MA, USA), LGM Vena-Tech vena cava filter (B. Braun Celsa Laboratories, Chasseneuil, France), Antheor temporary vena cava filter (Boston Scientific, Natick, MA, USA), and Bird's nest filter (Cook, Bloomington, IL, USA). Figure 1 shows the shape of each filter. The tulip filter is made of

*Corresponding author, Phone: +81-45-974-6529, Fax: +81-45-978-1525, E-mail: honda@fujirad-showa-u.gr.jp

Fig. 1. Shape of each vena cava filter

a: Günther tulip filter and Günther tulip MReye filter, **b:** Over-the-wire Greenfield stainless steel filter, **c:** Titanium Greenfield filter, **d:** TrapEase filter, **e:** Simon nitinol filter, **f:** LGM Vena-Tech filter, **g:** Antheor temporary filter, **h:** Bird's nest filter (modified from Jörg Neuerburg: Neuer wiederentfernbarer Cava-Filter Experimentelle und klinische Ergebnisse. p. 14–17, Koblenz/Rhein 1996)

304 stainless steel; the tulip MReye filter, Elgiloy; the stainless Greenfield filter, 316L stainless steel; the TrapEase and Simon filters, nitinol; the LGM Vena-Tech filter and Antheor temporary filter, Phynox; and the Bird's nest filter, 304 stainless steel.

Each of these filters was inserted into an acrylic tube (20 or 25 mm in diameter, 15 or 30 cm in length). Gd-DTPA at a concentration of 1/500 was poured into the tube, and both ends of the tube were sealed. Each tube was placed in a water-filled container. Three-dimensional, fast gradient-echo images were obtained with a Signa Horizon 1.0T MR scanner (GE Medical Systems, Milwaukee, WI, USA) with a torso phased-array coil. The MRA images were obtained at a repetition time of 6.2 ms, an echo time of 1.4 ms, a flip angle of 20 degrees, an inversion time of 31 ms, a field-of-view of 32 to 38 cm, a 256×160 matrix, a slice thickness of 5 to 8 mm, a slab thickness of 92 to 160 mm, and a NEX of 1. The longitudinal axis of the filter was kept parallel to that of the static magnetic field.

We judged the artifacts caused by the filters according to the following criteria: signal void beyond the tube, 3+; signal void within the tube but at greater than one-half the diameter of the

tube, 2+; and signal void within the tube but at less than one-half the diameter of the tube, 1+. We evaluated the artifacts extending from the tip, intermediate portion, and distal end of the filters.

Results

Our results are summarized in Table. We judged artifacts as follows: tulip (3+, 3+, 3+); tulip MReye (2+, 1+, 1+); stainless Greenfield (2+, 1+, 2+); titanium Greenfield (1+, 1+, 1+); TrapEase (1+, 2+, 1+); Simon (2+, 2+, 1+); LGM (2+, 2+, 1+); Antheor (2+, 2+, 2+); and Bird's nest (3+, 3+, 3+). The numbers in parentheses refer to the degree of signal void at the tip, intermediate portion, and distal end of the filter. The tulip filter caused extensive signal void; the tulip MReye filter created mild artifacts (Fig. 2). The stainless Greenfield filter produced mild artifacts; the titanium Greenfield filter produced only a few artifacts (Fig. 3). The TrapEase filter produced small artifacts, but a moderate signal void was observed in the filter. The Simon nitinol filter produced remarkable artifacts at the tip (Fig. 4). The LGM Vena-Tech and Antheor temporary filters produced mild artifacts (Fig. 5).

Table. Artifacts of vena cava filters in MRA *ex vivo*

Filter	Tip	Intermediate portion	Distal end
tulip	3+	3+	3+
tulip MReye	2+	1+	1+
stainless Greenfield	2+	1+	2+
titanium Greenfield	1+	1+	1+
TrapEase	1+	2+	1+
Simon nitinol	2+	2+	1+
LGM Vena-Tech	2+	2+	1+
Antheor temporary	2+	2+	2+
Bird's nest	3+	3+	3+

Notes:

Criteria: Signal void beyond the tube, 3+; signal void within the tube but at more than one-half the diameter of the tube, 2+; and signal void within the tube but at less than one-half the diameter of the tube, 1+.

Fig. 2. Günther tulip filter

a: The Tulip filter made of 304 stainless steel caused severe “black-hole” artifacts.

b: The Tulip MReye filter made of Elgiloy created mild artifacts.

The Bird's nest filter caused severe “black-hole” artifacts (Fig. 6).

Discussion

Previous investigators showed MR artifacts in patients with metallic implants.^{1,2,4-18} Many types of guide wires and catheters have been investigated in ultrafast MR imaging.¹⁹ Although we found several articles about MRA of vascular stents,²⁰⁻²⁴ reports evaluating the Simon nitinol filter with non-con-

trast MRA are limited.²⁵ Therefore, in this study we focused on artifacts from vena cava filters in contrast-enhanced MRA. Reportedly, filters made of 316L stainless steel display only moderate ferromagnetism at 0.35 and 1.5T in comparison to filters made of 304 stainless steel.⁷ Artifacts are apparently minimal with all 316L wires and the undeformed type 304 wire, while artifacts are reported to be significant with the deformed-type 304 stainless steel.¹⁷ A somewhat higher nickel content is present in 316L stainless steel than in the 304

Fig. 3. Greenfield filter

a: The over-the-wire Greenfield filter made of 316L stainless steel produced mild artifacts.

b: The Greenfield filter made of titanium produced only a few artifacts.

Fig. 4. TrapEase and Simon filters

a: The TrapEase filter made of nitinol produced small artifacts, but a moderate signal void was observed in the filter.

b: The Simon nitinol filter produced remarkable artifacts at the tip.

type. Nickel stabilizes iron in the nonmagnetic state and diminishes the magnetic susceptibility of stainless steel. This is an important factor contributing to the markedly decreased ferromagnetism of 316L stainless steel.^{7,17} The Gianturco stent, made of 304 stainless steel, was reported to create a large “black

hole” artifact in T_1 -weighted spin-echo MR images *ex vivo*.¹⁸ Clearly, 316L stainless steel is the preferred material with respect to ferromagnetic properties.¹⁷ Johnson et al. carried out MR imaging follow-up of 16 patients with the stainless Greenfield filter. Both axial two-dimensional time-of-

Fig. 5. LGM Vena-Tech and Antheor temporary filters
a: The LMG filter made of Phynox produced mild artifacts.
b: The Antheor temporary filter made of Phynox created mild artifacts.

Fig. 6. Bird's nest filter
 The Bird's nest filter made of 304 stainless steel caused severe "black-hole" artifacts.

flight MRA and coronal-phase contrast MRA at 1.5T were performed to evaluate caval patency and IVC thrombosis. MR artifacts from the filter were minimal and most pronounced at the filter apex.²⁶ Titanium alloy is apparently one of the metals best suited to MR imaging because of the lack of ferromagnetism and resulting absence of magnetic-susceptibility artifacts.⁷ The titanium Greenfield filter produced only a few artifacts on MRA in our study. Elgiloy is a cobalt-chromium-nickel alloy. The tulip MReye filter created mild artifacts in MRA in our study. In a study of an intracranial aneurysm clip made of Elgiloy with T₁- and T₂-

weighted images at 1.5T, the artifact size was directly proportional to the clip size and weight, although the ratio of the artifact to the actual width tended to decrease proportionately as the actual size and weight increased.¹⁴ Phynox is also a cobalt-chromium-nickel alloy similar to Elgiloy. The filters made of Phynox caused mild artifacts in our study. Permanent surgical Phynox implants can be imaged safely with magnetic resonance.¹⁵ Nitinol is a nickel-titanium alloy with a thermal shape memory.²⁷ Nitinol is also one of the best-suited metals for use with MR imaging. The TrapEase filter that was recently introduced caused small artifacts.²⁸ The Simon nitinol filter caused mild artifacts in our study except at the tip. Generally, the greater the ferromagnetism of a device, the greater its susceptibility to artifacts.⁷ Metallic artifacts arise from distortions in the main magnetic field caused by ferromagnetic materials.²⁹ Even nonferromagnetic materials create moderate artifacts.³⁰ The nonferromagnetic vascular clip has been depicted as a central area of extreme signal void adjacent to an asymmetric high-intensity border that is several times the size of the clip.³¹ New et al. examined the generation of artifacts by metallic objects, finding artifacts produced not only by ferromagnetic objects but also by nonferromagnetic objects.¹³ The cause of geometric distortion and localized signal changes during MR imaging of nonferromagnetic devices is thought to be a reduction in radiofrequency amplitude near the device, which is depend-

ent on its shape.¹⁶ The magnitude of the artifacts is related to the degree of magnetization of the object and its mass. Metallic artifacts have been shown to be more pronounced at higher field strengths.¹¹ We believe that artifact size is also dependent on the volume of the metal. The volume of metal at the filter tip was greater than that at other portions of the filter, so the artifact was pronounced at the tip. The direction of the main magnetic field in the Signa Horizon 1.0T MR scanner is horizontal. In the open-type MR scanner, the direction of the main magnetic field is usually vertical to the longitudinal axis of the patient. With this scanner, the artifacts arising from vena cava filters might differ from our results because the longitudinal axis of the filter appeared to be vertical to the direction of the main magnetic field.

In conclusion, artifacts of seven of nine types of filters were acceptable for MRA at 1.0T *ex vivo*. The tulip filter and Bird's nest filter made of 304 stainless steel were unacceptable for MRA, because they caused severe "black-hole" artifacts. These results suggest that MRA can be performed as a follow-up study in outpatients with these MRA-compliant filters.

Acknowledgments

We wish to express special thanks to Prof. Jörg Neuerburg (Zentrale Abteilung für Diagnostische und Interventionelle Radiologie Evangelisches und Johanniter Klinikum Duisburg/Dinslaken/Oberhausen gGmbH) for allowing us to use illustrations from his scientific report (Neuer wiederentfernbarer Cava-Filter Experimentelle und klinische Ergebnisse. p. 14–17, Koblenz/Rhein 1996).

References

1. Liebman CE, Messersmith RN, Levin DN, Lu CT. MR imaging of inferior vena cava filters: safety and artifacts. *AJR* 1988; 150:1174–1176.
2. Shellock FG, Curtis JS. MR imaging and biomedical implants, materials, and devices: an updated review. *Radiology* 1991; 180:541–550.
3. Kaufman JA, Waltman AC, Rivitz SM, Geller SC. Anatomical observations on the renal veins and inferior vena cava at magnetic resonance angiography. *Cardiovasc Intervent Radiol* 1995; 18: 153–157.
4. Neuerburg J, Bucker A, Adam G, et al. Cava filter placement under MRI control. Experimental *in vitro* and *in vivo* studies. *Rofo Fortschr Geb Röntgenstr Neuen Bildgeb Verfahr* 1997; 167:418–422.
5. Bartels LW, Bos C, van Der Weide R, Smits HF, Bakker CJ, Viergever MA. Placement of an inferior vena cava filter in a pig guided by high-resolution MR fluoroscopy at 1.5T. *J Magn Reson Imaging* 2000; 12:599–605.
6. Bucker A, Neuerburg JM, Adam GB, et al. Real-time MR Guidance for inferior vena cava filter placement in an animal model. *J Vasc Interv Radiol* 2001; 12:753–756.
7. Teitelbaum GP, Bradley WG, Klein BD. MR imaging artifacts, ferromagnetism, and magnetic torque of intravascular filters, stents, and coils. *Radiology* 1988; 166:657–664.
8. Mechlin M, Thickman D, Kressel HY, Gefter W, Joseph P. Magnetic resonance imaging of postoperative patients with metallic implants. *AJR* 1984; 143:1281–1284.
9. Shellock FG, Crues JV. High-field strength MR imaging and metallic biomedical implants: an *ex vivo* evaluation of deflection forces. *AJR* 1988; 151:389–393.
10. Teitelbaum GP, Lin MCW, Watanabe AT, et al. Ferromagnetism and MR imaging: safety of carotid vascular clamps. *Am J Neuroradiol* 1990; 11: 267–272.
11. Laakman RM, Kaufman B, Han JS, et al. MR imaging in patients with metallic implants. *Radiology* 1985; 157:711–714.
12. 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.
13. 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.
14. Ooka K, Shibuya M, Suzuki Y. Motion and image artifacts of various intracranial aneurysm clips in a magnetic field. *Acta Neurochir* 1996; 138:1241–1245.
15. Clerc CO, Jedwab MR, Mayer DW, Thompson PJ, Stinson JS. Assessment of wrought ASTM F1058 cobalt alloy properties for permanent surgical implants. *J Biomed Mater Res* 1997; 38: 229–234.
16. Heindel W, Friedmann G, Bunke J, Thomas B, Firsching R, Ernestus RI. Artifacts in MR imaging after surgical intervention. *J Comput Assist Tomogr* 1986; 10:596–599.
17. Bendel LP, Shellock FG, Steckel M. The effect of mechanical deformation on magnetic properties and MRI artifacts of type 304 and type 316L stainless steel. *J Magn Reson Imaging* 1997; 7: 1170–1173.
18. Girard MJ, Hahn PF, Saini S, Dawson SL, Goldberg MA, Mueller PR. Wallstent metallic biliary endoprosthesis: MR imaging characteristics. *Radiology* 1992; 184:874–876.
19. Koechli VD, McKinnon GC, Hofmann E, Von

- Schulthess GK. Vascular interventions guided by ultrafast MR imaging: evaluation of different materials. *Magn Reson Med* 1994; 31:309–314.
20. Lenhart M, Volk M, Manke C, et al. Stent appearance at contrast-enhanced MR angiography: *in vitro* examination with 14 stents. *Radiology* 2000; 117:173–178.
 21. Meyer JM, Buecker A, Schuermann K, Ruebben A, Guenther RW. MR evaluation of stent patency: *in vitro* test of 22 metallic stents and the possibility of determining their patency by MR angiography. *Invest Radiol* 2000; 35:739–746.
 22. Bartels LW, Smits HF, Bakker CJ, Viergever MA. MR imaging of vascular stents: effects of susceptibility, flow, and radiofrequency eddy currents. *J Vasc Interv Radiol* 2001; 12:365–371.
 23. Cavagna E, Berletti R, Schiavon F. *In vivo* evaluation of intravascular stents at three-dimensional MR angiography. *Eur Radiol* 2001; 11:2531–2535.
 24. Maintz D, Kugel H, Schellhammer F, Landwehr P. *In vitro* evaluation of intravascular stent artifacts in three-dimensional MR angiography. *Invest Radiol* 2001; 36:218–224.
 25. Kim D, Edelman RR, Margolin CJ, et al. The Simon nitinol filter: evaluation by MR and ultrasound. *Angiology* 1992; 43:541–548.
 26. Johnson SP, Raiken DP, Grebe PJ, Diffin DC, Leyendecker JR. Single institution prospective evaluation of the over-the-wire Greenfield vena cava filter. *J Vasc Interv Radiol* 1998; 9:766–773.
 27. Engmann E, Asch MR. Clinical experience with the antecubital Simon nitinol IVC filter. *JVIR* 1998; 9:774–778.
 28. Rousseau H, Perreault P, Otal P, et al. The 6-F nitinol TrapEase inferior vena cava filter: results of a prospective multicenter trial. *J Vasc Interv Radiol* 2001; 12:299–304.
 29. Pusey E, Stark DD, Lufkin RB, et al. Magnetic resonance imaging artifacts: mechanism and clinical significance. *RadioGraphics* 1986; 6:891–911.
 30. Wesbey G, Adamis MK, Edelman RR. Artifacts in MRI: description, causes, and solutions, In: Edelman RR, Hesselink JR, Zlatkin MB, eds. *Clinical magnetic resonance imaging*. 2nd ed. Philadelphia: W. B. Saunders, 1996; 88–144.
 31. Porter BA, Hastrup W, Richardson ML, et al. Classification and investigation of artifacts in magnetic resonance imaging. *RadioGraphics* 1987; 7:271–287.
-