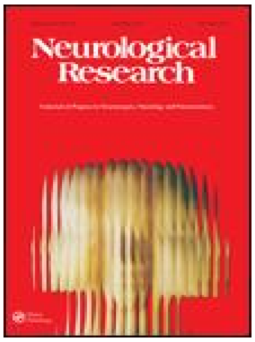

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Self-closing aneurysm clip: a historical review

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Objective: To analyse the self-closing aneurysm clip historical evolution.
Materials and methods: The authors reviewed the self-closing aneurysm clip's 50-year history. Major neurosurgical books, journals, testimonials, authors' personal experience, and scientific databases were analysed.
Results: Self-closing aneurysm clip malfunction was found to be related to different clip strengths (too strong or too weak) and clip's corrosion or fracture due to diverse stainless steel biocompatibility issues. It was found that 301, 401, 402, 58, and 17-7 PH alloys were not suitable for human implantation due to high risk of corrosion. In counterpart, 316MOSS, Elgiloy, Phynox, and titanium alloys were more biocompatible and less prone to corrosion. The last group showed no motion on the magnetic field. Titanium clip has shown to be artifact free on computerized tomography followed by high-grade cobalt–chromium clip all the other aneurysms clip present a significant artifact. The Federal Drugs and Administration/American Society of Testing and Materials (FDA/ASTM) was a major contributor on safety development of self-closing aneurysm clip.
Conclusion: Our 36-year self-closing aneurysm clip experience is reported.

Keywords: Brain, Artery, Aneurysm Clip, History, MRI, CT, Scattering

Introduction

Sixty years after Cushing and Horsley's cerebral arterial aneurysm neurosurgical treatment development, the first self-closing aneurysm clip was introduced.[1] Subsequently, operative microscopy, microanatomical dissections, bipolar coagulation, and brain retracting systems were added to the neurosurgical armamentarium and fostered further field development for three decades since the 1960s.[2,3]

Materials and Methods

The author studied the 50-year self-closing aneurysm clip history. Major neurosurgical journals, books, *Index Medicus*, testimonials, and authors' personal experiences were analysed. Self-closing aneurysm clips were classified according to their shape, mechanical configuration, clip characteristics, metal–body biocompatibility, and magnetic and radiographic behaviors. A combination of all factors aforementioned and minimal occlusive force was accounted for. Also, clips were also sub-classified as temporary or permanent depending on their role during surgery.

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Results

The analysis of the historical facts on the self-closing aneurysm clip can be summarized as follows: the self-closing aneurysm clip started in the 1960s with the introduction of the Mayfield and Schwartz aneurysm clip, followed by Heifetz, Yasargil, and Scovil–Lewis. This century was a learning period; the clip was utilized for clinical purposes only. The introduction of the self-closing aneurysm clip on the surgical armamentarium brought together the development of new technique and the use of the operative microscope, bipolar coagulation, brain retractor, cranial fixation, and new pharmaceutical therapy. From 1970 to 1980, the Committee for the Food Drug Administration/American Society of Testing and Materials was developed. This committee deals with the quality of the self-closing aneurysm clip. The clip was divided into two groups, temporary or permanent occlusion. A measurement of the clip closing force was introduced. Also the committee analysed the biocompatibility and ferromagnetic property and the potential for clip corrosion. Clips manufactured with SS301, 302, 401, 402, 17-7 PH, and N58 were not recommended for implantation. The only metal accepted was Elgiloy or Phynox (high-grade cobalt–chromium). The last material introduced was the titanium with a good property

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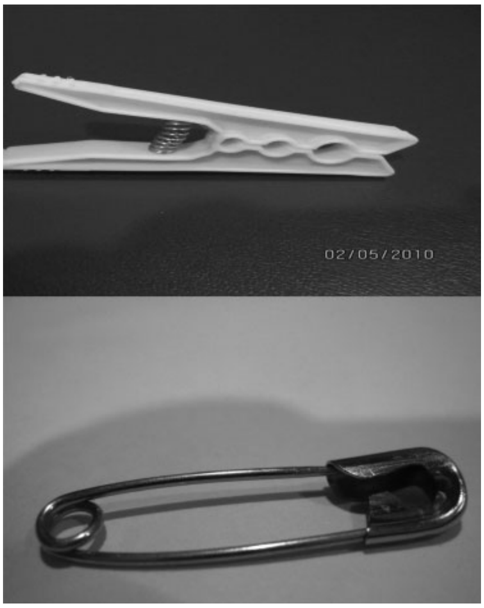

Figure 1 Ancestor of the aneurysm clip: (A) safety pin; (B) close pin.

on the magnetic field. The self-closing aneurysm clip made with this material does not have any movement on the magnetic field. The X-ray characteristic and the clip shape characteristic were analysed and they follow the Dujovny classification (body shape, leg closing, and tip). After 50 years since the introduction of the self-closing aneurysm clip, a significant level has been reached with the present designs.[4,5]

Discussion

In the decade of the 1960s, Schwartz and Mayfield introduced the first self-closing aneurysm clips.[1,6] Similar descriptions were mentioned in the medical literature, reflecting achievements from the 1960s.[7–9] Clip evolution can be traced back to the Egyptian period. During that period, the Egyptians used a variation of a safety pin to hold clothes together (M. Dujovny, personal communication). Safety mechanisms were removed from the pins and the blades were crossed over to allow occlusion and the concept was used in the first aneurysm clips developed (Fig. 1).

The Mayfield clip was very popular in the 1960s and 1970s with many variations introduced into the neurosurgical literature and market. Clips were made with a flat, stainless steel alloy (SS301, SS401, and SS402) (Fig. 2).

McFadden and Drake clips were the main developments at the same period. The Drake clip with the

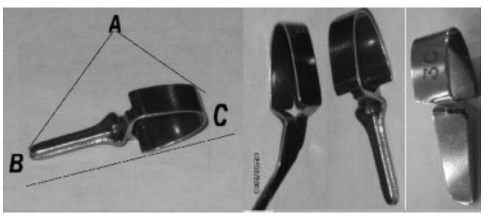

Figure 2 Alpha Mayfield, Pivot Heifetz clip, torch on bar Scoville–Lewis clip, and inverse-closing Perninsky.

Figure 3 Fenestrate clip, and Drake clip (Sugita and Yasagril).

assistance of George Kees was one of the most used clips for modification (fenestration) of the Mayfield clip. Drake's clip was thicker than the Mayfield's and its distal portion had a round circle that would allow incorporation of an artery or nerve inside; this clip was very useful on the interior or posterior brain circulation. McFadden's clip was made of thick, durable, and stainless steel alloy.[10,11]

Yasargil's clip was also introduced in the 1960s and became popular due to its mechanical characteristics.[5] His first aneurysm clip was made with a round thick wire and had a transverse serration. His second clip contained an outer ring which protected against the uncrossing of the aneurysm legs. This clip was manufactured with SS316 MO[12] (Fig. 2).

In 1964, Heifetz described a pivot-type aneurysm clip (according to Dujovny's classification of self-closing aneurysm clip) with details on its engineering design and metallurgic properties (Fig. 3). The clip was a miniature of the clothes pin and showed the importance of the blade. The blade is thin wide with mild curvature, and serration was incorporated in the inner side to increase grasping power.[13] The clip was made of three pieces: the blades and body, the internal spring, and the pin to hold the blades together. A groove in the main clip body allowed direct apposition of the clip applier to the body-blade complex. This exemplified the Laplace law with direct pressure application to a flat surface in determining clip blade stability. The spring was placed inside and utilized the alloy 17-7 (17 chromium–7 nickel) (Fig. 3).

The next clip to be developed in this decade was the Scoville-Lewis (Downs Surgical Ltd, Surrey, UK) who showed the miniaturization of the torsion bar. He presented two models: the straight and the curved. The clip was made with austenite stainless steel material that, during production, became semi-austenite.[14] The blade was flat and thicker with three rings in line with each other at the back of the blade. This clip was very popular in many countries in wait of development due to its low price.

The Khodadad (Baxter V. Mueller, Niles, IL, USA) and Kleinerkutz (Wuick, NC, USA) clips were similar to the Heifetz model, although in miniature.

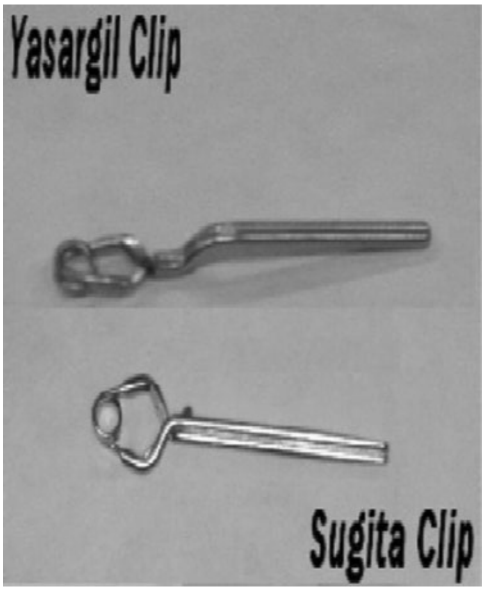

Figure 4 Yasagril clip and Sugita clip.

They were initially developed for plastic surgery and later utilized for performance of extracranial–intracranial bypass and sparingly in the surgery of intracranial aneurysms.[15,16]

In the late 1970s, the Sugita clip (manufactured by Mizuho in Niagata, Japan) was introduced. This clip presented the first high-grade cobalt–chromium alloy and an external crossing bar between the blade and the clip body to avoid misalignment or uncrossing of the clip arm. Also, the Sugita clip introduced a loop on the back of the clip body to allow a major opening of the clip blade. It was the alpha type clip with an incorporated loop (Fig. 4).[17,18]

In 1978, Dujovny demonstrated the need to differentiate the self-closing aneurysm clip for cerebral aneurysm from the clip designed for temporary occlusion of intracranial vessels. He showed clearly on scanning electron microscope the damage inflicted on the vascular endothelium after the placement of the miniature self-closing aneurysm clip. He also demonstrated that Archimedes', Hook's, and Laplace's laws explained the basic physics of how self-closing aneurysm clips functioned. Dujovny *et al.* also demonstrated in the laboratory the minimal vascular occlusion force, vascular wall damage on fine element analysis, and its scanning electron microscopy correlation.[19]

In the decade of the 1980s, the advent of the Yasargil–Phynox clip represented an improvement on Yasargil's clip.[5] The metal was replaced by high-grade cobalt–chromium alloy similar to the material used on the Sugita clip (Elgiloy). The crossing leg was covered by a box removing any extra wire outside the arm of the clip. The clip also got a loop in the back. It was manufactured in different sizes (3–40 mm), including special clips for temporary occlusion of cerebral arterial aneurysms during surgery. In the same decade, other pivot-type models were available in the market (Sundt–Kiees, Codman–Shurltf, and Randolf Massachuset). They were very similar to the Heifetz clip with increased thickness of the blade, but the clip applier could be exchanged easier than on previous models. The main representatives of that time were the Sundt–Kees, Vari-Angle, Sundt–Kees Slim clips (Codman & Shurtlef, Randolph, MA, USA), and the pivot clip (Baxter V. Mueller) (Fig. 5). The manufacturing company was headed by George Kees who was Mayfield's medical illustrator. McFadden's Vari-Angle could be rotated on the clip applier.[20] The last clip introduced in the 1980s was Perneczky's clip (von Zeppelin, Pullach, Germany), made out of high-grade cobalt–chromium Phynox metal. It had a reverse closing mechanism.[21]

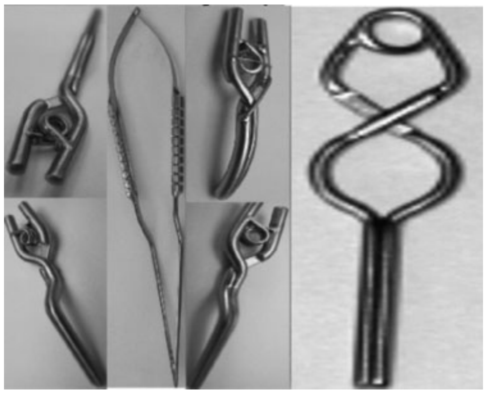

Figure 5 Beam hardening's artifact on computed tomography of the brain, and secondary aneurysm clip in the anterior communicating artery.

In the decade of the 1990s, the major change occurred with the commercial introduction of the titanium Spetzler clip alpha type. All later clips were manufactured with titanium, allowing for excellent biocompatibility and magnetic stability.[22,23]

The latest titanium clip

Lately in 2008, Sutherland *et al.* described their experience with a dual titanium–ceramic intracranial aneurysm clip. The clip was developed with priority for magnetic resonance imaging compatibility according to American Society of Testing and Materials (ASTM) Committee F-4.05 Guidelines. Ti–6A1–4V extra low interstitial titanium was chosen for the spring and pivot for its biocompatibility and high elasticity, or ability to flex without permanent deformation. Two different kinds of ceramics were tested: silicon nitride ceramic and yttria-stabilized zirconia ceramic. After material selection, computer-aided design and finite element analysis were used for accuracy in material development. Corrosion was also decreased in this new aneurysm clip due to the titanium alloy. In other words, the authors developed a clip with titanium blades and ceramic jaws, allowing for decreased artifact on the post-operative magnetic resonance imaging up to 3.0 T. The combination allowed for perfect magnetic resonance imaging compatibility without the inconvenient artifacts previously appreciated. The authors also developed a specific clip applier suitable for utilization with the newly developed intracranial aneurysm clip.[24]

Nitinol is very commonly utilized in interventional neuroradiology since it adapts to the body temperature and expands accordingly. More recently, nitinol self-closing clips have been developed to help in micro-anastomoses between small intracranial arteries. In 2008 and 2009, Ferroli *et al.* developed small aneurysm clips for intracranial micro-anastomoses. The system is composed of a needle-suture delivery system and a detachable nitinol self-closing wire. The authors justify the material due to its elastic characteristics and ability to be employed in diverse circumstances for treatment of complex intracranial aneurysms that will require artery-to-artery bypass.[25,26]

ASTM Committee

In 1972, major organizations introduced voluntary committees to standardize production, handling, and care of many instruments on the market. Regulation of aneurysm clip manufacture fell under the jurisdiction of the Food Drug Administration and ASTM Committee F-4.5. This committee was originally chaired by John M. Tew, Jr (Mayfield Neurological Institute) and had a collaboration with industry, academic, and government institutions. Members of the Committee were Nathaniel Simkins, William Curtin, and George Kees (Codman & Shurtlef), Curt Hollander (Aesculap, Holco, NY, USA), William Mertz (Baxter V. Mueller), Robert Vam Giersch (Weck, Durham, NC, USA), Manuel Dujovny, Joseph C. Maroon, Alfred Perlin, Ram Kossowsky, Nir Kossovsky (University of Pittsburgh, Pittsburgh, PA, USA), Robert Muntzer, Lawrence Kobren (Food and Drug Administration, Silver Spring, MD, USA), Peter Brown (ASTM, West Conshohocken, PA, USA), Joseph McFadden (Norfolk, VA, USA), William Scoville (computerized tomography; Hartford, CT, USA), William B. DeLong (Santa Barbara, CA, USA), Win Hirsh (American Silk Mills, Hudson, PA, USA), George Constantine (Down Surgical, Decatur, GA, USA), A. U. Daniels (Utah Biomedical Test Laboratory, Logan, UT, USA). After John Tew, the Committee was chaired by Ronald Appelbaum (Albert Einstein College of Medicine of Yeshiva University, New York, USA), and David Piepgras (Mayo Clinic, Rochester, MN, USA).

The Committee met for more 30 years at least twice a year and was one of the major contributors to the development of the self-closing aneurysm clip safety. In the early years, a catalog of all intracranial aneurysm clips was organized. It reported a thorough analysis, classification, and major failures encountered on all available clips. At that time, it was recognized that the major risk areas caused by the clip application were: (1) hemorrhage and possible death due to slipping if the grip strength or the jaw design were inadequate; (2) cutting of the aneurysm or the parent vessel by the clip's jaw during clip removal or maneuvering; (3) surrounding cerebral tissue toxicity if a non-biocompatible material was used; (4) initiation of thrombosis in the parent vessel secondary to injury of the vessel as a result of excessive clip pressure; and (5) clip corrosion and.[27,28] An unusual complication was a migration of the Heifetz clip from the posterior fossa to lumbar area causing lumbar pain.[29] Closing force was not evaluated by any of the manufactures, resulting in clips that had either too weak or too strong closing forces.

Initial scanning electron microscope analysis showed that all temporary occlusion clips induced endothelial damage, breakage, and thrombosis. This triggered better differentiation between self-closing and temporary occlusion aneurysm clips. Three instruments were then developed: Utah Biomedical Test Laboratory device, the George Kees clip force measurement, and the Perlin–Dujovny variable computerized clip force measurement.[30–32]

The first instrument which was sponsored by the Food and Drug Administration and ASTM presented a significant problem of poor reading due to unit's oscillation. The second instrument developed by George Kees was difficult to use due to its clip placement unit's depth and opening size.[31] The third instrument developed by the University of Pittsburgh in collaboration with Metatech (Northbrook, IL, USA) proved to be the most versatile equipment and it was accepted by the majority of the industry at the end of the 1970s. It was proved that the most accurate measurements were taken at 2 mm from the tip with the gap of 0.5 mm. The instrument allowed the force analysis during jaw opening and closing. The alpha clip had the same measurements during opening and closing, but the pivot type showed significant hysteresis, meaning that the opening and closing were asymmetric. Since this development, all clips manufactured recorded the opening and closing strengths, contributing to a decreased number of reports on clip slippage on the literature.

After the 1980s, the F-4 or -5 Food Drug Administration and ASTM Committee addressed numerous other issues including metallurgical composition, handling, appliers, exclusive, and single application of clips. It also reported clip stability on magnetic field. The aneurysm clips were to be designed for single application only. If sterile packaging was broken, but the clip was not directly exposed to the operating site, the aneurysm clip was to be re-sterilized in ethylene oxide. The Committee issued a statement that clip manufacturers using non-approved materials must label them as made of a material that did not meet ISO or ASTM F-4 standards. This allowed manufacturers to sell clips made of non-approved materials entirely at their own risk. As a result, several clips dropped off the market.

The Committee also recommended proper aneurysm clip packaging in a sterile box with insert describing the clip name, catalog number; force engrained, metal composition, and the clip applier to be used for the specific clip. Although behavior on the magnetic field of aneurysm clips was known to the aneurysm clip industry and Committee members since 1980, no action was taken by the Committee until catastrophic accidents involving clip slippage and patient demises occurred.[33,34] After that, the Committee recommended the use of the magnetometer to evaluate every single available clip. A disclaimer was introduced as a package insert. Dujovny was honored with a Sensitivity Award from ASTM in 1987 (most outstanding science engineering) for his collaboration on medical and surgical materials and devices (aneurysm clip).

Biocompatibility of metal–body interaction

In the early years of the self-closing aneurysm clips, little was known about the interaction between metal clips and body tissues. The Cushing silver clip was known to produce granulomatosis reaction around the clip as described by Nulsen in 1942.[2] Early clip manufacturers in the 1960s did not analyse metallic biocompatibility and their potential brain–tissue interactions. The only clip where they tried to improve the quality of the stainless steel was the second generation of the Yasargil clip with addition of molybdenum to the stainless steel chemical composition. This addition improved the anti-corrosive effect of the metal.

In 1977, Quest *et al.* reported another Heifetz clip fracture.[35] In 1978, Edner *et al.* reported a Heifetz clip fracture due to metal stress and fatigue.[36,37] In 1978, Rosenbaum *et al.* discovered another fracture clip.[38] Dujovny *et al.* received a fractured Heifetz clip from Joseph C. Maroon, obtained at autopsy on one of the operated patients. The clip was later submitted for further metallurgical analysis for identification of potential causes for the blade fracture. They observed that the fracture also occurred at the inner spring mechanisim.[39]

The study performed by Ram Kossowsky at the Metallurgical Research Laboratory in Westinghouse (Pittsburgh, PA, USA) showed that the 17-7 PH (17 chromium–7 nickel) stainless steel was incompatible to be implanted. The clip presented several problems because stainless steel was semi-austenite-magnetic. The polishing material utilized during the last phase of production was not removed and continued to act on the metal after clip implantation. Also, the clip was partially covered by an acrylic material utilized by the surgeon to hold the clip legs together. The uncovered area presented significant oxygen deprivation. The acrylic cover became the anode under clip cathode transforming the aneurysm clip into an electrical cell. Scanning electron microscope analysis of the fractured edge showed significant degradation of the stainless steel with loss of the carbon grains. Several small cracks were also observed. The redox analysis also shows the chemical composition of the fractured edge to predispose corrosion and ulterior fracture.[40–42]

The second Heifetz clip received at the Dujovny's laboratory was sent by Yves Keravel (Paris, France). The clip was implanted in a teenager with cerebral aneurysm. The clip's blade broke almost at the same area as the previous one (junction between the body of the clip and the blade) and led to patient's death. Clip analysis confirmed the previous findings and the magnetic wave was determined. Other four clips received at the same lab were analysed with similar results. In another clip, the internal spring was also fractured. These two clips and four later clips analysed in Dujovny's laboratory showed that the mechanism of failure was caused by stress corrosion. The results of a survey of several Latin American neurosurgeons revealed several failures of the Heifetz clip (M. Dujovny, unpublished data). Two Mayfield clips were analysed in Dujovny–Kossowsky lab in a case of a giant middle cerebral artery aneurysm. The clip induced a severe inflammatory reaction and granulomatosis around the clip and brain tissue. The clip was partially destroyed and presented a significant corrosion (E. Martinez, personal communication). A few Mayfield clips on stock in hospitals were found in a state of disintegration, corroborating with the above findings. (G. Kees, personal communication). The technique was developed by Kossowsky to determine the corrosion behavior of the different aneurysm clips in electrolytic base solution. The clip was placed in Ringer's solution and electrical current was transferred to the electrolytic bath. This was followed by scanning electron microscope analysis. The test showed that the 301SS, 304SS, 401SS (Mayfield clip series), 17-7 PH (Heifetz clip, Sundt–Kees Vari-Angle, Pivot, and Vari-Angle Slim), M58SS (Scoville–Lewis) presented significant implantation problems. The alloy on the Scoville–Lewis clip was changed from austenite to martensite during production. None of the clips analysed was suitable for long time implantation. Kossowsky *et al.* also suggested careful analysis of the chemical composition of the aneurysm clip as well as evaluation of the grain hardness, elasticity, and homogeneity.[42] This test was more efficient that the test performed on the Sujita clip by the manufacturer to place the clip in sea water for a period of 1 year (Food and Drug Administration: Freedom of Information).

In 1973, Aesculap introduced Yasargil's second generation clip. It introduced the 316 m alloy, with increased molybdenum proportion. This clip demonstrated no changes during the Kossowsky scanning electrolytic microscope test. Sugita introduced the Elgiloy in the early 1980s (Elgin, IL, USA) and was later followed by Yasargil (Phynox). The high-grade cobalt–chromium Elgiloy, Phynox, and MP 35 showed no alteration after this test and were compatible with body tissue. The only biocompatible clips available were the Sugita, the Yasargil–Phynox, and the McFadden Vari-Angle Pannescki, and later on the Spetzler made with titanium. In the late 1990s, Heifetz tried to introduce the same model clip manufactured from Elgiloy, but it was never made to the market.[30,31]

The introduction of titanium clips significantly improved the metallurgical properties of aneurysm clips, although the brittle characteristics of the metal may predispose its premature fracture (M. Dujovny, personal communication).

Clip applier

Clip handling, application, and cleaning were very important aspects of clip manufacturing since the introduction of self-closing aneurysm clips. The clip could not be manipulated with the finger tips and there was a specific clip applier for each individual aneurysm clip. Clip mishandling with the hands or an improper instrument led to strength loss and clip slippage. Blade misalignment or a gap could also be detrimental.

In the early 1960s, the clip appliers were short, but this changed in the 1970s with the introduction of the operative microscope.[1,6,43–45] The clip appliers became long and some of them had bayonet shape. The clip applier for temporary clip occlusion commonly had a different color.

The alpha type clip (Mayfield, Yasargil, and Sugita) had no problem between the clip and the clip applier except when the clip applier for temporary occlusion was utilized in lieu of the regular aneurysm clip applier.[41] They could not be manipulated, only with the appropriate clip applier. The clip appliers designed for the Sundt–Kees Vari-Angle, Pivot, or Sundt–Kees Slim were not perfectly fit between the clip applier and the aneurysm clip inducing significant damage on the back portion of the clip. There was significant transfer of the metal from the clip applier designed for the Sundt–Kees Vari-Angle to Mcfadden Vari-Angle clips, allowing metallic contamination and electrical charging.[46]

The F-4.05 Committee recommended the placement of the same material from the inner part of the clip applier which was in contact with the clip to avoid any metal transfer. The only self-closing clip that never had a special applier was a Scoville–Lewis clip. The Sanno clip applier was multi-functional and could be utilized in the Yasargil, Sugita, or Heifetz clip. The applier also had the capacity to change the clip holding angle. The Heifetz clip applier provided the best fit between the groove and the clip, and allowed no friction between the applier and the clip.[41]

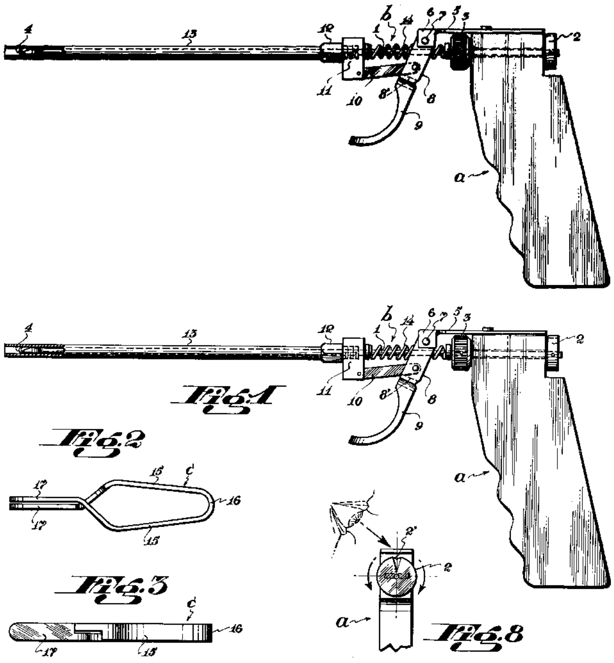

Figure 6 Darachinsky clip applier.

Derechinsky modified the Kandel stereotactic unit. The clip was held by a hook and introduced into a stereotactic tube. He modified the clip holder to take a shape of a pistol.[47] Following Dujovny's suggestion, the clip was modified to allow 360° circumvolution (Fig. 6). Later, this mechanism was copied and manufactured by Aesculap under the name of Caspar for the Yasargil clip. The only problem with the new clip applier was a gap between the jaw of the applier and the main shaft which sometimes trapped the arachnoid and produced severe complication.

Aneurysm clip storage

In the beginning, the clips were stored in an operating room inside a glass container with a piece of cardboard or cloth between the blades. It was difficult to track the age of the clip because old and newly ordered clips were kept in the same place (G. Kees, personal communication). Around the 1970s, the Heifetz clip was the first one that was manufactured individually and packed in a plastic box, although it was not sterilized beforehand. The Yasargil–Phynox aneurysm clip was delivered in a sterile special bubble-box design. The packaging also included information about the clip's characteristics and strength. Later on, Sugita Mizuhu Niagata developed a similar tray.

In the 1990s, the Mizuho Company as well as Aesculap developed a special tray to have the clip stored and delivered during the surgical procedure. More recommendations regarding handling and care of the aneurysm clip were published by the ASTM.[17,48]

Magnetic resonance imaging

The introduction of the magnetic resonance imaging in the diagnosis of neurological disease brought another challenge to the F-4.05 Committee. The magnetic field could be detrimental to the patient having a magnetic clip or other magnetic implant. The movement (torsion and displacement) of the self-closing aneurysm clip could induce a rupture of the cerebral vessel or another organ. Antidote had been reported case of blindness after retinal hemorrhage. It was demonstrated by Dujovny *et al.* in 1983 that all clips proven non-biocompatible such as the Mayfield, Heifetz, Scoville–Lewis, Sund–Kees Vari-Angle, and Sundt–Kees Slim moved significantly in the magnetic field. A catastrophic bleeding of a patient having a Sundt–Kees Vari-Angle clip brought attention of the Food Drug Administration that recommended that no patient with intracranial aneurysm clips could undergo magnetic resonance imaging. Dujovny *et al.* showed that the area of critical movement of the clip is about one-half of a meter from the magnetic resonance imaging gantry with a major increase at the gantry area.[49–51]

The introduction of the vibrating sample magnetometer (LDJ Electronics, Troy, MI, USA) by Dujovny *et al.* clearly showed that it is possible to determine magnetic quantification and magnetic imaging safety of aneurysm clips.[51] This instrument allowed the quantification of electromagnetic units per gram (EMU/g) of any aneurysm clip. It was found that the Heifetz 17-7 PH, Mayfield, Scoville–Lewis, and Sundt–Kees Vari-Angle clips had high magnetic values measured in EMU/g, ranging from more that 1–152.7 EMU/g (Heifetz 17-7 PH, 152.7 EMU/g; Mayfield, 83.63 EMU/g; Scoville–Lewis, 5.28 EMU/g; Sundt–Kees Vari-Angle, 112.4 EMU/g). The Heifetz Elgiloy, McFadden Vari-Angle, Perneczky, Sugita, Sundt-Kees Slim, and Yasargil clips produced very low magnetic values, ranging from 0.16 to 0.9 EMU/g (Heifetz Elgiloy, 0.49 EMU/g; Perneczky, 0.9 EMU/g; Sugita, 0.43 EMU/g; Sundt–Kees Slim, 0.16 EMU/g; Yasargil 316SS, 0.59 EMU/g; Yasargil Phynox, 0.61 EMU/g; Yasargil titanium, 0.07 EMU/g; Yasargil temporary, 0.46 EMU/g).

The torque of clips with high values of electromagnetic units per gram was 72 560 dyne/cm for Heifetz 17-7 PH, 90 869 dyne/cm for Mayfield, and 52 050 dyne/cm for Sundt–Kees Vari-Angle. Other clips, including the Heifetz Elgiloy, MacFadden Vari-Angle, Perneczky, Scoville–Lewis, Sundt–Kees Slim, and all Yasargil clips did not show any measurable torque.[50–52]

Recently, many authors have investigated aneurysm clips under different magnetic field strengths varying between 0.5 and 8.0 T. For field strengths up to 3 T, all pure titanium clips are magnetically safe and provide little movement to the application of magnetic field. At 8 T, however, titanium aneurysm clips are likely safe, producing a variable angle alteration during the application of magnetic field. Magnetic resonance imaging (8 T) is, however, not currently used in standard medical practice, since its medical hazards are not yet fully determined.[52–54]

Aneurysm clip radiological recognition

Since the introduction of the magnetic resonance imaging into daily medical practice, the potential risk has been a concern of the radiological community after 1985.[55] Although aneurysm clips were recognized by radiologists, the main characteristics of different types of clips were rarely seen in the X-ray reports. Only after the introduction of magnetic resonance imaging, radiologists started asking neurosurgeons what kind of clip was utilized during surgical procedure. There were, however, no specific guidelines to identify self-closing aneurysm clips. Shellock and Curtis extensively described the characteristics of the aneurysm clips, but there was no description on the biplane analysis of aneurysm clips on plain radiography.[56]

Dujovny's aneurysm clip classification has four different groups. The first group includes the V clip, commonly known as the silver clip. Originally, it was manufactured in the operating room by the surgeons, from the tantalum and the titanium, and clips were manufactured by Ethicon Inc. (Summerville, NJ, USA). None of them have modifications during magnetic resonance imaging examination. In the X-ray, it will show as a straight wire or wire with two little wings. Oliver Crooner showed the same experience.

The second group consists of alpha type which is built from one piece of wire (flat or round) (Yasargil clip) and the legs of the wire are crossed against each other. The wider area will be the portion corresponding to the base of the triangle in an X-ray. On the middle of the triangle, the clip becomes narrow and that is the crossing of the blade. We will also see the blade crossing as seen in X-ray. The crossing of the legs is only applicable to alpha type clips. The Sugita clip presents an extra wire crossing the body on the clip to the distal leg. This is a typical Mayfield serial clip. The Drake clip (fenestrate) belong to this group encircled shape after the crossing of the leg to allow placing the main artery by the compressing blade. This type also appears on other clips such as Sugita and Yasargil; however, there are other features that differentiate them such as loop on the back, encircled ring around the crossing point of the leg or the boxed-in cover of the leg of the clip. The McFadden Vari-Angle is seen practically the same as a Mayfield clip with a two-pin hole in the back portion to allow the grasping by the Sundt–Kees clip applier.

The third group is pivot type, which is built from three components: blade, pin and spring. In the

Figure 7 Clip characteristics to be observed on X-rays: (A) proximal; (B) leg closing; (C) leg tip.

Heifetz clip, the back portion of the clip presents the groove in which the clip applier will hold the clip. There is no crossing blade in this clip and the blades are comebacks. In Sundt–Kees Vari-Angle, Pivot and Sundt–Kees Slim, the back portion of the clip does not have a groove for the clip holding but an open square frame. These clips are made with wider blade.

The fourth group is called the torsion bar. In this clip, there are no closing legs and they present a loop on the back. This is represented in the Scoville–Lewis clip.

According to Dujovny and Samii (unpublished data), the best diagnostic tool to analyse the characteristic of the clip is plain X-ray of the skull with different positions (anteroposterior, lateral, skull based, and oblique). Although today most of the clips in the market are manufactured with high-grade cobalt–chromium or titanium, metals that are characterized biocompatible and non-ferromagnetic, we need to think that there are many aneurysm clips implanted in patients of older generation, which could move in the magnetic field. It is known from the study of Dujovny *et al*. that many aneurysm clips can move in an area up to 50 cm from the gantry and can be detrimental or fatal to the patient. The titanium clip does not present any artifact on the computerized tomography scan.[57] Although the introduction of this very important diagnostic tool on the neuroscience practice brought a significant development on the diagnosis, the potential of complications was also high.

Since the introduction of the computerized tomography in the 1970s and the magnetic resonance in

Table 1 Avoidance factor involved on computerized tomography artifact

Streaking	Generally due to an inconsistency in a single measurement
Shading	Owing to a group of channels or views deviating gradually on the true measurement
Ring	Owing to errors in an individual detector calibration
Distortion	Owing to helical reconstruction.
Physics-based artifacts	Acquisition of computerized tomography data
Patient-based artifacts	Caused by metallic materials in or on the patient
Scanner-based artifacts	Result from imperfections in scanner function
helical and multisection artifacts	Produced by the image reconstruction process.
Beam hardening	Individual X-ray beams composed with rages of energy
Cupping artifacts	X-rays passing through the phantom
Streaks and dark bands	Object passage
Built-in features for minimizing beam	Filtration and calibration correction
Partial volume	Occurs when a dense object lying off-center protrudes partway into the width of the x-ray beam
Photon starvation	Attenuating shoulders
Automatic tube current modulation	Allows sufficient photons to pass through the widest parts of the patient without unnecessary dose to the narrower parts
Adaptive filtration	Reduce the streaking in photon-starved images
Undersampling	Projections used to re reconstruct a computerized tomography image
Metallic materials	Abnormal range handled by computer in an incomplete attenuation
Metal artifacts by the operator	Patients are asked to remove; jewellery
Software corrections for metal artifacts	Streaking caused by over-ranging
Patient motion	Cause misregistration artifacts
Avoidance of motion artifacts by the operator	Metals removed from patients before scan
Built-in features/or minimizing motion artifacts	Overscan and underscan modes, software correction, cardiac gating
Incomplete projections	Incomplete photon-gantry reception from the body after test
Ring artifacts	Uniform visible phantoms
Avoidance and software corrections	Software detector variations
Helical artifacts in the axial plane: single-section scanning	Changes of anatomical structures
Helical artifacts in multisection scanning	Complication of image
Cone beam effect	Number of rotations acquired per rotation
Multiplanar and three-dimensional reformation	Used with narrow acquisition sections and overlapping reconstructed sections
Stair step artifacts	Appear around the edges of structures
Zebra artifacts	Reformatted images from helical

Source: According to Barrett JF, Keat N. Artifacts in computer tomography recognition and avoidance. Radiographics 2004;24: 1679–91.

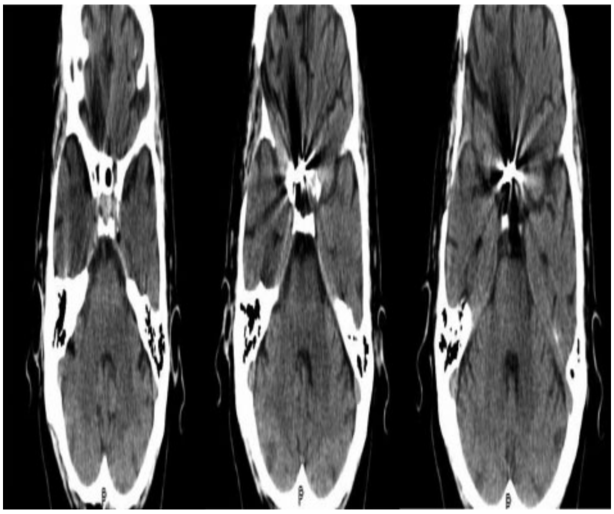

Figure 8 Metal scattering.

the 1980s, the radiological community had no major worry about the aneurysm clip. The major concerns started in the 1980s about the possible clip displacement due to the magnetic moment of the implant. Dujovny *et al.* started in 1990 to investigate the potential risk of the aneurysm clip. The search for the non ferromagnetic clips brought the introduction of the high-grade cobalt–chromium and the titanium on the market. Numerous studies show that those implants were compatible with the magnetic resonance imaging, but artifacts continued to be a significant problem to both computerized tomography and magnetic resonance imaging tests, although the analysis of aneurysm clips does not endanger the patients. Computerized tomography was not used as primary analysis to determine the characteristics of the clip as large strike artifacts may cover all the surrounding areas (Table 1).

In 1989, Romner *et al.*[58] analysed the ferromagnetic properties of the aneurysm clip. The main problem with the old aneurysm clip was the artifact on the computerized tomography. The titanium clip has shown a significant improvement over the high-grade cobalt–chromium clip[59,60] (Fig. 7). Pechilivanis analysed the evaluation of clip artifacts in three-dimensional computerized tomography and found that the analysis of the titanium Yasargril clip depends on the angle of the gantry (0, 45, and 90°). The fewer artifacts were observed on 0° as they were exclusively distributed along long axis. They increased on 45 and 90° *in vitro*. Veldkamp *et al.* in 2010 developed an interpolation technique for metal artifact suppression in computerized tomography. Kirvan *et al.* used multislice thick segmented cadmium tungstate photodiode detectors to improve contrast detectability in a megavoltage cone beam for computed tomography. Prell showed the reduction of metal artifact clipping and coiling in an interventional C-arm computerized tomography (Fig. 8). His study shows an overall improvement of brain tissue modeling and implant visibility using a flat panel computerized tomography metal detector.

In the last 5 years, new techniques using algorithm implementations have improved in the metal artifact detection on computerized tomography using a projection mask and computation of a three-dimensional relaxation factor that allows compensation for beam divergence.

Conclusion

The self-closing aneurysm clip has evolved during the last 50 years. Since the late 1970s, an understanding of the biocompatibility and metallurgical knowledge has been acquired. Also, the safety of the clip became better understood, the computerized measurement of the clip forces, and the early complications of the lacerations or slippage in the vessel wall, and the standardization and manufactured production became more accurate. A new problem occurred with the usage of the magnetic resonance imaging causing clip mobility and rupture of the vessel in the magnetic field. Clips manufactured with 301SS, 401SS, 402SS, PA 17-7PH, have been retrieved by the manufacturer from the market. The only safe products are clip manufacturers with 316MOSS, Elgiloy, Phynox, and titanium, are safe to be implanted. The latest improvement of the computerized tomography algorism may eliminate the metal artifact from the computerized tomography angiogram and the digital subtraction angiogram.

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References

1 Mayfield FH, Kees G, Jr. A brief history of the development of the Mayfield clip. Technical note. J Neurosurg 1971;35:97–100.
2 Dujovny M, Kossovsky N, Kossowsky R, Nelson D, Wackenhut N, Perlin A, *et al.* Vascular clips: a historical and biomechanical perspective. In: Fein JM, Flamm ES, editors. Cerebrovascular surgery. Berlin: Springer-Verlag; 1985. p. 997–1045.
3 Gibo H, Carver CC, Rhoton AL, Jr, Lenkey C, Mitchell RJ. Microsurgical anatomy of the middle cerebral artery. J Neurosurg 1981;54:151–69.
4 Gomes F, Dujovny M, Umansky F, Ausman JI, Diaz FG, Ray WJ, *et al.* Microsurgical anatomy of the recurrent artery of Heubner. J Neurosurg 1984;60:130–9.
5 Yasargil MG. [Significance of microsurgery in brain surgery]. Dtsch Med Wochenschr 1969;94:1496–7.
6 Yasargil MG, Krayenbuhl H. The use of the binocular microscope in neurosurgery. Bibl Ophthalmol 1970;81:62–5.
7 Schwartz HG, Holmes TG. Surgical management of intracranial aneurysms. South Med J 1961;54:493–8.
8 Zada G, Christian E, Liu CY, Giannotta SL. Fenestrated aneurysm clips in the surgical management of anterior communicating artery aneurysms: operative techniques and strategy. Neurosurg Focus 2009;26:E7.
9 del Maestro RF. Origin of the Drake fenestrated aneurysm clip. J Neurosurg 2000;92:1056–64.
10 Drake CG. On the surgical treatment of ruptured intracranial aneurysms. Clin Neurosurg 1965;13:122–55.

11 McFadden JT. Modifications of crossed-action intracranial clips. Technical note. J Neurosurg 1970;32:116–8.
12 Yasargil MG. [Development of diagnosis and surgical therapy of cerebrovascular diseases]. Schweiz Med Wochenschr 1967;97:1734–6.
13 Heifetz MD. A new intracranial aneurysm clip. J Neurosurg 1969;30:753.
14 Dujovny M, Kossovsky N, Kossowsky R, Perlin A, Segal R, Diaz FG, *et al*. Intracranial clips: an examination of the devices used for aneurysm surgery. Neurosurgery 1984;14:257–67.
15 Khodadad G. New clip for intracranial surgery and vascular microsurgery. J Neurosurg 1967;26:448–9.
16 Lougheed WM, Khodadad G. A new clip for surgery of the intracranial and small blood vessels. J Neurosurg 1965;22:397–8.
17 Sugita K, Kobayashi S, Kyoshima K, Nakagawa F. Fenestrated clips for unusual aneurysms of the carotid artery. J Neurosurg 1982;57:240–6.
18 Sugita K, Kobayashi S, Inoue T, Takemae T. Characteristics and use of ultra-long aneurysm clips. J Neurosurg 1984;60:145–50.
19 Dujovny M, Wakenhut N, Kossovsky N, Gomes CW, Laha RK, Leff L, *et al*. Minimum vascular occlusive force. J Neurosurg 1979;51:662–8.
20 McFadden JT. Evolution of the crossed-action intracranial aneurysm clip. Technical note. J Neurosurg 1989;71:293–6.
21 Perneczky A, Fries G. Use of a new aneurysm clip with an inverted-spring mechanism to facilitate visual control during clip application. Technical note. J Neurosurg 1995;82:898–9.
22 Lawton MT, Heiserman JE, Prendergast VC, Zabramski JM, Spetzler RF. Titanium aneurysm clips: Part III – Clinical application in 16 patients with subarachnoid hemorrhage. Neurosurgery 1996;38:1170–5.
23 Lawton MT, Ho JC, Bichard WD, Coons SW, Zabramski JM, Spetzler RF. Titanium aneurysm clips: Part I – Mechanical, radiological, and biocompatibility testing. Neurosurgery 1996;38:1158–63.
24 Sutherland GR, Kelly JJ, Boehm DW, Klassen JB. Ceramic aneurysm clips. Neurosurgery 2008;62(5 Suppl. 2):ONS400–5.
25 Ferroli P, Ciceri E, Addis A, Broggi G. Self-closing surgical clips for use in pericallosal artery-pericallosal artery side-to-side bypass. J Neurosurg 2008;109:330–4.
26 Ferroli P, Acerbi F, Tringali G, Polvani G, Parati E, Broggi G. Self-closing nitinol U-clips for intracranial arterial microanastomosis: a preliminary experience on seven cases. Acta Neurochir (Wien) 2009;151:969–76.
27 Toyota BD, Ferguson GG. Basilar artery dissection: an early postoperative complication of aneurysm clipping. Case report. J Neurosurg 1994;81:139–42.
28 Asgari S, Wanke I, Schoch B, Stoike D. Recurrent hemorrhage after initially complete occlusion of intracranial aneurysms. Neurosurgical Rev 2003;26:269–74.
29 Oyesiku, MM, Jones RK. Migration of a Heifetz aneurysm clip to the cauda equine causing lumbar radiculopathy. Case report. J Neurosurg 1986;65:256–7
30 Dujovny M, Osgood CP, Barrionuevo PJ, Perlin A, Kossovsky N. SEM evaluation of endothelial damage following temporary middle cerebral artery occlusion in dogs. J Neurosurg 1978;48:42–8.
31 Dujovny M, Perlin A, Wackenhut N, Leff L, Kossovsky N, Nelson D. Aneurysm clip testing meter. Acta Neurol Latinoam 1980;26:183–92.
32 Dujovny M, Kossovsky N, Kossovsky R, Perlin A, Segal R, Diaz F, *et al*. Intracranial clips: an examination of the devices used for aneurysm surgery. Neurosurgery 1984;14:257–67.
33 New PF, Rosen BR, Brady TJ, Buonanno FS, Kistler JP, Burt CT, *et al*. Potential hazards and artifacts of ferromagnetic and nonferromagnetic surgical and dental materials and devices in nuclear magnetic resonance imaging. Radiology 1983;147:139–48.
34 Nievas MN, Hollerhage HG. Risk of intraoperative aneurysm clip slippage: a new experience with titanium clips. J Neurosurg 2000;92:478–80.
35 Quest DO, Countee RW. Fractured aneurysm clip. Case report. J Neurosurg 1977;47:463–5.
36 Nishikawa M, Yonekawa Y, Matsuda I. Experimental aneurysms. Surg Neurol 1976;5:15–8.
37 Edner GF, Ericson K, Forster DM, Steiner L. The broken clip. Acta Neurochirurg 1978;40:145–9.
38 Rosenbaum TJ, Sundt TM, Jr. Interrelatioiiship of aneurysm clips and vascular tissue. J Neurosurg 1978;48:929–34.
39 Dujovny M, Kossovsky N, Kossowsky R, Haines S, Maroon JC. Heifetz clip failure. A metallurgical study. J Neurosurg 1979;50:368–73.
40 Kossowsky R, Dujovny M, Kossovsky N, Keravel Y. Failure of a Heifetz aneurysm clip. J Neurosurg 1982;57:233–9.
41 Kossowsky R, Dujovny M, Kossovsky N. Metallurgical evaluation of the compatibility of surgical clips with their appliers. Acta Neurochir (Wien) 1981;59:95–109.
42 Kossovsky R, Dujovny M, Kossovsky N, Diaz F, Ausman J. Corrosion of aneurysm clips: evaluation and clinical implications. Part I: Metallurgical foundations of stress corrosion failure. Acta Neurochir 1984;72:31–43.
43 Yasargil MG, Krayenbuhl HA, Jacobson JH. Microneurosurgical arterial reconstruction. Surgery 1970;67:221–33.
44 Yasargil MG. Intracranial microsurgery. Clin Neurosurg 1970;17:250–6.
45 Yasargil MG. Surgery of vascular lesions of the spinal cord with the microsurgical technique. Clin Neurosurg 1970;17:257–65.
46 Dujovny M, Dujovny N, Slavin K. Aneurysm clips: 20 years later. Neurol Res 1994;16:4–5.
47 Derechinsky VE. Clip-holder instrument for clipping blood vessels. US Patent 14,367,746, 1983.
48 ASTM: Medical and surgical materials and devices. Vol. 13.01. West Conshohocken, PA: ASTM, 2009.
49 Dujovny M, Kossovsky N, Kossovsky R, Valdivia R, Suk J, Diaz F, *et al*. Anerysm clip motion during NMR imaging: *in vivo* experimental study with metallurgical factor analysis. Neurosurgery 1985;17:760–7.
50 Dujovny M, Dujovny N, Fiat D, Gundamraj NR, Misra M, Serdar AM, *et al*. Magnetic field gradients in the MRI suite and their effects on aneurysm clips. Neurol Res 1996;18:483–6.
51 Dujovny M, Alp MS, Dujovny N, Zhao YJ, Gundamraj NR, Misra M, *et al*. Aneurysm clips: magnetic quantification and magnetic resonance imaging safety. Technical note. J Neurosurg 1997;87:788–94.
52 Kangarlu A, Shellock FG. Aneurysm clips: evaluation of magnetic field interactions with an 8.0 T MR system. J Magn Reson Imaging 2000;12:107–11.
53 Lauer UA, Graf H, Berger A, Claussen CD, Schick F. Radio frequency versus susceptibility effects of small conductive implants – a systematic MRI study on aneurysm clips at 1.5 and 3 T. Magn Reson Imaging 2005;23:563–9.
54 Olsrud J, Latt J, Brockstedt S, Romner B, Bjorkman-Burtscher IM. Magnetic resonance imaging artifacts caused by aneurysm clips and shunt valves dependence on field strength (1.5 and 3 T) and imaging parameters. J Magn Reson Imaging 2005;22:433–7.
55 Hunter TB, Yoshino MT, Dzioha RB, Light RA, Berger WG. Medical devices of the head, neck, and spine. Radiographics 2004;24:257–85.
56 Shellock FG, Curtis JS. MR imaging and biomedical implants, materials, and devices: an updated review. Radiology 1991;180:541–50.
57 Dujovny M, Dujovny N, Fiat D, Gundamraj NR, Misra M, Serdar Alp M, *et al.* Magnetic field gradients in the MRI suite and their effects on aneurysm clips. Neurol Res 1996;18:483–6.
58 Romner B, Olsson M, Ljunggren B, Holtås S, Säveland H, Brandt L, *et al.* Magnetic resonance imaging and aneurysm clips magnetic properties and image artifacts. J Neurosurg 1989;70:426–31.
59 Mamourian AC, Pluta DJ, Eskey CJ, Merlis AL. Optimizing computed tomography to reduce artifacts from Titanium aneurysm clips: an *in vitro* study. Technical note. J Neurosurg 2007;10:1238–43.
60 van der Schaaf IC, Velthuis BK, Wermer MJ, Frenkel NJ, Maioie CB, Witkamp TD, *et al.* Multislice computed tomography angiography screening for new aneurysms in patients with previously clip-treated intracranial aneurysms: Feasibility, positive predictive value, and interobserver agreement. J Neurosurg 2006;105:682–8.