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Magnetic resonance imaging and aneurysm clips

A review

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The problem of implanted metals causing tissue damage by movement in patients exposed to MRI fields has produced a confusing welter of erroneous, pseudoscientific publications about magnetics, metals, medical equipment, and tissue compatibility. Quite simply, among the devices made for implantation, only those fabricated of stainless steel have the ferromagnetic properties capable of causing such accidents. The author, who introduced the basic design of the modern aneurysm clip in the late 1960s and then a cobalt nickel alloy as an improvement over steel, while chairing the neurosurgical committee assigned to the task of establishing neurosurgical standards at American Society for Testing and Materials, exposes this flawed information and offers clear guidelines for avoiding trouble. *(http://thejns.org/doi/abs/10.3171/2012.1.JNS111786)*

Key Words • **aneurysm clip** • **magnetic resonance imaging** • **neurosurgery history** • **stainless steel** • **science** • **titanium** • **MP35N**

Amid continued furor over lurking danger, it is indeed astonishing to find, in the annals of radiology and neurosurgery, only one reported fatality, this being also the only adverse incident caused by an implanted aneurysm clip moving in the magnetic field of an MRI scanner. One preventable death is, of course, one death too many, and no reasonable safety measure should be spared, nor any effort to eliminate the confusion, where confusion has become rife in a surfeit of flawed information. To this end, the tragedy of this fatality—and the noise behind its singularity—call for another look at the basics of clip design and the involved metallurgy as both relate to MRI and to tissue compatibility in the developing field of microvascular neurosurgery.

Clip Evolvement: Structure

The modern era of spring clip aneurysmorrhaphy began after World War II. Until then, only malleable metal clips and silk, linen, or cotton ligatures were available to the neurosurgeon. Because these methods were too difficult and too hazardous, neurosurgery developed several lines of vascular clips over a period of decades.[11] Among these, the crossed-action spring clip, based on an old technology,[29] is the most universal type in use today. Its adaption to intracranial vascular surgery began in 1954 when Black and German[1] described a modified tiny phosphor-bronze crossed-action electrician's test clip as a handy device for the temporary occlusion of cerebral arteries in humans and laboratory animals (Fig. 1).

In 1955 Schwartz[11,20,24] introduced a smaller crossed-limb clip made of a stainless steel known to be below the anticorrosion standards already recognized by orthopedic surgery, but thought to have greater spring strength (martensitic Type 420), and carefully designated it for temporary blood vessel clipping only (Fig. 2).

But, desperation charging the explosive atmosphere of an exposed, bulging, and often bleeding aneurysm deep in a surgical field led to the use of anything at hand to prevent an immediate catastrophe. Thus, for a brief time, Schwartz clips were implanted,[13] nothing else being available. Of note, some 56 years later, not one of these clips has caused an MRI-documented accident. However, the martensitic steels are frankly ferromagnetic, and MRI exposure of a patient harboring such a clip in the brain might have caused an incident, perhaps fatal.

In 1956 Mayfield[20] designed a line of even smaller stainless-steel clips (austenitic Type 301–304) for temporary clipping and tacitly for permanent implantation on the base of an aneurysm (Fig. 3), tacit meaning with caution because no one knew the ultimate safety limits of stainless steel. The austenitic device quickly became the dominant available clip.[11] At the time, about 25 years

Abbreviations used in this paper: AANS = American Association of Neurological Surgeons; ASTM = American Society of Testing and Materials; CNS = Congress of Neurological Surgeons; MIT = Massachusetts Institute of Technology.

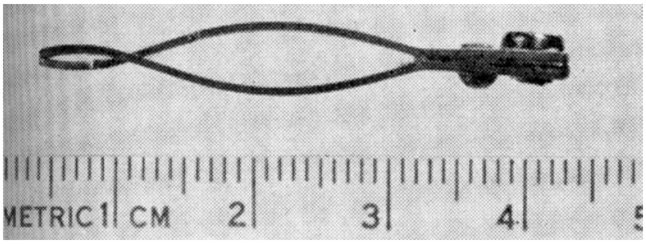

Fig. 1. Photograph of an inexpensive electrical test clip, which could be adapted to provide a small effective artery clamp. Adapted with permission from Black SPW, German WJ: A clamp for temporarily occluding small blood vessels. **J Neurosurg 11:**514–515, 1954.

before the advent of MRI, the austenites (nonferromagnetic), because of their greater tissue compatibility, had been in use for decades by orthopedic surgeons.

McFadden[27] modified the razorblade-thin limbs of Mayfield's clip by adding split wire (stainless-steel austenitic Type 316) to round off the edges and tips. This addition made the clip safer for aneurysm-artery interclusions (Fig. 4), at the same time introducing to neurosurgery the truly curved and the right-angle clip configurations (Fig. 4). The new design toed the leg tips inward[27] to impair any tendency to slip off the clamped tissue.

A Boston manufacturer of neurosurgical instruments made the first models, attaching split wire to clip limbs with silver solder. The manufacturer defended the use of silver in this mixture of metals, denying the possibility of galvanic action and claiming (erroneously) silver to be a noble metal and free from corrosion. On testing, however, the modified clips rusted overnight in normal saline baths, and the first maker threw up his hands. The device concept and its problems were then taken to Dr. Frank Mayfield, who engaged George Kees, maker of the Mayfield clip and at the time a Mayfield employee, to use the proper techniques to modify his clip safely. The new product passed the saline test. Through Mayfield's largesse, Kees made and marketed the modified clip under both names (McFadden-Mayfield), until the device became obsolete with the next step in clip evolution.

In the developing field of microsurgery, these clips all appeared obstructively big. To address the problem Scoville,[36] in 1966, devised the miniature torsion bar clip, made of EN58 J, a British austenitic stainless steel (Fig. 5), essentially the same metal as American 301–304 stainless steel.

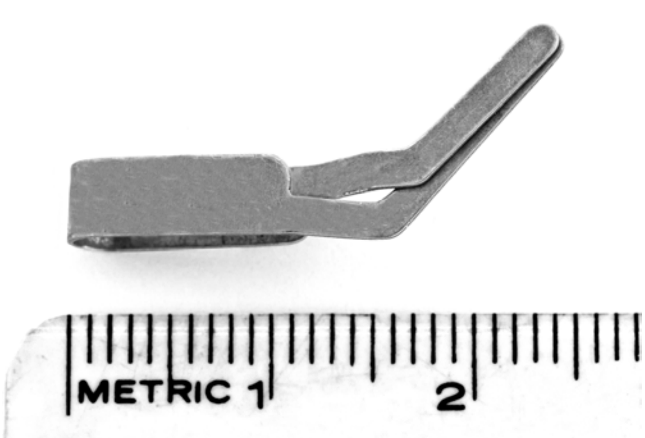

Fig. 2. Schwartz aneurysm clip. Photograph by Robert Ander (2011) from the author's collection.

Fig. 3. Mayfield stainless-steel aneurysm clip. Photograph by Robert Ander (2011) from the author's collection.

In bulk and strength, Scoville's clip proved to be excellent: small, very powerful, and simple to use. It could be applied at any chosen angle with a hemostat or a long slender needle holder, but its limbs were not crossed; instead, they opened in a V shape, with all the inherent risks, and were of one length only. These limitations made the clip not only useless but actually dangerous when a large, tough aneurysm base had to be embraced in the closing limbs. So, why not put the Scoville spring on the Mayfield clip? McFadden gave this idea to George Kees. The result (Fig. 6) proved to be something of a compromise, but the clip functioned well because of the tiny, powerful, helical coiled spring and the crossed limbs capable of embracing an aneurysm base.

Slight modifications, deflections bent from the original single piece of metal, eliminated the clip's tendency to scissor and to open too far (Fig. 7).[24] Holes were made in the spring arms, the outer rims sized to accommodate the ball-tipped applier, giving the clip more than 300° of variable-angle range.

Kees introduced the new device to market in 1969, as the McFadden Clip (Vari-Angle). Codman and Shurt-

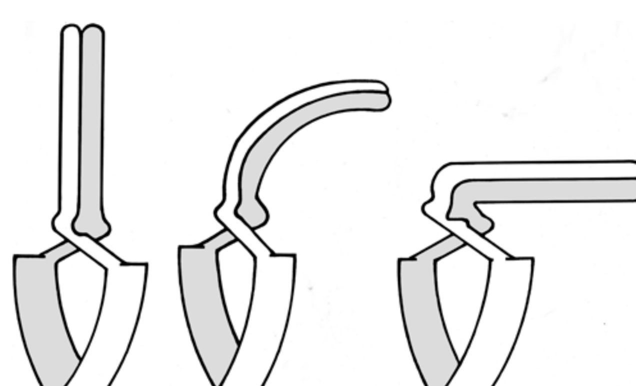

Fig. 4. McFadden-Mayfield aneurysm clip. From the author's collection.

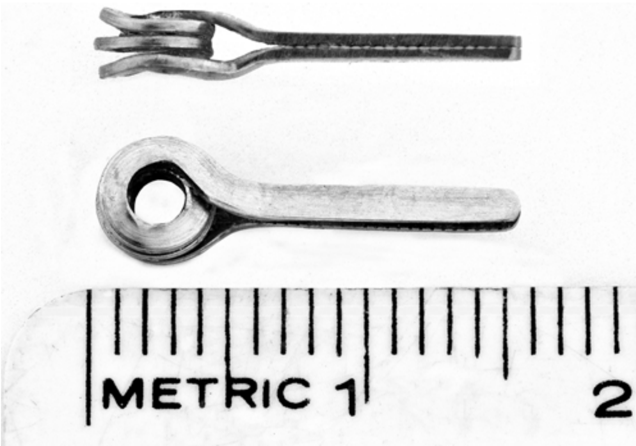

Fig. 5. Scoville miniature torsion-bar aneurysm clip. Photograph by Robert Ander (2011) from the author's collection.

leff later took over distribution, and the device quickly became, and remains, the dominant clip type, mimicked worldwide. To this day, it stands, in all aspects, as a product of Western technology: United States, Canada, Germany.[24,43] The US patent (No. 3,827,438, issued August 6, 1974),[21] in Kees name only, soundly records priority of the basic design. During the next 3 decades several people devised modifications (Yaşargil, Sundt, Sugita, and Spetzler). Of these authors only Yaşargil[45] acknowledged the priority, and only Sugita et al.[41] claimed it. Despite the immediate unequivocal refutation[21] and publications tracing the evolvement of this clip,[24] not to mention numerous letters to editors,[14,23,28] the infringement goes unchecked (AANS Sugita International Symposium, 2011). Charles G. Drake and Sydney J. Peerless in London, Ontario, gave ideas for various configurations to both Kees and Sugita, who then each developed a line of clips with some 70 shapes and reaches, but the basic design has remained the same for 43 years. The clip resembles nothing so much as a simple safety pin, with its limbs crossed and extending various lengths in a wide variety of configurations. The spiral spring, as a part of the entire clip body, and the crossed limbs give the clip its dominance.

Smith and later Sundt developed encircling curves proximal in the clip arms to spare contiguous arteries—the fenestrated clip.[11] Using Drake's idea for adapting the concept to the Mayfield and the McFadden-Mayfield clips, Kees made the first Drake clip. The pattern later went into all lines of the helical coiled-spring type.

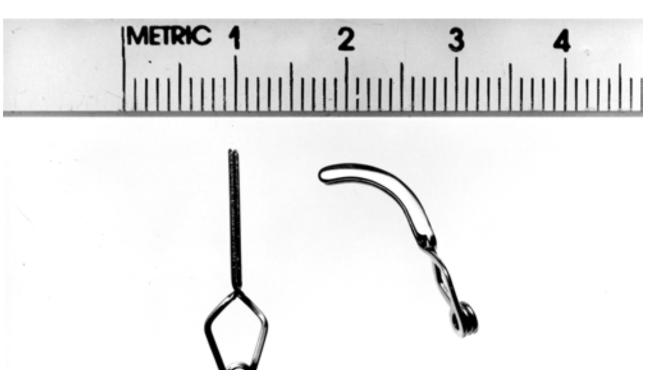

Fig. 6. McFadden aneurysm clip. Photograph from the author's collection.

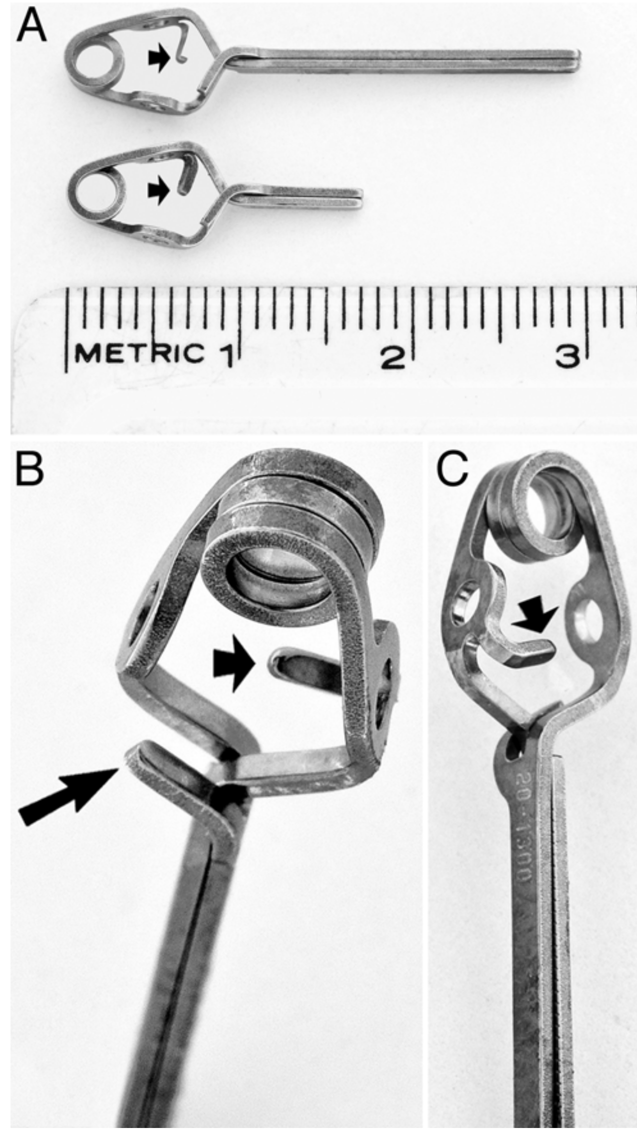

Fig. 7. Photographs of a McFadden Vari-Angle aneurysm clip showing the opening brake mechanism (*short arrows* in **A**), the anti-scissor guard (*long arrow* in **B**), and holes in the spring limbs **(C)**; the *short arrows* in C indicate the brake. Photographs by Robert Ander (2011) from the author's collection.

Clip Evolvement: Materials

The evolution of materials took a more circuitous route than did the improvements in structure. Early in the era, all spring clips were made of stainless steel. No other available metal at the time afforded both the necessary spring action and acceptable tissue compatibility. In 1956 Mayfield made the first move away from martensitic stainless steel, but some manufacturers continued to use it for a few years because of its stronger spring action. Corrosion problems and clip failure due to faulty design contributed to its abandonment. But many ferromagnetic clips were implanted during the 1960s and 1970s.

The silver solder imbroglio uncovered a disturbing paucity of metallurgy information in neurosurgical annals. The resulting publication[26] stimulated the AANS board of directors to send a representative in 1969 to the ASTM to establish standards in a burgeoning neurosurgical technology. Under the aegis of this organization now known as ASTM International, major industry (for example, General Electric, Kodak, General Motors, and medical device companies) work to establish necessary consensus standards. On the scene at the time, other surgical specialties and dentistry were already at work.[3] Here, inside open doorways, industry and academia commingle freely to discuss, in roundtable fashion, existing problems. In one of these committee sessions dealing with clip properties, a casual observer from MIT suggested the following: replace steel with MP35N (molybdenum, cobalt, chromium, and nickel), an alloy developed by Dupont for vat storage of acids, and incidentally found to be superior to stainless steels in both spring action and tissue compatibility. The committee approved the idea, thus introducing the cobalt alloys to neurosurgery. Using this metal, MP35N, to make the McFadden Vari-Angle Clip, George Kees took the first step away from using stainless steel in and around the human nervous system. Essentially MP35N is nonferromagnetic, its use by chance predating MRI by some 12 years. Titanium came under scrutiny but was considered at the time not to be the best metal for strong and reliable spring action; L. Steiner introduced it later to diminish clip artifacts in CT and MRI.[43] Several companies now make two lines of clips, those using titanium or its alloy and those using Phynox and the similar or identical Elgiloy, a wire alloy devised by the Elgin watch company for watch springs; the metal resembles MP35N with a 17% iron content.

With titanium now in vogue, its greatest advantage is the minimal or absent distortion of its own image on scans.[32] The maker of the Spetzler clip claims a secret process by which pure titanium is rendered as springy and as powerful as any metal in use. Other clips are made from a titanium alloy (Ti Al16, V4). Reports of mechanical failure of titanium clips have appeared in the annals of neurosurgery.[4,15] Of the other material choices, MP35N distorts and balloons MR images more than titanium, but it is mechanically superior.[25] Phynox (Elgiloy) produces the worst distortion because of its iron content. However, a stainless-steel clip causes even more image distortion.

Standards

The silver solder misadventure led to other progress and improvements. Activities of the AANS at ASTM attracted attention. The CNS soon joined the efforts. Drugs were added to the tasks, a name change was enacted, and the *Committee on Drugs and Devices* has since dealt with clips, shunts, other devices, and various drugs, representing the AANS and CNS at ASTM and ISO (International Standards Organization).[3] Committee members testified before Congress when laws were being written to regulate devices and drugs, and they later served on the FDA advisory panel for neurology and neurosurgery as regulations were being formulated. In both places they buffeted the too restrictive and too punitive measures under consideration. Among other accomplishments, the committee, writing its consensus standards for aneurysm clips, improved materials and established closing pressures and other physical standards; in the realm of malleable clips, the committee removed silver (actually sterling silver [7.5% copper]) from the list of approved metals because of its extreme corrosive and inflammatory action in body tissue.[30] The committee is still active, now under its fifth chairman. Since its inception 42 years ago, the committee has been dedicated to improvement of the metallurgy and the mechanics of aneurysm clips.

Stainless Steel

Steel by definition is predominantly iron (50% or more [personal communication, JR Gladden, 2011]).[25,33] The alpha iron in ferromagnetic stainless steel changes to the gamma (nonferromagnetic) phase when heated to the required temperature and, if then alloyed effectively, retains most of the gamma phase at environmental temperatures. These, the austenites, are regarded in neurosurgery as less likely than other steels to move upon exposure to a magnetic field. Thomas W. Eager (personal communication, 2011), Professor of Materials Engineering at MIT, states in his critique of the present article, "...the austenitic steels in their annealed state are non-ferromagnetic, but with mechanical working (such as forming into the strength and shape of a clip) will transform to the ferromagnetic martensite phase. This could have disastrous results. These types of steels are called TRIP steels (Transformation Induced Plasticity) ...Types 301 and 302 are some of the most susceptible steels to TRIP."

The steels used in the Mayfield clip and its descendants belong to this category (Types 301 and 302). These steels, sought after in industry for their unique physical characteristics, form into a satisfactory clip mechanically, but may prove to be treacherous in the MRI scanners in clinical medicine. Higher in the austenitic range (316, 316L), ferromagnetic activity is less likely, but the metal has less spring strength. Despite the ferromagnetic propensities of the austenitic stainless steel used to make the early clips, no adverse incident has been reported from exposure to MRI. In the 1960s and early 1970s, the Mayfield, the McFadden-Mayfield, and the Yaşargil (version of the Mayfield) clips were made of austenitic stainless steel, Types 301–304. The very first models of the helical coiled-spring crossed-action clip (McFadden Vari-Angle) in the late 1960s were fashioned from austenitic stainless steel and then, very soon, changed to the alloy MP35N. The Yaşargil was changed to Phynox.

No one should be making intracranial aneurysm clips of stainless steel; vastly superior metals are now available. If a surgeon has implanted a McFadden Vari-Angle, Yaşargil, Sundt Slim-Line, Spetzler, or Sugita clip made since 1980, his patient should not harbor a stainless-steel clip. Of the 40 or more vascular clip types in existence,[11] only the self-closing crossed-action coiled-spring clips are addressed in this statement.

Magnetism

Diamagnetic and paramagnetic materials become magnetic only when exposed to an external magnetic field (personal communication, CL Chien, 2011),[2,5,16,44] the first weakly repelled and the other weakly attracted. Both revert when removed from the exposure. The three commonplace ferromagnetic elements—cobalt, nickel, and iron—are strongly attracted to a magnetic field and retain magnetic properties when removed (personal communication, JR Gladden, 2011).[26] Quoting Professor Eager again (personal communication, 2011), "...diamagnetism and paramagnetism are properties inherent in the electronic structure of the atom, ferromagnetism is not. Ferromagnetism is created by cooperative action of multitudes of atoms forming crystal domains on a vastly larger scale than the atomic."

MP35N contains cobalt and nickel. Phynox or Elgiloy contains the same two metals plus 17% iron. Thus alloyed, these metals do not display ferromagnetic behavior when exposed to the scanners currently in use. Professor Eager writes, this from the critique[25] of an article by Dejovny et al:[6] "...clips...made from MP35N, Elgiloy, Phynox, titanium and its alloy are permanently immune to ferromagnetism, and the cobalt-based alloys (MP35N, Elgiloy, and Phynox) have twice the elastic modulus of titanium and hence greater spring or clamping for equivalent designs."

Clips tested in an 8.0-T MRI system have shown what Kangarlu and Shellock[17] consider to be acceptable reactions to MP35N and to titanium and titanium alloy. Movement of austenitic stainless steel and of Phynox raised concern. Elgiloy, essentially the same alloy as Phynox, raised no concerns in the test, but this result does raise questions about the testing methods and interpretation of the results. Biological effects in the ascending Tesla scale may limit the range of field strengths safe for clinical use. Small laboratory animals and frogs levitate at a 15-T exposure[16] through the repulsion of diamagnetic water content of living tissue.

Implants

Failed implants in a patient's skull cavity do not produce a characteristic clinical response as they do in dental (violent tooth ache) and orthopedic patients (fractured prosthesis and collapsed weight-bearing parts, purulent rejection of foreign material through soft-tissue surroundings, and so on). For this reason, early on, neurosurgery was slower to recognize the salient principles of metals and other materials. Beginning in 1969, the AANS addressed the problem and rapidly improved the practices, as described in the standards section above.[3,26] Industry was striving for a more powerful spring when making clips out of martensitic stainless steel before the MRI era.

A clip formed from a single piece of corrosion-resistant metal will have less electrochemical activity in tissue than a device formed of several parts. The actuating spring of alligator clips is an appurtenance, and in stainless steel, it may be at a distance in the galvanic series from the other parts, thus contributing to corrosion, and failure in certain models. The alligator clip with its many limitations has been the major offender in clip failures. More acceptable materials are now being used to manufacture clips of the type.

Juxtaposed clips of widely different composition such as stainless steel and sterling silver will react rapidly.[26] Lesser differences in kindred alloys do not always cause trouble. For instance, Hamby's patient[13] in whom both Mayfield and Schwartz clips were implanted in 1958 to treat multiple intracranial aneurysms had shown no evidence of complications as of the late 1960s (personal communication at the time). These two clips together in a saline environment would undergo galvanic action.[21,26]

Spring clip technology, now approaching its 60th year, like other disciplines and other technologies, has progressively evolved and produced improved devices. Beginning with the Schwartz and the Mayfield clips, neurosurgeons used what the industry could produce, and most of the devices were based on ideas and feedback from surgeons. The significance of refinements in corrosion prevention was overshadowed by surgical contingencies early in the era and by relative brief periods of observation. The AANS, later joined by CNS, began in 1969 its contributions to the science and the art. Most of the mechanical and materials deficiencies contributing to clip failure have been eliminated. No doubt better materials and better designs will appear in the future. The muddle in radiology over MRI should not be blamed on the neurosurgical technology in use many years before a patient appears on site to undergo MRI. It's the wrong place for a witch hunt, and the right place for rationality.

Specious Work

Despite abundant correct information in the annals, the most misleading sophistry has crept into published articles pertaining to clips. In metallurgy, for instance, various authors have referred to Phynox (Elgiloy) (17% iron) and MP35N (no iron) as stainless steel.[6,7,9,32,34] Neither material can accurately be labeled stainless steel and to do so confuses the issue. Metallurgical guidelines cannot make sense if the nomenclature is wrong, specifically because stainless steel is the only offender. As a result, confusion and frustration have inhibited the proper handling of patients needing MRI.

Erroneous statements about stainless steel add to the confusion. For instance, Romner et al.[34] have written, "Clips...of martensitic stainless steel such as the Mayfield and..." This statement is wrong and serves to confuse any effort to deal with an implanted clip of the Mayfield configuration, a very damaging error, indeed. Mayfield's clip was always austenitic stainless steel. He pioneered its use in the evolving clip technology.[20]

Careless language has added to the identification problems. The term "Vari-Angle," for instance, causes confusion when used without the proper eponym. Thus, Codman has sold several different Vari-Angle products, one being the Sundt-Kees Vari-Angle Clip (the culprit in the fatal case, see *The Patient*]). Use of the term Vari alone could mean anything, from this involved outdated martensitic stainless-steel clip to the latest product with proper engineering and up-to-date metallurgy. Careless reportage of history has obscured the facts of clip evolution[14,19] and created a false impression of neurosurgical irresponsibility. The article written by Louw et al.,[19] in particular, is an example of such reportage, reverting to deceptive sensationalism and erroneousness when the authors write, "...and a patient in whom an incompatible clip had been placed died during an MR imaging session. In response the American Society for Testing and Materials Committee developed…" In fact, this unfounded and erroneous claim appeared in print some 30 years after the committee of neurosurgeons and neurosurgical device manufacturers representing the AANS had begun work at ASTM on the mechanics and materials of intracranial aneurysm clips. The committee never approved the use of martensitic stainless steel for implantation, and none of their work was done in response to disasters. Furthermore, the clip in the fatal case was not incompatible. It had been there roughly 14 years, obliterating the aneurysm and doing no harm.

Shellock and Crues[37] condemned certain clips with incomplete and inaccurate identification by saying, "... these aneurysm clips (Drake, Mayfield, McFadden, Sundt-Kees) had sufficient ferromagnetism to warrant the exclusion of patients with these implants...," a statement made in 1988, some 18–20 years after neurosurgery had established materials standards for aneurysm clips. A review of the known characteristics of these clips, one at a time, reveals the faults of the article in question: 1) The early Drake clip, the fenestrated model of the Mayfield, or the McFadden-Mayfield clip, was made of austenitic stainless steel. Beginning in the 1970s, the design was incorporated in all four lines of the helical coiled spring clip, the McFadden Vari-Angle, the Yaşargil, the Sugita, and finally the Spetzler clip; not one by then was made of stainless steel. 2) The Mayfield clip was made of austenitic stainless steel 301–304, and the McFadden-Mayfield clip was composed of austenitic stainless steel. 3) The McFadden clip, or the McFadden Vari-Angle clip, after the initial austenitic models of 1969, was made of MP35N. 4) The Sundt-Kees Vari-Angle clip was made of martensitic stainless steel, a frankly ferromagnetic stainless steel, in the early models; the later Sundt-Kees Slim-Line clip[42] was and still is made of MP35N. So which McFadden, which Sundt, and which Drake model did the authors intend to implicate? This careless use of language, with its eponymous slights, only creates confusion and gives no one any useful information. In another article, Shellock and Crues[38] stated, "...the few fatalities that have occurred were the result of failure to follow guidelines..." Nine pages later in the same article,[38] the authors wrote, "To our knowledge, only one ferromagnetic aneurysm clip-related fatality has been reported in the peer-reviewed literature." They offered no reference and no proof for the first claim, and without the evidence this amounts to irresponsible and gratuitous sensationalism.

In an article by Dujovny and colleagues,[6] basic metallurgical errors found in tables cast doubt on the accuracy of the text. Consequently, opinions were sought from reliable experts in materials science: Thomas W. Eager, Professor of Materials Engineering at the MIT, and James C. Ho, Trustees Distinguished Professor of Physics and Chemistry at Wichita State University. Both authorities confirmed errors in the tables and the text, and the details were published.[25] The same scrutiny should be turned to other articles.

ClipFinder (http://clipfinder.klinikum.uni-muenchen.de/en/Doku.htm), with authoritative posturing, sets a flippant tone by classifying aneurysm clips as good guys (nonferromagnetic) and bad guys (ferromagnetic); the article then goes on to introduce mistakes: "It may be an obsolete dangerous ferromagnetic Drake clip..." As stated above, the Drake clip was made of austenitic stainless steel by Kees and Codman but never of a frankly ferromagnetic material such as martensitic stainless steel. A few paragraphs later, addressing materials, the authors remarked, "For the uncommon deformable clips… inert types of steel like tantal [sic] and titanium are used." Tantal, as they use the word, presumably means tantalum. Neither metal is in any way related to stainless steel. Still further in the document, "Cobaltalloys like the MP 35 N...contain very low steel and much nickel..." Here, again, is an example of the confusing misrepresentation and misunderstanding of steel. In no way is MP35N even remotely related to steel, stainless or otherwise.

The monograph *The Sugita Clip, Innovations in Neurosurgery*, written by a physicist and translated by John Junkerman, strives to credit Sugita with inventing and developing the helical coiled-spring crossed-action clip, now the dominant type.[12] The book is fraught with errors, whether intentional or otherwise, and largely ignores the previous existence of this clip, its composition, and its standards, all developed in the Western world before Sugita appeared on the scene. The absence of a bibliography, references, and precise dates of claimed events points to deception. The erroneous representations are too numerous to be addressed here. In accurate historical significance the book is far worse than inconsequential.

The Patient

First do no harm. The ferromagnetic (martensitic) aneurysm clip, in its 14th year of resting astride the, by then, thrombosed, atrophied, and scarred aneurysm base close to the brain of this patient, is causing no problems. It has done its job well, it has saved and extended a life, it is a product of a dwindling technology at the time of its use, and it will remain no threat left alone. The dangerous element in this scenario is not the clip. The danger is the radiologist. And the radiologist has accused the clip itself, stating "… the most dangerous ... are aneurysm clips."[18] In contrast to this blame placing, James C. Ho, Trustees Distinguished Professor of Physics and Chemistry, Wichita State, University, in his 1999 critique[25] of a clip article,[6] wrote: "… instruments are always innocent…"

In the report of the one fatality,[18] the authors describe the alleged incorrect identification of the implanted clip, said to be a Yaşargil clip. Photographs of the clip (Fig. 8), recovered at autopsy[18] and designated in the text as a Codman Vari-Angle, show a clip resembling a type once sold by Codman and also resembling a similar or identical type being sold by other manufacturers.

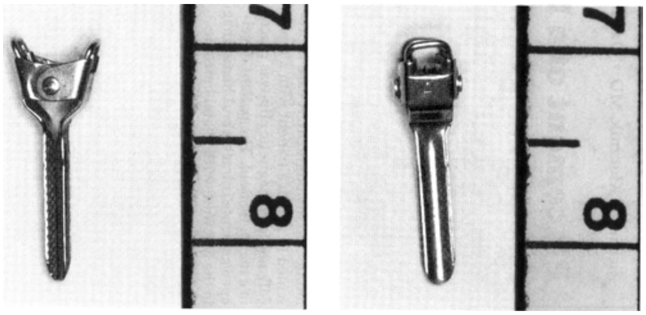

Fig. 8. Aneurysm clip recovered at autopsy. Reprinted with permission from Klucznik RP, Carrier DA, Pyka R, Haid RW: Placement of a ferromagnetic intracerebral aneurysm clip in a magnetic field with a fatal outcome. **Radiology 187:**855–856, 1993. Radiological Society of America.

These are alligator clips, spring loaded, like a plastic clothespin, and the attached spring is invisible on radiographs. The earlier models were made of ferromagnetic (martensitic) stainless steel. One of the product lines became notorious for clip slippage and clip disintegration. Clips of this type do not have crossed limbs, and they open in a V shape. Skull radiographs or a postclipping angiogram would have revealed identifying features to anyone familiar with the various types (Figs. 3, 9, and 10A). The absence on the radiograph of a clip image resembling the butt end of a safety pin (Figs. 6 and 7) would eliminate the later Yaşargil helical coiled-spring type, and the absence of a loop spring (Figs. 9, 10A, and 10C) would eliminate the earlier Yaşargil clip of the Mayfield type.

Figure 9, from the article written in 1959 by Hamby[13] on the treatment of multiple aneurysms, clearly shows the recognizable outline of Schwartz and Mayfield clips in a postoperative angiogram. Schöller and colleagues[35] demonstrated the aid conferred on clip identification by x-ray images, with the results marred by use of an unofficial and unproven classification of various types.[7,8,22]

To further prove the point of x-ray identification, several clips separately inside a human skull were radiographed (May 2011) (Fig. 10A–D).

Blame for the one reported death caused by clip movement in a magnetic field can be assigned to the single metal, martensitic stainless steel, a ferromagnetic alloy, iron in its alpha phase being the single element. This clip, implanted in 1978, very likely had been in stock a while before it was used.

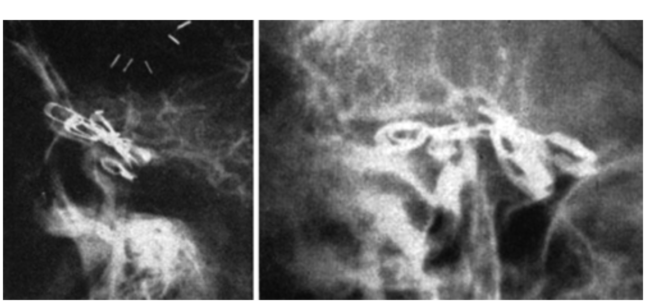

Fig. 9. An array of Mayfield and Schwartz clips on multiple aneurysms. Used with permission from Hamby WB: Multiple intracranial aneurysms: aspects of treatment. **J Neurosurg 16:**558–563, 1959.

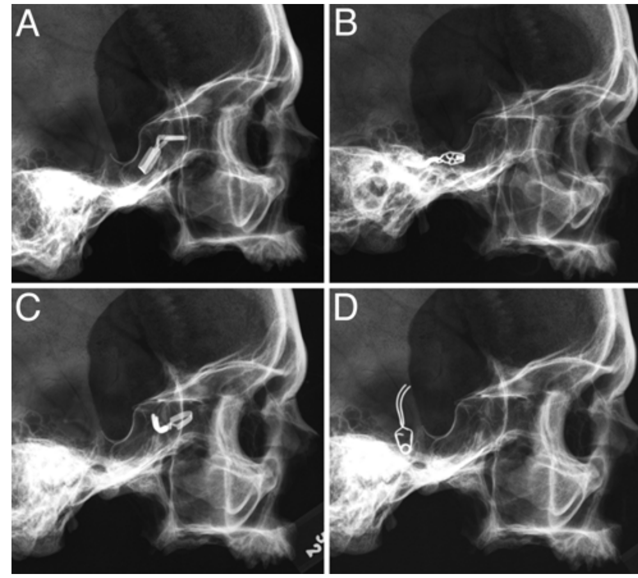

Fig. 10. Radiographs showing a variety of aneurysm clips: Schwartz clip **(A)**, McFadden Vari-Angle clip **(B)**, McFadden-Mayfield clip **(C)**, and McFadden Vari-Angle clip **(D)**.

The published article[18] engendered by this incident is a remarkable piece of work, its cryptic import in many ways too significant to not be examined. It impugns neurosurgery, but something is missing, and the story thereby lacks the spine of veracity. The radiology department made the right decision at the beginning in refusing the examination. And then the situation deteriorated into a tragedy of errors, raising several puzzling questions. Among them: What condition was the primary care physician looking for and why was he insisting on MRI scans? What or who provoked the family members to insist on MRI (and to volunteer to investigate the clip question? The report[18] states "...the family returned to the MR scheduling office with the information that a Yasargil clip...was placed on a middle cerebral artery aneurysm..."). Where did the relative bearing messages get the word Yaşargil? Surely not from the patient's record. Who in the family or who at a clerical level in the hospital or at the doctor's office would be aware of the safety and the integrity implicit in the Yaşargil name? Who passed on the incorrect information to the relative and from what source, or did anyone in fact do so? Here is a gaping void in information fraught with intrigue. Is this a plot—very cunning and clever and premeditated mischief—or an attempted cover-up, or an attempted whitewash, or just a bumbling mistake? Was a military order brought down to force the MRI scan? Why did no one in radiology contact the neurosurgeon who implanted the clip? How did the general practitioner and family members come to overrule the superior (in the existing circumstances) knowledge and judgment of a specialty, radiology?

Why did no one look for post- or intraoperative angiograms, and if such did not exist, why were radiographs not used to visualize the clip? These questions pose another cogent question: Was the situation handled entirely at a subordinate level until the accident? Then, in the midst of this calamity and in what appears to be a self-cleansing gesture of magnanimity, the radiology department sounds an alarm to the FDA, giving neurosurgery an unjust and invalid smear of complicity, and this agency responds with a broadcast of the most amazingly impossible, restraining edict on both neurosurgery and radiology: "...unless an aneurysm clip has been tested prior to implantation to establish whether it has ferromagnetic properties, it should not be scanned with MRI."[10] Literal compliance would eliminate from MRI almost all patients harboring a clip. Radiology defends its actions by referring to publications addressed above in the *Specious Works* section, and finds the imaginary Yaşargil clip, whether of stainless steel or Phynox, " ... had no deflection in a magnetic field up to 1.89 T." And on the tenuous thread of this irrelevance, radiology hangs the patient's life.

What, then, are the realities for such patients? The following are offered:

1) The ferromagnetic behavior of an implanted clip cannot be proven by any available means now and cannot be predicted except through its history, which may be unobtainable or unreliable. However, a few clip features may help:

A) Skull radiographs revealing a clip without a loop or coiled spring as part of the entire clip body contraindicate MRI exposure unless a nonferromagnetic composition can be verified. In other words, beware of the alligator clip (Fig. 8).

B) Skull radiographs (Figs. 9, 10A, and 10C) revealing a loop spring as part of the clip body indicate stainless steel in every case. All are austenitic with one exception: the Schwartz clip. On skull x-ray pictures, the Schwartz silhouette, resembling a pelican profile, should be unmistakable (Figs. 2 and 10A). Only this one clip of the loop-spring type was made of ferromagnetic stainless steel.

C) Skull radiographs revealing a helical coiled spring (spiral) as part of the entire clip body, resembling the butt of a safety pin, usually indicate the presence of MP35N, titanium, or its alloy, Phynox or Elgiloy. All of these metals are nonferromagnetic. Austenitic stainless steel, however, was used in very early models.

2) From a practical standpoint, when an old Mayfield clip lying inert on a granite surface snaps audibly onto the approaching end of a $2 pen-magnet from the hardware store, is there cause for concern about the behavior of its equals in a brain exposed to a 1.5-T field? Perhaps this can best be answered with another question: Is the life of any patient in the hands of a competent neurosurgeon fatally dependent on information obtainable only by MRI? Surely the answer is a unanimous no. Clips made of austenitic stainless steel are known to manifest partial return to ferromagnetism. They are not considered entirely safe for MRI (personal communication, TW Eager, 2011).

3) The cautionary wisdom would be not to undertake MRI in any patient harboring a stainless steel clip. Not many such patients are still alive, they all are bound to be quite old, and the results could not be worth the risk, especially when the necessary information is otherwise available. This applies to not only the types discussed here, but to all spring clips such as the Lougheed-Kerr, Khodadad, and other clips as illustrated by Fox[11] in his 1976 article.

4) In all cases the operative record should be perused, and unless the implanted clip is identified—eponym, material, and manufacturer (for example, Yaşargil clip, titanium alloy, and Aesculap)—the examination should be refused. Too often the search will reveal nothing more than the laconic brevity, "...was clipped."

5) The question has been presented to a reviewer of this article, Joseph Rhea Gladden (Department of Physics, National Center for Physical Acoustics, University of Mississippi): Could advances in physical acoustics be used to obtain definitive information about metals buried in living tissue? The answer (paraphrased) offers encouragement: Exposure to a weak AC magnetic field will cause ferromagnetic metal to vibrate slightly, producing Doppler shifts in the reflected acoustic waves...; amplitudes of less than one millimeter should be detectable acoustically (personal communication, 2011).

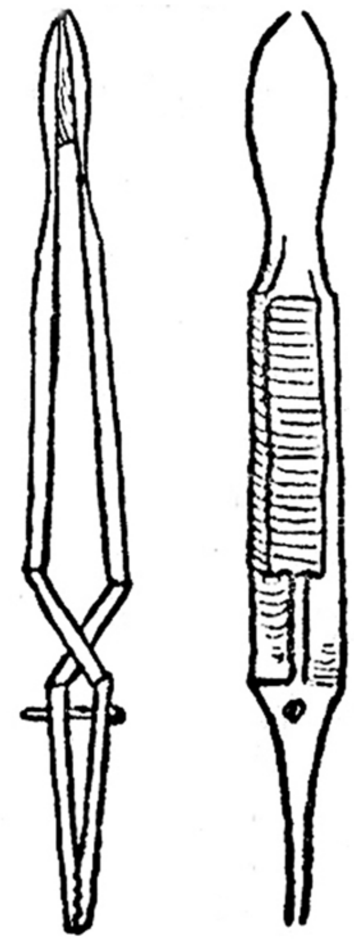

Fig. 11. Drawing of Charrière forceps. Reprinted from Møller-Christensen V: **The History of Forceps: an Investigation on the Occurrence, Evolution and Use of the Forceps From Prehistoric Times to the Present Day.** Copenhagen: Levin and Munksgaard, 1938.

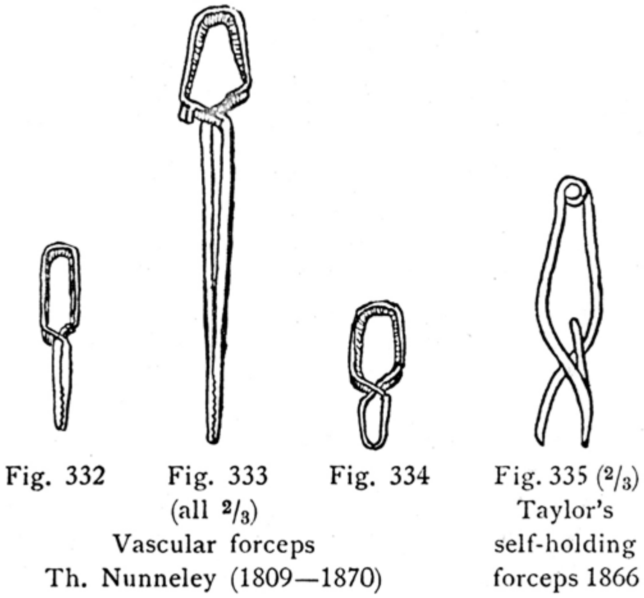

Fig. 12. Nunneley's device **(left)** and Taylor's forceps **(right)**. Reprinted from Møller-Christensen V: **The History of Forceps: an Investigation on the Occurrence, Evolution and Use of the Forceps From Prehistoric Times to the Present Day.** Copenhagen: Levin and Munksgaard, 1938.

Science

The advanced symbolic language of science, as well as the accompanying expository script—of physics, mathematics, metallurgy, magnetism, chemistry and others—appearing in a medical journal stonewalls practitioners not accustomed to it. Editors too, who may avoid responsibility for validity and pass the manuscript on to an editorial board; then it appears in print under no greater discipline than the assumed umbrella of absolute academic verisimilitude. Which means, they don't understand it either, not to an authoritative depth. Errors and deceptions slip through the gap. This travesty on reason plagues not just the neurosurgery world, and the radiology world, but the world of science in general.[31] When rebellion erupted with the publication of Sokal's article[39,40] spoofing scientific jargon, deceiving the editors of *Social Text*, and followed by his book, *Impostures Intellectuelles,* exposing these obfuscating flaws, scientists, Richard Dawkins for one, reacted gleefully. Unfortunately, nothing so witty has come to the aid of neurosurgery and radiology. Some of the authors, in an air of portentous seriousness, create a false impression of lagging technology and negligent behavior, and of themselves coming to the rescue. Shamefully this pretentious foundation of slippery sands at times has had dedicated and

Fig. 13. Rendering of a Thompson-Walker penile clamp developed in the 1920s. Courtesy of Speedway Surgical Co. (http://www.speedwaydelhi.com).

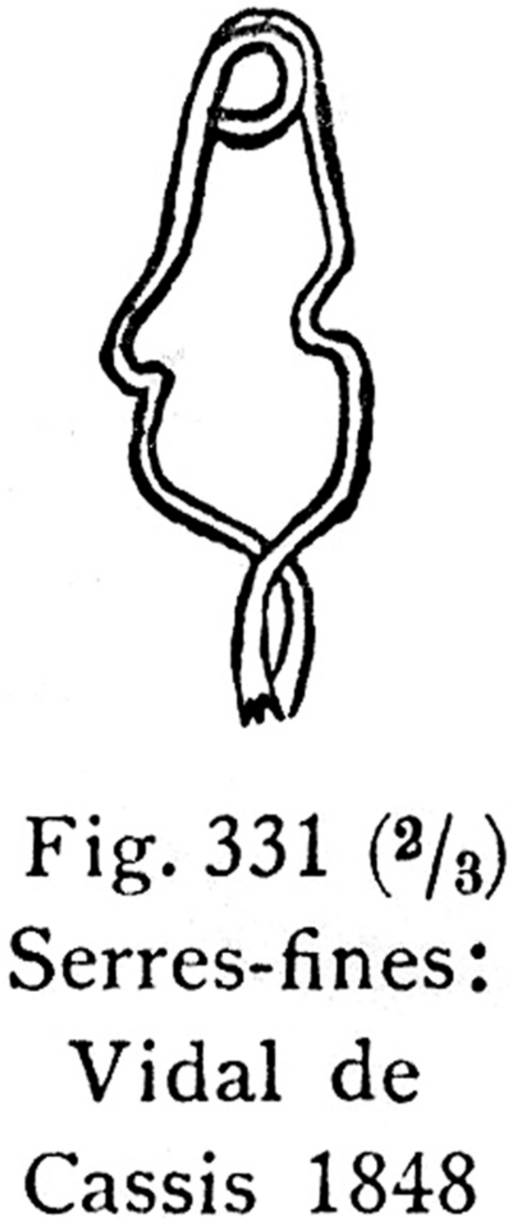

Fig. 14. Helical coiled spring–powered cross-action clip. Reprinted from Møller-Christensen V: **The History of Forceps: an Investigation on the Occurrence, Evolution and Use of the Forceps From Prehistoric Times to the Present Day.** Copenhagen: Levin and Munksgaard, 1938.

sober but wasted support of grants and other charities. In this unfortunate plethora of writings little is to be found of practical use. Correct and relevant is one thing; otherwise, useless at best, and dangerous. The neurosurgeon clipping an aneurysm today has no need for anything written by a radiologist about clips, nor does he need to pay attention to the inaccurate or irrelevant scientific strivings from others. No metal offenders remain in the picture; stainless steel is gone, and everything of the canon is nonferromagnetic when exposed to current scanners. To have to test each clip before use for a property known to be absent is absurd. On the other side of the dilemma, the patient arriving on the MRI scene with an unidentified clip already somewhere in

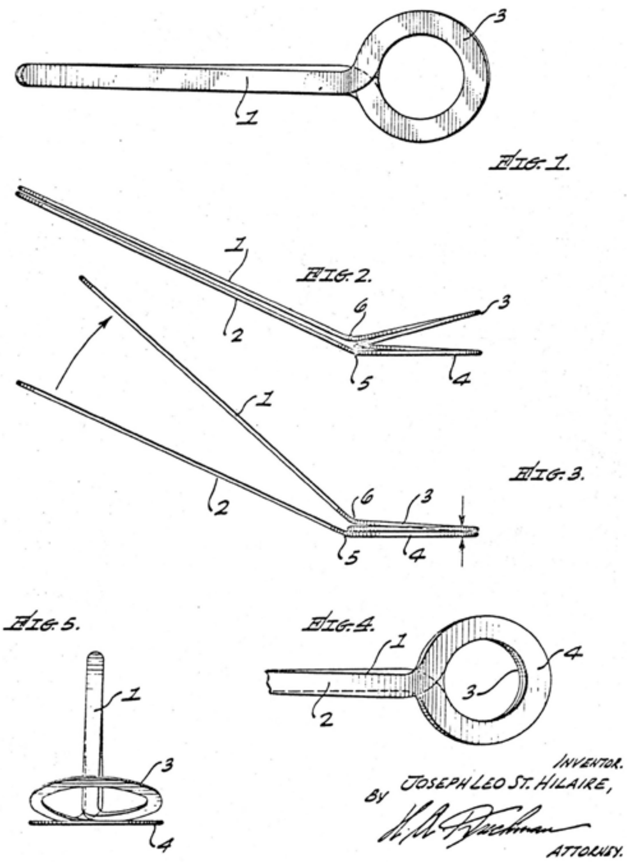

Fig. 15. Hair pin. Reproduced from US Patent no. 2,888,938, Hair Clip, Inventor Joseph L. St. Hilaire, June 2, 1959.

the skull cavity can in no way benefit from the elaborate testing methods or anything else in this welter of would be scientific articles.

Only two guiding factors should be followed: 1) No MRI should be performed if iron is present in the alpha phase. Among medical implants this one element is found only in stainless steel. 2) Primum non nocere. First, do no harm. When in doubt do nothing.

History

Among the many clip forms of this type, none are new. They are all little spring clamps of one configuration or another. The crossed-action feature came from Charrière in 1840[29] (Fig. 11).

Nunneley's device (late 1860s) resembles the Mayfield concept, as does the penile clamp of the 1920s (Figs. 12 and 13).

A helical coiled-spring powered cross-action instrument remarkably resembles the McFadden clip (Fig. 14). Note Taylor's forceps in Fig. 12.

A hair pin of the 1930s embodies the same concepts as the Scoville clip (Figs. 5 and 15).

In 1940, DiPalma reported the use of modified no. 3 safety pins as simple and inexpensive artery clamps (Fig. 16).

All of these six archetypes lay dormant in various archives while neurosurgery reinvented the wheel for aneurysm clips.

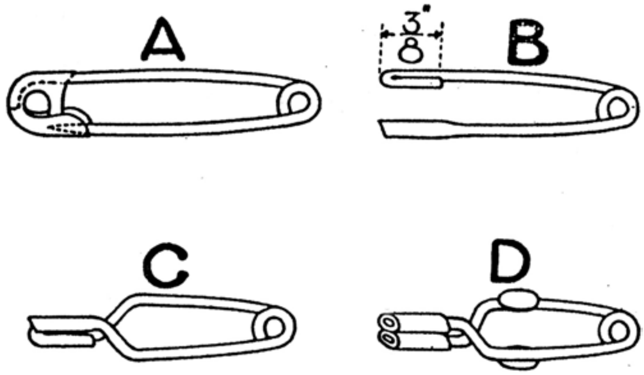

Fig. 16. Modified No. 3 safety pins used as artery clamps. From DiPalma JR: A simple artery clip. **Science 92:**44, 1940. Reprinted with permission from AAAS.

Disclosure

Dr. McFadden currently has no financial interest in any of the clips mentioned in this article.

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