The beginning and the evolution of the endovascular treatment of intracranial aneurysms: from the first catheterization of brain arteries to the new stents

G Guglielmi

The field of endovascular neurosurgery was paved by the work of a few creative "pioneers" who invented new delivery systems and new embolic agents capable of treating vascular diseases of the brain, such as aneurysms. Knowledge of the historical basis, of the foundations, of our discipline is always beneficial: it allows appreciation of the work of the "fathers" and gives a sense of continuity in science. It also gives doctors in training the fundamental background information. And, why not, history is also entertaining!

The history of the endovascular treatment of brain aneurysms can be divided into three periods or eras: the pre-balloons era, the balloons era and the coils era.

THE PRE-BALLOONS ERA

We can say that, as of today (2009), our discipline of endovascular neurosurgery–interventional neuroradiology is 45 years old!

In fact, Luessenhop and Velasquez performed the first catheterization of intracranial vessels in 1964.[1] They invented a system capable of entering brain arteries with a silastic microcatheter, via the surgically exposed external carotid artery in the neck. They even performed endovascular temporary balloon occlusion of the neck of a posterior communicating artery aneurysm. They prophetically predicted that "catheterization as well as embolization of the intracranial arteries may have therapeutic usefulness, particularly in the treatment of aneurysms and arteriovenous malformations".

In the mid-1960s, Frei, Yodh, Driller, Montgomery, Cares and Hilal utilized a new microcatheter called para-operational device (POD).[2–7] The proximal portion was made of polyethylene and the distal portion of soft silicone rubber. The distal section measured only 1.3 mm in outer diameter and was 7 cm in length. Embedded in the tip of the silicone tubing was a micromagnet which measured 1 mm in diameter. External magnetic fields, both continuous and alternating, could be applied to pull and bend the micromagnet tipped microcatheter (by the continuous field) and to cause it to vibrate (by the alternating magnetic field). The effect was to induce the catheter to "swim" within the vessels by reducing friction between the catheter tip and the inner vessel wall.

In 1974, Hilal and colleagues[7] reported on the clinical use of a slightly modified version of the POD microcatheter in 120 patients. They were able to perform percutaneous catheterization of vessels such as the basilar, middle cerebral and lenticulostriate arteries. They injected embolic substances, including acrylics, into arteriovenous malformations, performed intracranial intravascular electroencephalography and, in one patient, performed endovascular electrothrombosis of a basilar artery aneurysm.

In spite of some success in negotiating intracranial vessels, the POD did not become popular and was later abandoned because new improved microcatheters appeared on the horizon.

THE BALLOONS ERA

In 1974, the field of endovascular neurosurgery was astounded by a report of Serbinenko who described the endovascular treatment of more than 300 patients with detachable and non-detachable balloons, with sacrifice or preservation of the parent artery.[8] His work started the "balloons era" and had an exceptional influence on endovascular neurosurgeons worldwide.

The next 15 years saw the establishment of neuroendovascular centers in which Serbinenko's technique was practiced. Debrun, Viñuela and Fox (London, Ontario, Canada), Romodanov and Shcheglov (Kiev, USSR), Hieshima, Higashida and Halbach (San Francisco, USA), and Moret (Paris, France), among other centers, applied Serbinenko's concepts and performed endosaccular balloon occlusion of intracranial aneurysms, preserving the parent artery.[9–14] A detachable balloon, mounted on the tip of a microcatheter, was navigated into the aneurysm sac, inflated with a solidifying substance and detached. The balloon filled aneurysm was therefore excluded from the blood circulation. Romodanov and Shcheglov stated that this endovascular operation was contraindicated in small aneurysms, in aneurysms with a wide neck, in the acute phase post-subarachnoid hemorrhage (SAH) and in presence of severe vasospasm as mortality among such patients was 22%.

In 1975, Debrun *et al* tested and clinically applied a coaxial microcatheter with a detachable latex balloon at its tip.[15] This system was widely utilized for the treatment of carotid–cavernous fistulae (preserving the parent artery) and giant intracavernous and posterior circulation aneurysms (with sacrifice of the parent artery).

In 1981, Hieshima *et al* devised a thin soft microcatheter to be utilized with a detachable silastic balloon for the endosaccular occlusion of aneurysms.[16]

The disadvantage of all of these systems was the lack of a deflecting tip to negotiate vascular bifurcations.

To overcome this problem, Engelson (engineer at Target Therapeutics, California, USA), in the mid-1980s, invented a variable stiffness microcatheter with a radiopaque marker in its tip.[17] The tip was also steam shapeable. He also devised a steerable micro-guidewire with a deformable, shapeable tip to negotiate vascular bends and bifurcations. The "over-the-wire Tracker" microcatheter was born. This system was a fundamental milestone in the catheterization of brain arteries. It overcame all of the previous problems and became the ideal delivery system for the detachable coils (see below).

At the end of the 1980s it became clear that endosaccular balloon embolization was not safe. Balloons produced an "angioplasty" of the aneurysm with a consequent high risk of immediate or delayed aneurysm rupture or recanalization. The morbidity–mortality rates were exceedingly high with this technique. Therefore, balloon embolization was utilized only in small clinical series of inoperable aneurysms. It was supplanted by coils in the early 1990s.

Correspondence to: Professor G Guglielmi, Department of Neurosciences, University of Rome "La Sapienza", Piazza Mazzini 27, 00195 Rome, Italy; guidogdc@yahoo.com

THE COILS ERA

To find a less traumatic alternative, Hilal *et al* in 1988 and 1989 reported on the first use of short pushable coils for the endosaccular treatment of aneurysms.[18 19] However, these coils were stiff, non-retrievable and non-controllable. The risk of coil deposit in the parent artery was highly probable.

In 1991 Guglielmi *et al* reported on the experimental results and the clinical application of electrolytically detachable platinum coils.[20 21] These coils were very soft, retrievable, controllable and detachable at will. They solved most of the problems encountered by previous investigators. These coils gently adopted the shape of the aneurysm with less deforming pressure on its fragile walls. Aneurysms could be treated in the acute phase of SAH and in the presence of vasospasm. These coils had a circular, helical shape with different diameters of the circular memory and different lengths.[22]

The development of detachable coils did not finish with the initial clinical application. Softness, length, shape, diameter of the circular memory, diameter of the platinum wire, diameter of the coil and diameter of the delivery wire had to be evaluated and implemented. At the beginning there were only three types of detachable coils; this increased to over 100 in the mid-1990s. The delivery microcatheter and micro-guidewire were also made smaller in order to treat small acute aneurysms in the presence of vasospasm. Furthermore, the junction between the stainless steel delivery wire and the platinum coil underwent various modifications in order to decrease the detachment time of the coil. Markers were also added, for a precise positioning of the electrolytic junction. Viñuela *et al* published the anatomical and clinical results in the treatment of 403 acutely ruptured aneurysms with the coil technique.[23] Excellent anatomical results were obtained in aneurysms with a small neck (≤4 mm in diameter).

New techniques appeared on the horizon to solve the problem of progressive compaction of the coils in terminal aneurysms and in aneurysms with a wide neck. In the mid-1990s, Moret *et al* proposed to deliver the coils while a temporary balloon (positioned utilizing a second microcatheter) was inflated across the neck of the aneurysm.[24] The hope was to obtain a more dense "packing" of the aneurysm. With this technique it was possible to deliver more coils in an aneurysm, especially in wide necked lesions, with improved results. It is the author's opinion that this technique might entail more thromboembolic complications. Furthermore, loops of coils may herniate out of the aneurysm on deflation of the balloon.

Imaging techniques such as CT and MRI angiography became available, which allowed understanding of the anatomy of the aneurysm, identification of normal arteries possibly arising from the aneurysm base and precise measurements of the aneurysm neck preoperatively.

In the late 1990s, new coil designs became available, as well as new faster detachment mechanisms and the so-called "stretch resistant" coils. The goal was to make the technique safer, faster and more efficacious. Coils became tridimensional (and even spherical), especially for better anchoring of the first coil in the aneurysm. Softer coils were also developed for small acutely ruptured aneurysms and for better overall filling of the aneurysms. Improved coatings of microcatheters and guidewires improved the catheterization of aneurysms. It is the author's opinion, however, that proper steam shaping of the microcatheter is the main factor for a successful and atraumatic navigation into the aneurysm sac. Steam shaping should be done according to the anatomy of the proximal parent vessel and to the spatial direction of the sac of the aneurysm.

In the early 2000s, the so-called "bioactive" coils became part of the armamentarium. The goal was to produce a better "healing" of the interface parent artery–aneurysm neck. It is the author's opinion that these coils generated the concept of eliciting a biological response using the coil as a carrier of appropriate substances. However, they generated the concept of eliciting a biological response using the coils as a "carrier" of appropriate substances. Coils that could "swell" were also proposed and utilized: unwanted side effects were observed with these coils.

Driven by the increasing utilization of the endovascular technique, industry continued offering new devices, new delivery systems and new coils. These materials, however, although beneficial in several cases, did not always improve the overall treatment results. The main problem remained the anatomical outcome and the long term results in wide necked or terminal-type aneurysms.

In the meantime, a new tool became available: rotational digital angiography. It allowed geometrical information and helped in the quick determination of the appropriate "working projection", with a perfect separation of the aneurysm–parent artery interface. Biplane and rotational angiography shorten the procedure time, making the procedure more safe. They also offer a tri-dimensional assessment of the aneurysm, possibly reducing the incidence of aneurysm perforation and adding "protection" from untoward coil deposit in the parent artery. Rotational angiography entailed improved results and constituted a real and important advantage for patients and for the treating physician.

In addition, new compliant balloons (for the treatment of vasospasm), and more efficient drugs and devices (for the treatment of thromboembolic complications), became part of the technical armamentarium.

In the 2000s, another method was proposed to try and solve the same problem (again and again): treatment of wide necked and terminal aneurysms. Supporting stents, delivered and positioned in the parent artery across the aneurysm neck, started being utilized. Stents act as a scaffold while coils are delivered through a microcatheter navigated into the aneurysm through the stent struts: this allows more dense filling of the aneurysm. Stents designed for intracranial use (soft enough and able to overcome the curves of the carotid siphon and the curves and bifurcations of the intracranial vasculature) became available. Stents allowed the endovascular treatment of wide necked aneurysms that were otherwise untreatable. The use of a "Y" stent configuration is sometimes utilized in terminal aneurysms. In this configuration, the blood flow has to pass through the stent struts, with increased risks of thromboembolic complications. "Covered" stents have also been utilized in selected clinical cases to obliterate the aneurysm orifice while maintaining patency of the parent vessel.

Stents constitute a foreign object in the parent artery and therefore medications are utilized to prevent thromboembolic complications. Long term use of these medications may have some disadvantages. Stenting in the acute phase of SAH is still problematic. The stent assisted coiling may moderately improve the long term anatomical outcome. However, it often allows a better immediate anatomical outcome. Although beneficial in difficult cases, stent utilization adds complexity to a simple technique.

As an attempt to improve the results in wide necked aneurysms, an entire new technology was proposed: embolization (filling) of the aneurysm with a non-adhesive liquid glue. By inflating a protecting balloon across the aneurysm neck,

 J NeuroIntervent Surg 2009;**1**:53–55. doi:10.1136/jnis.2009.000422

glue was injected into the sac and allowed to solidify. This technique did not attain widespread utilization because of the difficulty in performing the procedure and the high rate of complications. Only anecdotal cases of giant aneurysms were treated, with often dismal results. Fortunately, glue treatment was practically abandoned, with a few exceptions. It is the author's opinion that, at the present time, aneurysms cannot be safely treated with any type of liquid agents, irrespective of the technique utilized.

In the late 2000s, new stents became available: the so-called "flow diverting" stents. These new stents are at the forefront of endovascular neurosurgery. For the time being, only a few reports have described the clinical applications of these stents. However, the main concept is new and attractive: they could cure the aneurysm without using coils! These stents are braided, tubular, tiny holed, microcell-like and less porous. Once delivered across the neck of an aneurysm, they can divert the flow (away from the aneurysm). These stents do not seem to compromise the parent artery. They can be used in a variety of wide necked or fusiform aneurysms, showing promising results. These stents have the potential to become a breakthrough in the endovascular armamentarium.

CONCLUSION

The author believes that, for the time being, in most cases the safest endovascular treatment is still the classical simple coiling technique, without adjunctive devices. In many cases it is the gold standard procedure, safer than surgery and safer than complex endovascular procedures. At this point in time, approximately 300 000 patients have been treated worldwide with detachable coils. Further research is necessary to find a way to prevent the phenomenon of coil compaction in the months that follow the intervention, in wide necked and terminal aneurysms. This could be achieved by changing the composition of the metal utilized to fabricate the coils (from platinum to tantalum, perhaps?) to elicit a faster and stronger biological response.[25] Often, the alternative to the classical coiling technique is surgical clipping. Because of the continuous technical and cultural evolution, surgical clipping has become a very rational procedure. The precise planning of all surgical steps leaves nothing to chance. However, surgery is inherently invasive and implies craniotomy, brain retraction, aneurysm manipulation and possible perforator injury. The decision regarding coiling versus clipping must be taken on a case by case basis. The skills and experience of the treating physician also play an important role in the decision making process.

Endovascular neurosurgery is a discipline in continuous evolution. Every progress is founded on the work and creativity of past investigators. The background information on this discipline shows how devices and techniques progressed from simple (often handmade) prototypes to modern and sophisticated delivery systems and embolic agents.

One thing is certain: the future will bring us more and more safe and effective devices. However, we do have to learn from the mistakes done in the past. Rigorous analysis of results and complications are fundamental elements for the progress of our discipline. History teaches us, for instance, that endosaccular balloons were unsafe and dangerous. Current materials are so sophisticated that one may be attempted to perform "heroic" procedures. This "enthusiasm" must be tempered with wisdom in deciding if what is new is also safe. Vainglory should not enter the angio suite!

To describe the importance of wisdom during our procedures, I would like to mention two sentences of Dr Viñuela: "The worst enemy of good is better" and "It's better to be safe than sorry".

New ideas often arise from criticism of currently available techniques. We will always have to confront ourselves with a mature and well established discipline: classic vascular neurosurgery. Cooperation (and, why not, mutual, fruitful criticism) between the two disciplines will always entail better results for our patients.

Competing interests: GG is the inventor of the GDC Coils.

Received 23 March 2009
Accepted 23 March 2009

REFERENCES

1. **Luessenhop AJ**, Velasquez AC. Observations on the tolerance of the intracranial arteries to catheterization. *J Neurosurg* 1964;**21**:85–91.
2. **Frei EH**, Driller J, Neufeld HN, *et al*. The POD and its applications. *Med Res Eng* 1966;**5**:11–18.
3. **Yodh SB**, Pierce NT, Weggel RJ. A new magnet system for intravascular navigation. *Med Biol Eng* 1968:**6**;143–7.
4. **Driller J**, Hilal SK, Michelsen WJ, *et al*. Development and use of the POD catheter in the cerebral vascular system. *Med Res Eng* 1969;**8**:11–16.
5. **Montgomery DB**, Hale JR, Pierce NT. A magnetically guided catheter system for intracranial use in man. *IEEE Trans Magn* 1970;**6**:374–5.
6. **Cares HL**, Hale JR, Montgomery DB, *et al*. Laboratory experience with a magnetically guided intravascular catheter system. *J Neurosurg* 1973;**38**:145–54.
7. **Hilal SK**, Michelsen WJ, Driller J. Magnetically guided devices for vascular exploration and treatment. Laboratory and clinical investigations. *Radiology* 1974;**113**:529–40.
8. **Serbinenko FA**. Balloon catheterization and occlusion of major cerebral vessels. *J Neurosurg* 1974;**41**:125–45.
9. **Fox A**, Vinuela F, Pelz D. Use of detachable balloons for proximal artery occlusion in the treatment of unclippable cerebral aneurysms. *J Neurosurg* 1987;**66**:40–6.
10. **Romodanov AP**, Shcheglov VI. Intravascular occlusion of saccular aneurysms of the cerebral arteries by means of a detachable balloon catheter. In: Krayenbuhl H, Ed. *Advances and technical standards in neurosurgery, vol. 9*. Berlin:Springer, 1982: 25–48.
11. **Higashida R**, Halbach V, Dowd C, *et al*. Detachable balloon embolization therapy of posterior circulation intracranial aneurysms. *J Neurosurg* 1989;**71**:512–19.
12. **Higashida R**, Halbach V, Barnwell S, *et al*. Treatment of intracranial aneurysms with preservation of the parent vessel: results of percutaneous balloon embolization in 84 patients. *AJNR Am J Neuroradiol* 1990;**11**:633–40.
13. **Higashida R**, Halbach V, Dowd C, *et al*. Endovascular detachable balloon embolization therapy of cavernous carotid artery aneurysms: results in 87 cases. *J Neurosurg* 1990;**72**:857–63.
14. **Moret J**, Boulin A, Mawad M. Endovascular therapy of berry aneurysms by endosaccular balloon occlusion. *Neuroradiology* 1991;**33**:135–6.
15. **Debrun G**, Lacour P, Caron JP, *et al*. Inflatable and release balloon technique. Experimentation in dog-application in man. *Neuroradiology* 1975;**9**:267–71.
16. **Hieshima GB**, Grinnell VS, Mehringer CM, *et al*. A detachable balloon for transcatheter occlusions. *Radiology* 1981;**138**:227–8.
17. **Engelson E**. Catheter for guide-wire tracking. US patent 4,739,768. 1986.
18. **Hilal SK**, Khandji AG, Chi TL. Synthetic fibre-coated platinum coils successfully used for endovascular treatment of arteriovenous malformations, aneurysms and direct arteriovenous fistulas of CNS. *AJNR Am J Neuroradiol* 1988;**9**:1030.
19. **Hilal SK**, Khandji A, Solomon RW. Obliteration of intracranial aneurysms with pre-shaped highly thrombogenic coils. *Radiology* 1989;**173**:250–7.
20. **Guglielmi G**, Vinuela F, Sepetka I, *et al*. Electrothrombosis of saccular aneurysms via endovascular approach. Part 1: electrochemical basis, technique and experimental results. *J Neurosurg* 1991;**75**:1–7.
21. **Guglielmi G**, Vinuela F, Dion J, *et al*. Electrothrombosis of saccular aneurysms via endovascular approach. Part 2: preliminary clinical experience. *J Neurosurg* 1991;**75**:8–14.
22. **Guglielmi G**. History of endovascular endosaccular occlusion of brain aneurysms: 1965–1990. *Interventional Neuroradiology* 2007;**13**:217–24.
23. **Viñuela F**, Duckwiler G, Mawad M, *et al*. Guglielmi detachable coil embolization of acute intracranial aneurysm: perioperative anatomical and clinical outcome in 403 patients. *J Neurosurg* 1997;**86**:475–82.
24. **Moret J**, Pierot L, Boulin A, *et al*. "Remodelling" of the arterial wall of the parent vessel in the endovascular treatment of intracranial aneurysms. *Neuroradiology* 1994;**36**:83.
25. **Guglielmi G**. Preliminary report on the thrombogenic properties of tantalum-GDC coils. An experimental study. *Interv Neurorad* 2008;**14**:45–8.

The beginning and the evolution of the endovascular treatment of intracranial aneurysms: from the first catheterization of brain arteries to the new stents

G Guglielmi

J NeuroIntervent Surg 2009 1: 53-55 originally published online July 3, 2009
doi: 10.1136/jnis.2009.000422