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Special Article

Electrothrombosis of saccular aneurysms via endovascular approach

Part 1: Electrochemical basis, technique, and experimental results

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Eleven experimental saccular aneurysms were created on the common carotid artery of swine. Between 3 and 15 days after creation of these aneurysms, they were thrombosed via an endovascular approach, using a very soft detachable platinum coil delivered through a microcatheter positioned within the aneurysm. This detachable platinum coil was soldered to a stainless steel delivery guidewire. Intra-aneurysmal thrombosis was then initiated by applying a low positive direct electric current to the delivery guidewire. Thrombosis occurred because of the attraction of negatively charged white blood cells, red blood cells, platelets, and fibrinogen to the positively charged platinum coil positioned within the aneurysm. The passage of electric current detached the platinum coil within the clotted aneurysm in 4 to 12 minutes. This detachment was elicited by electrolysis of the stainless steel wire nearest to the thrombus-covered platinum coil. Control angiograms obtained 2 to 6 months postembolization confirmed permanent aneurysm occlusion as well as patency of the parent artery in all cases. No angiographic manifestation of untoward distal embolization was noted. Due to the encouraging results of this research, this technique has been applied in selected clinical cases which are described in Part 2 of this study.

KEY WORDS • **electrothrombosis** • **electrolysis** • **aneurysm** • **endovascular therapy** • **embolization** • **detachable coils**

THE technique of intra-aneurysmal electrothrombosis via an endovascular approach was conceived about a decade ago,[8] based upon the observations of Mullan, *et al.*,[16-19] Piton, *et al.*,[22] and other authors.[10,25-27] Not until recently, however, has the technology to produce microcatheters soft enough to navigate atraumatically into an aneurysm become available. A novel device, consisting of a soft detachable platinum coil soldered to a stainless steel delivery wire, can now be positioned within an aneurysm in a controlled fashion.

The technique of intra-aneurysmal occlusion with detachable coils is based upon two electrochemical principles: electrothrombosis and electrolysis. Electrothrombosis occurs because white blood cells, red blood cells, platelets, and fibrinogen are negatively charged.[1,3,25] If a positively charged electrode is positioned in the blood stream, it will attract these negatively charged blood components, promoting clot formation.[25,27] Electrolysis occurs when two iron electrodes connected to a source of direct electric current are dipped into a solution. Under these conditions, the immersed end of the positive wire dissolves, and the other wire recruits the migrating ferrous ions from the anode to the cathode. Noble metals such as platinum are not affected by this phenomenon.[23] Electrolysis is the process that will detach the platinum coil from the stainless steel delivery wire within an aneurysm.

Materials and Methods

Since February, 1989, experimental saccular aneurysms were surgically created in swine by grafting a vein

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Inspired by Serbinenko's and Debrun's development and clinical use of detachable balloons, neurointerventionalists throughout the world for the first time began attempts to treat intracranial aneurysms by using endovascular techniques (1, 2). Although the use of balloons for treatment of aneurysms in circumstances where occlusion of the parent artery could be tolerated was a tremendous addition to endovascular therapy, the ability to use these devices in situations where parent artery preservation was required was limited. The technique was technically challenging and the results were often unpredictable. Thus was the situation in 1991 when Guglielmi and colleagues reported on the use of an endovascular technique that combined electrolysis and electrothrombosis for the treatment of non-surgical intracranial aneurysms. This concept and the device that has evolved from its application, the Guglielmi detachable coil (GDC), has revolutionized the treatment of intracranial aneurysms.

Guido Guglielmi was born in Rome, Italy in 1948. His father, a urologist, encouraged an early interest in electronics that subsequently led Guido to achieve considerable understanding and expertise in this field. Entering the University of Rome as an engineering student, Guido quickly changed his field of study to medicine and, because of his interest in ''wires and relays'', gravitated into the neurosciences. Accepted into a neurosurgery residency at the University of Rome, Guido did some of the early clinical investigation related to the use of epidural intracranial pressure measurement devices. Knowing of his interest in electronics and engineering, in 1974, his chairman, Dr. Beniamino Guidetti, encouraged him to read reports Mullen et al (3) describing the concept of electrothrombosis of intracranial aneurysms. Coincidentally, this same year, Guido's father suffered an aneurysmal subarachnoid hemorrhage. These two events were to prove pivotal to his future career.

In 1976, Guglielmi began his neurosurgical practice as a junior physician at the University of Rome. Over the next 3 years, he read and thought more about the possibility of using electrothrombosis for aneurysm treatment and, in 1979, he conducted a series of in vivo experiments by using electrothrombosis for obliteration of experimental aneurysms in rabbits. Stimulated by the reports of Debrun and Serbinenko, he accelerated his efforts to understand the endovascular approach for treatment of CNS vascular abnormalities and, to accomplish this, sought every opportunity to observe embolization procedures both in Rome and in other institutions in Europe. After watching treatment of a traumatic carotid cavernous fistula with detachable balloons (by Dr. Lacour, in Reims, a previous associate of Dr. Debrun), Guido made the decision to modify his practice so that it emphasized the use of endovascular techniques. It was also during this time that, while assisting his cousin in preparation of a thesis, that, by chance, he observed separation of the tip of a wire being used for an electrode from the rest of the wire. While not fully grasping the significance of the ''detachment'' resulting from the process of electrolysis, he documented and illustrated it with photographs in the thesis.

In 1983, because of efforts to expand his capacity to use endovascular techniques in his practice, Dr. Guglielmi came into contact with Fernando Viñuela, who was then a junior staff physician at the University of Western Ontario in London, Ontario. Over the next several years, a relationship was established between these two young physicians and, when Fernando moved from London to Los Angeles, formal efforts began to collaborate on research efforts directed toward development of new techniques for the treatment of aneurysms. After nearly 5 years of correspondence and occasional transatlantic visits, Dr. Viñuela secured funding that was sufficient for Guido and his family to come for an extended stay in Los Angeles. In January 1989, a research project involving treatment of aneurysms, not with electrothrombosis but with a combination of metallic microspheres and micromagnets delivered using an endovascular approach, was begun at UCLA. Frustrated by incomplete aneurysm obliteration by use of the small magnets and metallic particles, but encouraged by the amount of thrombus that was generated in the aneurysms with the technique, Guglielmi once again began to explore the possibility of using electrothrombosis as a therapeutic technique. A conversation between Dr. Viñuela and a sales representative from Target Therapeutics (Kevin Riley) concerning engineering assistance with making prototype devices for animal research resulted in Guido's introduction to Ivan Sepetka, a research and development engineer at Target. This contact and the relationships that followed proved critical to the development of the GDC.

Over the 9 months following Guido's introduction to Ivan, the concept of employing a guidewire mechanism for electrothrombosis of aneurysms rapidly evolved. Soft platinum coils in a variety of sizes were attached to a stainless steel pusher wire so that they could be delivered through a small catheter and positioned into an aneurysm. These could then either be retrieved or detached, as desired. On March 6, Dr. Viñuela used the GDC for the first time in a human, treating a patient with a traumatic cavernous sinus fistula in whom closure of the fistula with detachable balloons had proven to be impossible. An IDE for use of the device in aneurysm treatment was obtained in late 1990 and, in January 1991, the first patient with an aneurysm was treated at UCLA. On September 8, 1995, the Food and Drug Administration approved commercial sale of the GDC. This simple yet elegant device would revolutionize the way that aneurysms were treated.

In Part 1 of the two-part report, Guglielmi, Viñuela, Sepetka, and Macellari (4) describe and illustrate the preclinical testing of the GDC in an experimental swine aneurysm model:

> *Eleven experimental saccular aneurysms were created on the carotid artery of swine. Between 3 and 15 days after creation of these aneurysms, they were thrombosed via an endovascular approach, using a very soft detachable platinum coil delivered through a microcatheter positioned within the aneurym. This detachable platinum coil was soldered to a stainless steel delivery guidewire. Intra-aneurysmal thrombosis was then initiated by applying a low positive direct electric current to the delivery guidewire. Thrombosis occurred because of the attraction of negatively charged white blood cells, red blood cells, platelets, and fibrinogen to the positively charged platinum coil within the clotted aneurysms in 4 to 12 minutes. This detachment was elicited by electrolysis of the stainless steel wire nearest to the thrombus-covered platinum coil. Control angiograms obtained 2 to 6 months post embolization confirmed permanent occlusion as well as patency of the parent artery in all cases. No angiographic manifestation of untoward distal embolization was noted.*

In Part 2 of the report, Guglielmi, Viñuela, Dion, and Duckwiler (5) provide an account of the use of this device in the treatment of aneurysms in 15 patients:

> *Fifteen patients with high-risk intracranial saccular aneurysms were treated using electrolytically detachable coils introduced via an endovascular approach. The patients ranged in age from 21 to 69 years. The most frequent clinical presentation was subarachnoid hemorrhage (eight cases). Considerable thrombosis of the aneurysms (70% to 100%) was achieved in all 15 patients, and preservation of the parent artery was obtained in 14. Although temporary neurological deterioation due to the technique was recorded in one patient, no permanent neurological deficit was observed in this series and there were no deaths. It is believed that this new technology is a viable alternative in the management of patients with high-risk intracranial saccular aneurysms. It may also play an important role in the occlusion of aneurysms in the acute phase of subarachnoid hemorrhage.*

In the 5 years since it has been commercially available, more than 30,000 patients world wide have been treated with the GDC. Although there have been significant improvements in the detachment zone between coil and the pusher wire as well as in the sizes and varieties of coils available (2D, 3D, soft, stretch resistant), the fundamental design of the device has endured. Because of the impact that these reports and the device that they describe have had on the care of patients with saccular aneurysms, recognition of their historical significance is fully warranted.

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