My History of Carotid Angioplasty and Stenting

Jacques Théron, MD

My mentor, René Djindjian, one of the fathers of interventional neuroradiology, used to say that it was very difficult to write the history of a technique because one can never satisfy everyone. I agree, thus I will only present here the history of the endovascular treatment of carotid bifurcations based upon my personal experience and my view of its future evolution.

After the fundamental work in endovascular therapy by Charles Dotter[1] and Andreas Gruntzig,[2] it was inconceivable at the end of the 1970s to apply their work to arteries supplying the brain. Klaus Mathias chose to ignore this strict limit and was able to successfully perform angioplasty of atherosclerotic stenoses at the carotid bifurcation in 1980.[3,4]

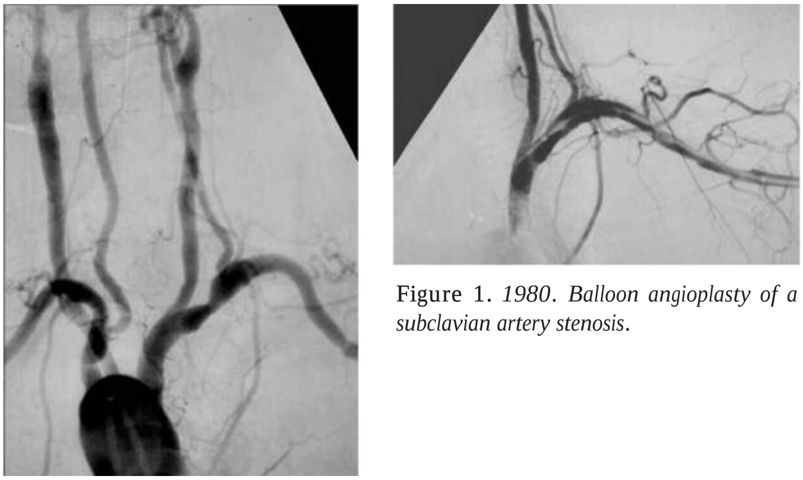


Figure 1. *1980. Balloon angioplasty of a subclavian artery stenosis.*

We were not aware of Klaus Mathias's breakthrough when, in 1980, we performed angioplasty of a subclavian artery (Figure 1). In the professional environment of the time, this case appeared extremely risky and my behavior unconventional. From 1980 to 1982, we did not risk approaching atherosclerotic stenoses at the carotid bifurcation because of frequent plaque ulceration at this level. We did, however, continue to perform a series of subclavian and vertebral angioplasty procedures.[5] In 1981, we thought we had performed the first inversion of a subclavian steal syndrome (Figure 2), but later discovered that Bachman in Canada had already published his work on this topic.[6]

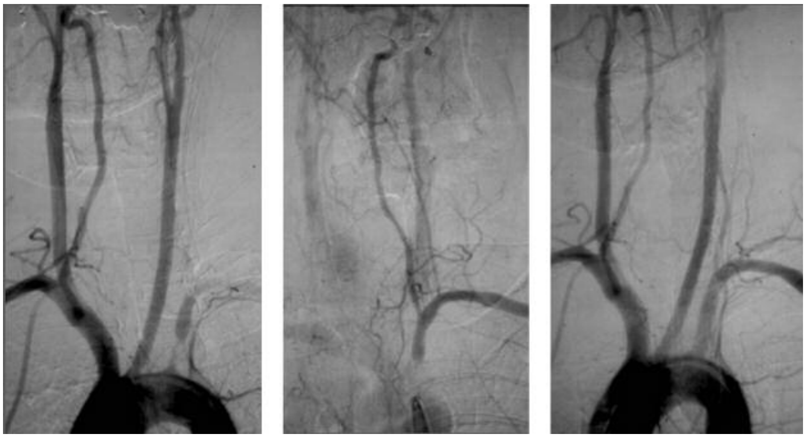


Figure 2. *1981. Subclavian steal syndrome correction by balloon angioplasty.*

From 1981 on, along with others in the field, we began performing angioplasty of nonatherosclerotic stenoses at the carotid bifurcation such as fibromuscular dysplasias,[7,8] inflammatory stenoses,[9,10] post endarterectomy restenoses,[11] post radiotherapy stenoses,[12] as well as several cases of atherosclerotic stenoses of the external carotid artery.[13] These cases appeared less risky to us.

We did not approach the treatment of atherosclerotic stenoses of the internal carotid artery before 1982, at which time we performed a series of 38 cases. In this first series, there were 5% dissections and 8% embolic complications that were fairly severe. The last embolic complication of this series

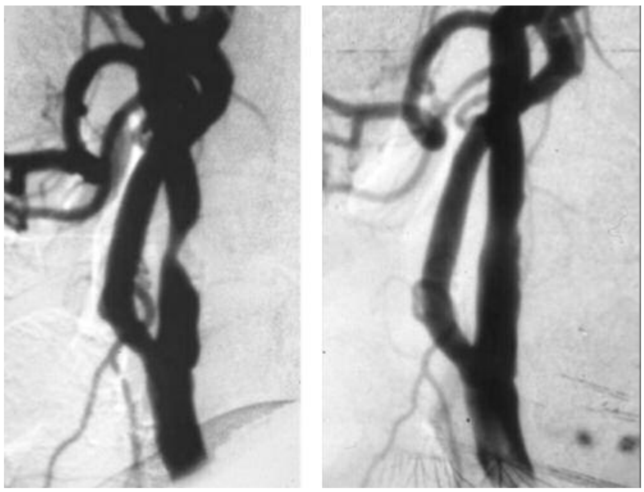


Figure 3. *1982. Balloon angioplasty of a simple stenosis of the internal carotid artery that was complicated by a nonreversible scotoma.*

From the CHU Cean, Hôpital Côte Nacre, Cean, France.
The authors report no conflicts of interest regarding the content herein.
Address for correspondence: Jacques Théron, CHU, Cean, France. E-mail: theronjcq@aol.com.

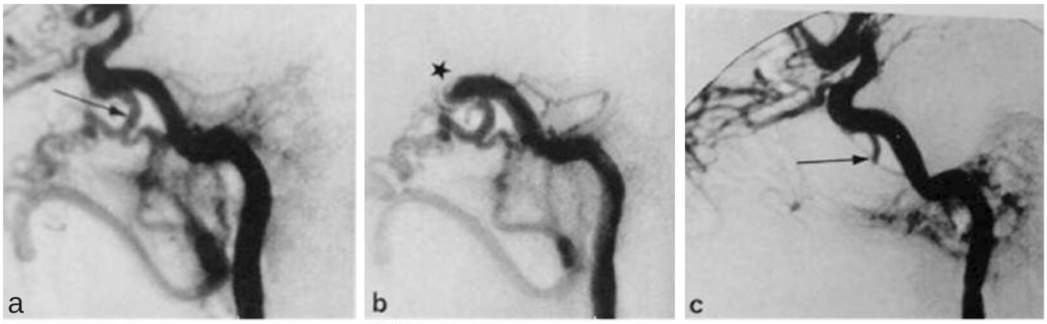
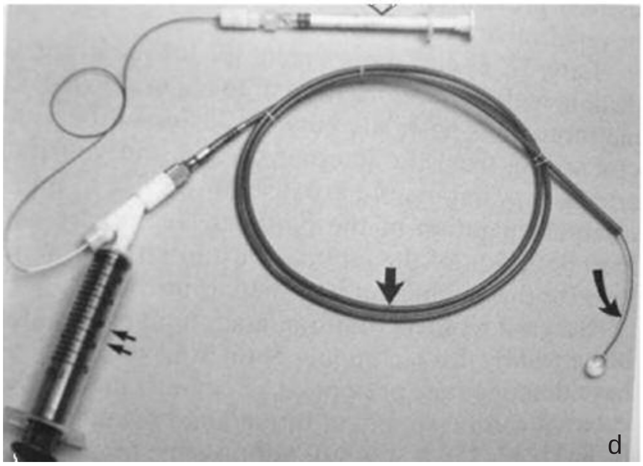


Figure 4. *1983. Technique of embolization of vascular facial malformations with protection of the brain by temporary occlusion of the internal carotid artery.*



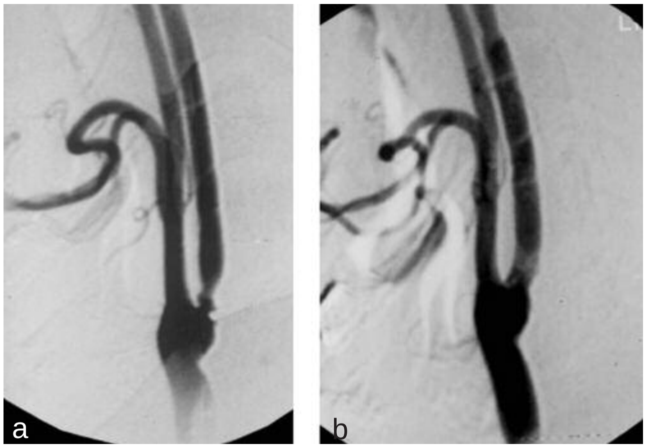


Figure 6. *1984. First case of protected angioplasty of an ulcerated symptomatic stenosis of the internal carotid artery.*

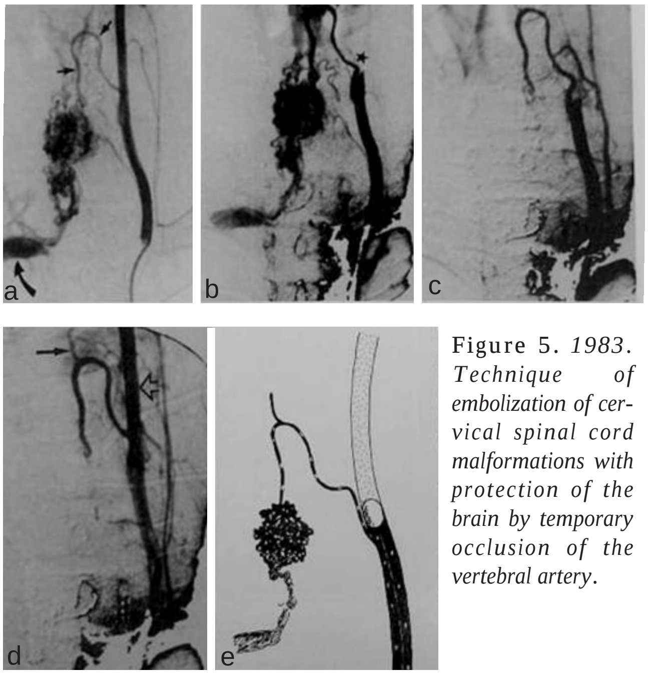


Figure 5. *1983. Technique of embolization of cervical spinal cord malformations with protection of the brain by temporary occlusion of the vertebral artery.*

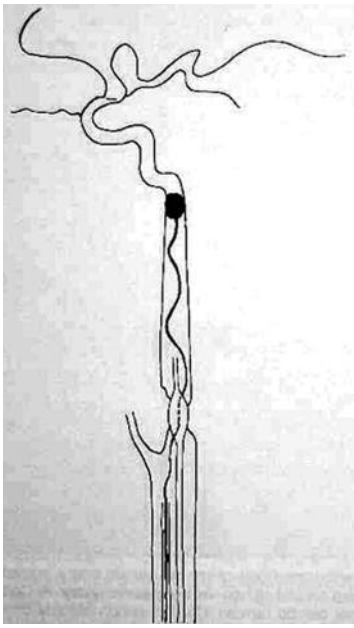
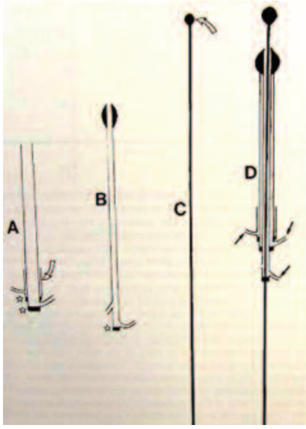


Figure 7. *1984. Early technique of balloon angioplasty of the internal carotid artery achieved with 2 catheters, an angioplasty catheter and a guiding catheter containing a microcatheter with an attached distal occlusive balloon. The angioplasty was performed by inflating the balloon over the microcatheter while potentially detached atheroclerotic particles were aspirated via the guiding catheter.*

occurred on an apparently very simple stenosis (Figure 3), but this case ended with a complication of scotoma from which the patient did not recover. It was a shock for me because it appeared obvious that it was impossible to routinely treat carotid atherosclerotic stenoses without facing risks that we could not control.

At this time, interventional neuroradiologists, following the work of Serbinenko in Russia, were often using all types of balloons. I was working at the Neurological Institute Mac Gill University of Montreal, and had described and published a technique, still currently used, of embolization of vascular malformations of the face[14] (Figure 4) and of the spinal cord[15] (Figure 5), incorporating cerebral protection by temporary occlusion of the distal internal carotid or the vertebral artery. The idea to use temporary occlusion of the distal internal carotid artery in angioplasty of the carotid bifurcation was a direct consequence of this work.

We performed the first case of protected angioplasty of an



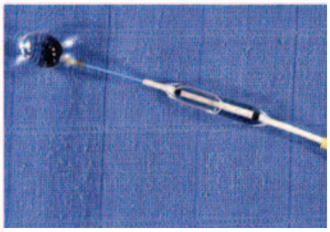


Figure 8. *1986. Description of the triple-coaxial catheter.*

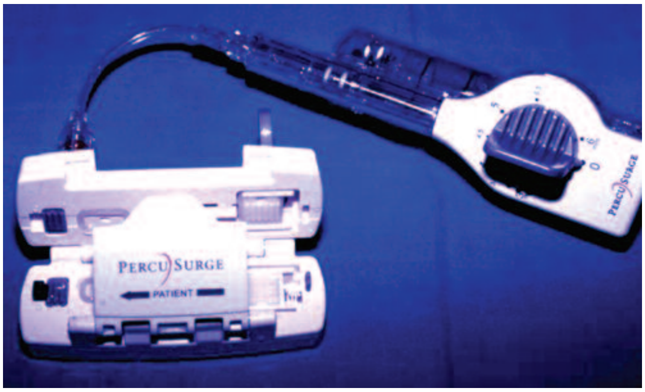


Figure 9. *PercuSurge system based on the same concept.*

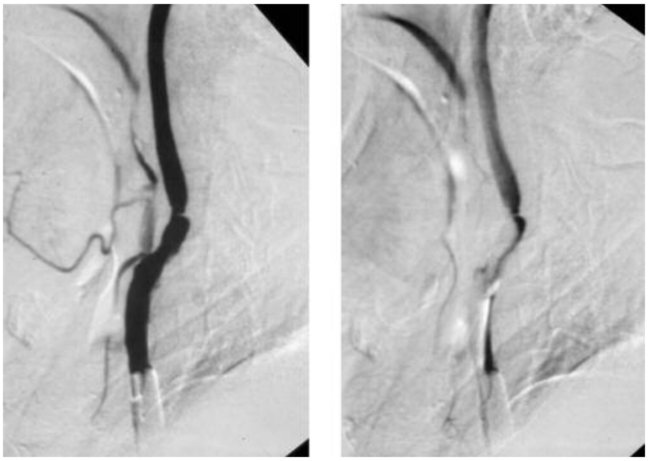


Figure 10. *1987. Experiment of temporary occlusion of the common carotid artery. With injection of contrast into the balloon guiding catheter, one observes the wash of the contrast into the internal carotid artery.*

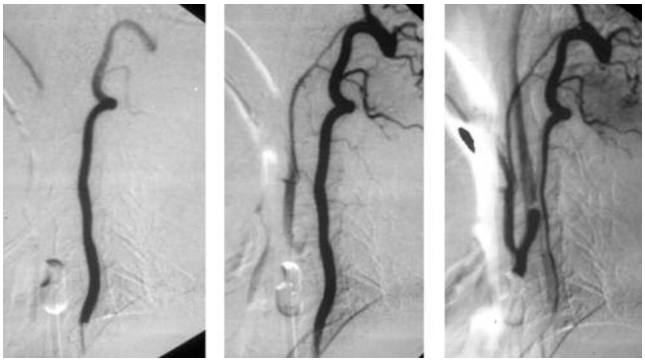


Figure 11. *Same experiment of temporary balloon occlusion of the common carotid artery. With simultaneous injection of contrast in the ipsilateral vertebral artery, one observes the inversion of flow in the external carotid artery with retrograde opacification of the occipital artery, and finally, antegrade opacification of the carotid bifurcation above the balloon occlusion.*

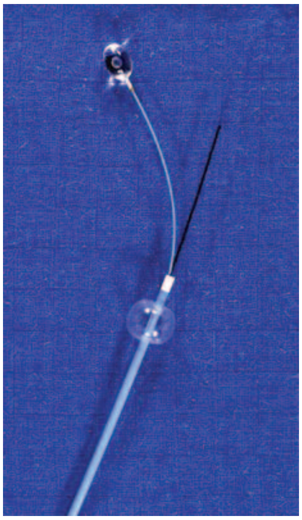


Figure 12. *1989. Simultaneous temporary occlusion of the common carotid artery and of the origin of the external carotid artery designed to prevent the inversion of flow in the carotid artery.*

ulcerated atherosclerotic stenosis in Montreal in 1984 (Figure 6). This first case used 2 catheters, an angioplasty catheter and a guiding catheter containing a microcatheter with an attached distal occlusive balloon (Figure 7). The angioplasty was achieved by ballooning over the microcatheter, and the potentially detached atherosclerotic particles were aspirated via the guiding catheter. At the same time, Jiri Vitek, another neuroradiologist, had successfully performed angioplasty of the innominate artery using cerebral protection by placing a balloon at the origin of the common carotid artery.[16] Like our embolization technique, it actually involved protection only of the carotid supply, which was accomplished by capturing the particles that were potentially detached and headed toward the subclavian artery, but the vertebral artery supply remained unprotected, as particle capture was not possible. We now know that the potential risk of treating an innominate artery without protection is no higher than treating the subclavian artery, but this case is a good example of neuroradiologists' concern at the time for protecting the brain.

In 1986 we succeeded in concentrating the cerebral protective material in a single triple-coaxial catheter (Figure 8) using various materials that originally required a 2-meter long microcatheter.[17] This concept was subsequently incorporated into the PercuSurge GuardWire® *(PercuSurge, Inc., Minneapolis, Minnesota)* (Figure 9) and other similar systems.

We were also interested, at the end of the 1980s, in the possibility of using temporary occlusion of the common carotid artery, but quickly realized that this entailed an inversion of the flux in the external carotid artery, and particularly in the occipital artery. The consequence was that the internal carotid artery continued to be supplied despite the occlusion of the common carotid artery. Thus, temporary occlusion did not protect the cerebral circulation. We published the images (Figures 10 and 11) from an experiment performed in 1987 showing the inversion of the flux in the external carotid in a letter[18] commenting on the works of

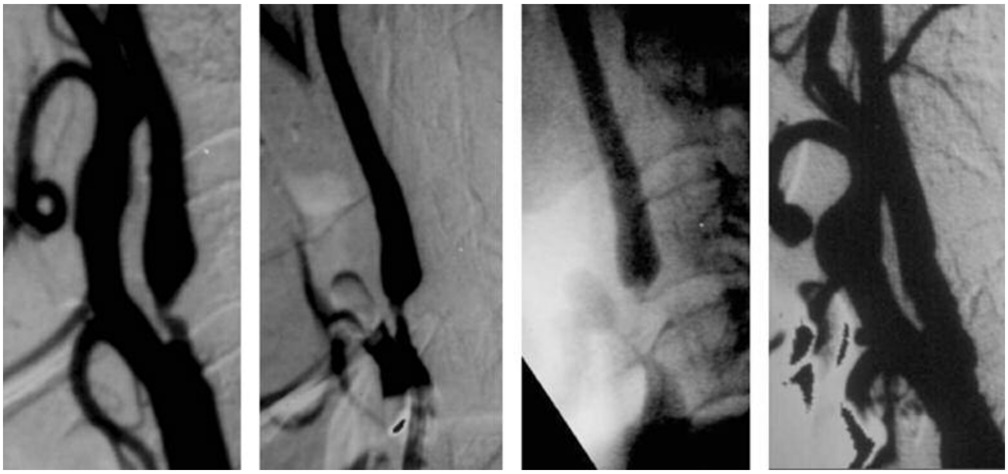


Figure 13. *1989. Angioplasty of a symptomatic stenosis of the internal carotid artery. From left to right: pretherapeutic angiogram, occlusion of the common carotid and extenal carotid arteries, stagnation of contrast in the internal carotid artery and post-therapeutic angiogram.*

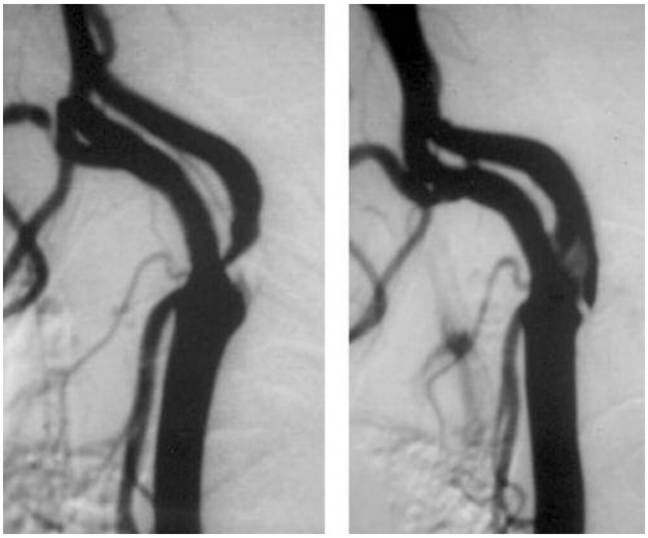


Figure 14. *1990. Our first carotid stent. Narrow stenosis of the internal carotid artery. Suboptimal immediate result after protected angioplasty.*

Figure 15. *Same procedure on the left. A Strecker stent was positioned in the carotid artery, covering the origin of the external carotid. A follow-up angiogram was performed 5 years later. The patient has remained neurologically asymptomatic.*

Kachel,[19] who used this temporary occlusion technique alone as cerebral protection.

To improve the technique of temporary occlusion of the common carotid artery, in 1989 we performed several temporary occlusions of the common carotid artery along with simultaneous temporary occlusion of the origin of the external carotid artery (Figure 12). We presented these cases (Figure 13) at several international conventions including the Andreas Grüntzig Society meeting in Sydney in 2002, but did not publish them. They probably, at least partially, inspired the work by Juan Parodi.[20] We abandoned work on this system because we considered it too complex compared to temporary occlusion of the distal internal carotid artery. Although this system is currently sold by two companies, we personally see it as best employed exclusively for the treatment of total occlusions of the internal carotid artery.

As for carotid endarterectomy, the question remains open as to who was the author of the first carotid stent case — Klaus Mathias or myself. What is most important is that the stent is now among the various therapeutic tools for the treatment of carotid bifurcations. How did I decide in 1990 to implant the first carotid stent, a case which was subsequently published[21]? The patient was a 64-year-old female who had presented a few weeks previously with a clinically regressive brain infarction. She had a tight and irregular stenosis of the left internal carotid artery (Figures 14 and 15). We performed balloon-protected angioplasty in which the morphological result was unsatisfactory. Our experience had already shown us that this kind of result entailed rapid restenosis. Because the patient had already presented with a brain infarction, we decided to implant a Strecker stent (Boston Scientific Corp., Natick, Massachusetts)[22] in the carotid artery without cerebral protection. Intuitively, we positioned the stent so as to cover the origin of the external carotid artery. As expected, my vascular surgeons colleagues confirmed that I was insane and had taken an enormous risk putting a foreign body in an artery supplying the brain. The patient subsequently showed no restenosis or new neurological symptoms. She agreed to undergo follow-up angiography 5 years later.

We believe that cerebral protection and stents are the two major advances that have permitted physicians to seriously

Figure 16. *Protected stenting of a symptomatic stenosis of the internal carotid artery using the Twin-One® cerebral protection system. Left to right: pretherapeutic angiogram, positioning of the guiding catheter in the stent and inflation of the protective balloon in the stent.*

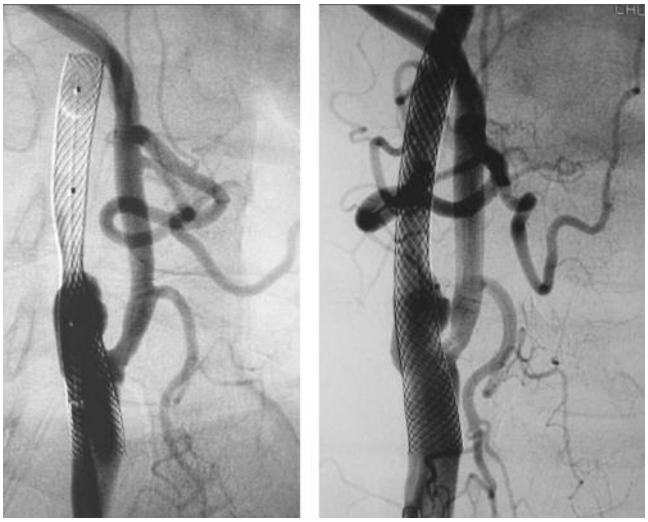


Figure 17. *Same procedure following the steps. Left to right: control angiogram confirming the efficiency of the intrastent temporary occlusion, post-therapeutic control angiogram after aspiration of the potential particles via the guiding catheter and deflation of the protective balloon.*

consider an endovascular approach as an alternative in the treatment of the atherosclerotic stenoses at the carotid bifurcation because they have eliminated dissection complications and significantly reduced embolic complications.

The 1992 Andreas Gruntzig Society meeting held in Sydney was another milestone because we were able to present our work on the various types of carotid endovascular treatments, cerebral protection and stenting. This meeting was the true beginning of Gary Roubin's interest[23,24] in treating carotid arteries. His position as an eminent cardiologist in the United States, and even more importantly, his charisma, helped spread these techniques throughout the world. Neither Klaus Mathias nor myself would have been able to succeed alone given our European radiological backgrounds.

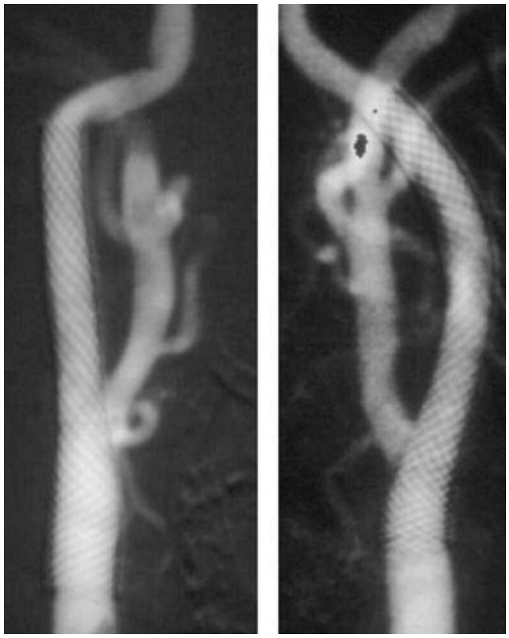


Figure 18. *Bilateral wallstent. Two-year follow-up angiogram.*

Numerous authors have subsequently worked on carotid endovascular therapy, but I would like to emphasize the role played by Nick Hopkins for two reasons. First, his research on cerebral protection systems using filters has been very important, even though we are not completely convinced that this is the ideal protection system, as will be seen below. His other major contribution has been to reposition, with his reputation of neurosurgeon using both endovascular and endarterectomy[25] and his wide neurological background, the discussions away from the usual basic corporatist point of view.

As others did, we published our experience on our angioplasty with stenting and on cerebral protection.[26,27] Nevertheless, I remain convinced that this technique is not completely developed. The main points of the debate and the future directions as I see them are as follow:

1) On a technical level we know that cerebral protection is necessary.[28,29] Since the first balloon angioplasty procedures, we know that angioplasty without protection and without stent placement is associated with a 5% dissection rate and a 5–10% embolic complication rate. The stent has eliminated the dissection complications. The discussion persists as to which are the best cerebral protection systems.

Although attractive, is the filter the perfect answer? Probably not. All protective techniques are partial, and what is most important is to select the one that offers minimum risk and ease-of-use. The filter does not protect against clots or particles upon passage of the stenosis, it does not protect from particles smaller than the pores of the filter, and most notably, it does not protect against "shower" embolisms. Finally, the filter itself can sometimes generate more embolic complications than does unprotected angioplasty.[30,31]

We personally continue to think that the best protection is provided by temporary occlusion of the distal internal carotid artery on condition that the occlusion is efficient. This was not always achieved with the early commercial systems. Our experience has brought us to reconsider cerebral protection (Figures 16

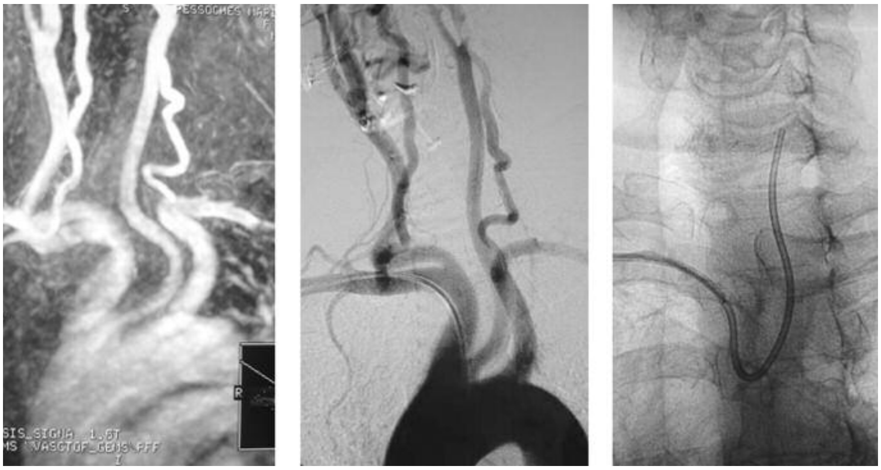


Figure 19. *Radial approach of a left symptomatic stenosis of the internal carotid artery. From left to right: Angiographic magnetic resonance image showing a nonfavorable orientation of the left common carotid artery for a femoral approach, corresponding arch angiogram, right radial approach of the left carotid.*

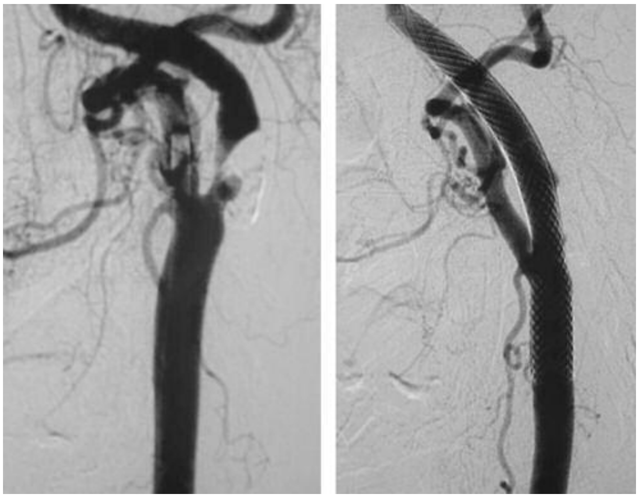


Figure 20. *Same procedure. Ulcerated stenosis of the internal carotid artery before and after protected wallstenting.*

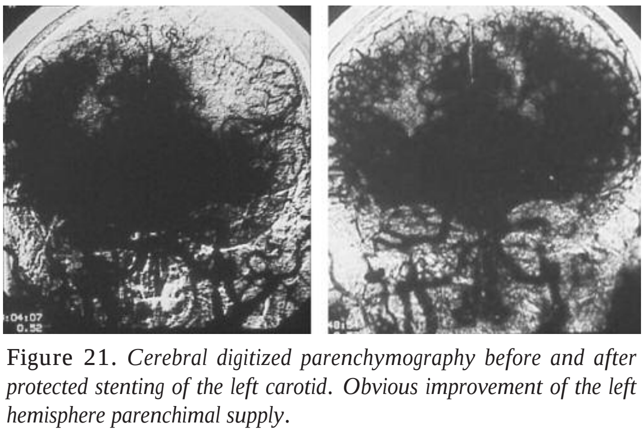


Figure 21. *Cerebral digitized parenchymography before and after protected stenting of the left carotid. Obvious improvement of the left hemisphere parenchimal supply.*

and 17) (Twin-One® System, Minvasys, France), whose early results[32] confirm our technical options. We base this on a certain number of points: (a) the carotid sinus represents a natural filter that entails regrouping of the atherosclerotic deposits at the origin of the internal carotid artery; (b) the only step of the procedure that presents a meaningful embolic risk is postdilatation, when the plaque is broken; (c) with the new stent profiles, predilatation is rarely necessary (< 5%); when predilatation is necessary, it must be performed with a small-diameter (2 mm) balloon that will allow passage of the stent, and definitely not with a 3 or 4 mm balloon that could cause plaque rupture, rapid platelet aggregation and increase the risk of embolism at the site of stent deployment; (d) long stents (4–5 cm) do not increase the risk of restenosis at the level of the carotid bifurcation and they treat the entire lesion (Figure 18).

2) In practice, we believe that many of the impossibilities and complications related to endovascular carotid treatment are due to vascular approach problems. It is for this reason that we developed the radial approach,[33] which solves the problem of difficult femoral approach cases and completes our therapeutic tool options (Figures 19 and 20).

3) Carotid endovascular treatment is a technique that is undergoing both technical evolution and diversification. Today's operators now come from various specialties (vascular radiologists, neuroradiologists, vascular surgeons, neurosurgeons, cardiologists). The first protocols compared it with endarterectomy, which was considered a relatively mature procedure. It is important to remember that NASCET (North American Symptomatic Carotid Endarterectomy Trial),[34] which established the benefit of endarterectomy versus medical treatment, involved selected patients who were operated on by trained surgeons, and was the first positive study after two similar unfavorable studies. The major difference between NASCET and these negative studies is that the carotid surgery had not been interrupted. On the contrary, the unfavorable results of the EVA 3S[35] study, in which many elements could be easily contested, has totally halted the use of endovascular therapy in France, with the exception of high-risk surgical cases.

4) We are convinced that supra-aortic endovascular treatment holds great potential for the future, not only in symptomatic carotid stenoses, but also in so-called asymptomatic stenoses that are responsible for cerebral vascular insufficiency. These latter are due to the hemodynamic summation of several moderate stenoses simultaneously reducing flow in several arteries supplying the brain, which leads to a loss of cerebral vascular reserve and significant changes in cognitive function (Figure 21). Considering the aging population, this group of patients is becoming increasingly important.[36]

References

1. Dotter CT, Judkins MP. Transluminal treatment of arteriosclerotic obstruction: Description of a new technique and a preliminary report of its applications . *Circulation* 1964;30:654–670.
2. Grüntzig A, Hopf H. Perkutane Rekanalisation chronischer arterieller verschlüsse mit einem neuen katheter: Modifikation der Dottrer-technik. *Deutsch Med Wochenschr* 1974;99:2502–2505.

3. Mathias K. Perkutane transluminale Katheterbehhandlung supraaortaler Arterienobstruktionen . *Angiology* 1981;3:47–50.
4. Bockenheimer SA, Mathias K. Percutaneous transluminal angioplasty in arteriosclerotic internal carotid stenosis. *Am J Neuroradiol* 1983;4:791–792.
5. Théron J, Courtheoux P, Henriet JP, et al. Angioplasty of supraaortic arteries. *J Neuroradiology* 1984;11:187–200.
6. Bachman DM, Kim RM. Transluminal dilatation for subclavian steal syndrome. *Am J Radiol* 1980;136:995–996.
7. Garrido E, Montoya J. Transluminal dilatation of internal carotid artery in fibromuscular dysplasia: A preliminary report. *Surg Neurol* 1981;16:469–471.
8. Hasso AN, Bird CR, Zinke DE, Thomson JR. Fibromuscular dysplasia of the internal carotid artery: Percutaneous transluminal angioplasty. *Am J Radiol* 1981;136:955–960.
9. Hodgins GW, Dutton JW. Subclavian and carotid angioplasties for Takayazshu's arteritis. *J Can Assoc Radiol* 1982;33:205–207.
10. Théron J, Tyler JL. Takayasu's arteritis of the aortic arch: Endovascular treatment and correlation with positron emission tomography. *Am J Neuroradiol* 1987;8:621–626.
11. Théron J, Raymond J, Casasco A, Courtheoux F. Percutaneous angioplasty of atherosclerotic and post-surgical stenosis of carotid arteries. *Am J Neuroradiol* 1987;8:495–500.
12. Guthaner DF, Schmidt L. Percutaneous transluminal angioplasty of radiation induced arterial stenoses. *Radiology* 1982;144:77–78.
13. Vitek JJ, Morawetz RB. Percutaneous transluminal angioplasty of the external carotid artery: Preliminary report. *Am J Neuroradiol* 1982;3:541–546.
14. Théron J, Cosgrove R, Melançon D, Ethier R. Embolization with temporary balloon occlusion of the internal carotid and vertebral arteries. *Neuroradiology* 1986;28:246–253.
15. Théron J, Cosgrove R, Melançon D, Ethier R. Advances in the embolization of spinal arteriovenous malforamtions. *Radiology* 1986;158:163–169.
16. Vitek JJ, Raymon BC, Oh SJ. Innominate artery angioplasty. *Am J Neuroradiol* 1984;5:113–114.
17. Théron J, Courtheoux P, Alachkar F, Maiza D. New triple coaxial catheter system for carotid angioplasty with cerebral protection. *Am J Neuroradiol* 1990;11:869–874.
18. Théron J. Cerebral protection during carotid angioplasty. *J Endovasc Surg* 1996;3:484–485.
19. Kachel R. Results of balloon angioplasty in the carotid arteries. *J Endovasc Surg* 1996;3:226–230.
20. Parodi JC, Fereira LM. Cerebral protection during carotid stenting using flow reversal. *J Vasc Surg* 2005;41:416–422.
21. Théron J. Angioplasty of brachiocephalic vessels. In: Interventional Neuroradiology: Endovascular Therapy of the Central Nervous System. (Vinuela F, et al. eds). Raven Press: New York, 1992.
22. Strecker EP, Hagen B, Liermann D. Current status of the Strecker stent. *Cardiol Clin* 1994;12:673–687.
23. Roubin GS, Yadav S, Iyer SS, Vitek J. Carotid stent-supported angioplasty: A neurovascular intervention to prevent stroke. *Am J Cardiol* 1996;78(3A):8–12.
24. Roubin GS, Iyer SS, Vitek JJ, et al. Immediate and late outcome of carotid artery stenting in patients with symptomatic and asymptomatic carotid stenosis: A 5-year prospective analysis. Circulation 2001;103:532 ¬–537.
25. Hanel RA, Levy EI, Guterman LR, Hopkins LN. Carotid angioplasty with stenting and carotid endarterectomy: Both are here to stay. In: Horowitz MB, Levy EI (eds). *Neuroendovascular Surgery*. Basel: Karger, 2005, pp. 32–53.
26. Théron J, Payelle GC, Hu H, et al. Carotid artery stenosis: Treatment with protected balloon angioplasty and stent placement. *Radiology* 1996;201:627–636.
27. Theron J, Guimaraens L, Casasco A, et al. "Protected" wallstenting of atheromatous stenoses at the carotid bifurcation. *Interv Neuroradiol* 2003;9:99–126.
28. Macdonald S. The evidence for cerebral protection: An analysis and summary of the literature. *Eur J Radiol* 2006;60:20–25.
29. Martin JB, Pache JC, Treggiari-Venzi M, et al. Role of the distal balloon protection technique in the prevention of cerebral embolic events during carotid stent placement. *Stroke* 2001;32:479–484.
30. Macdonald S. Thesis for the Degree of Philosophy: Neuroprotection and flow dynamics in carotid stenting. October 2004. University of Sheffield Main Library Volumes I & II 2004 [MO115661SH] Main Lib Thesis 12638.
31. Macdonald S, McKevitt F, Venables GS, et al. Neurological outcomes after carotid stenting protected with the NeuroShield filter compared to unprotected stenting. *J Endovasc Ther* 2002;9:777–785.
32. Théron J, Bedogni F, Venturi C, et al. Immediate and mid-term clinical outcome of patients treated with the "TwinOne" cerebral protection system. Communication at TCT meeting, Washington D.C., October 2007.
33. Théron J, Guimaraens L, Casasco A, et al. Radial approach in the treatment of supraaortic arterial lesions. *Interv Neuroradiol* 2007;13:133–144.
34. North American Symptomatic Carotid Endarterctomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients wth high grade stenosis. *New Engl J Med* 1991;325:445–453.
35. Mas JL, Chatellier G, Beyssen B, et al. Endarterectomy versus stenting in patients with symptomatic severe carotid stenosis. *N Engl J Med* 2006;355:1660–1671,1726–1729.
36. Théron J, De Oliveira D, Alachkar F, Maiza D. Dynamic digitalized parenchymography. *Neuroradiology* 1992;34:361–364.