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Extracranial-intracranial bypass
The ELANA technique: high flow revascularization of the brain

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Summary

High flow revascularization of the brain is hampered by the fact that temporary occusion of a major cerebral artery is necessary to create the distal anastomosis, which may result in brain ischemia. The excimer laser-assisted non-occlusive anastomosis (ELANA) technique circumvents this problem. In this paper we elucidate the development of a non-occlusive way to make anastomoses to the major cerebral arteries.

Keywords: ELANA technique; cerebral revascularization; vascular anastomosis; non-occlusive anastomosis; EC/IC bypass; IC/IC bypass.

Introduction

The idea to increase the amount of blood flow to the ischemic brain, bypassing any stenoses or occlusions, seems so simple. However, it is still difficult to define which group of patients, who are at risk for a major stroke, will benefit from Extracranial-to-Intracranial (EC/IC) bypass surgery. EC/IC Bypass surgery was developed to improve the cerebral blood flow (CBF) in patients with complete carotid occlusion or ICA stenosis not amenable to extracranial endarterectomy. The International randomized EC/IC Bypass Study showed that the conventional EC/IC bypass, in which the superficial temporal artery (STA) is connected to a cortical branch of the middle cerebral artery (MCA), does not prevent the occurrence of stroke or transient ischemic attacks (TIAs) in patients with symptomatic atherosclerotic lesions of the MCA and/or internal carotid artery (ICA) compared to a non-surgical treated group [1, 2]. The most important critique on the study concerned the evaluation of patients before exclusion or inclusion and randomization in the study [4]. Apart from the clinical criteria, the only additional examination consisted of bilateral carotid angiography. It is therefore not surprising that a new EC/IC bypass trial has been launched in which patients are examined with more advanced techniques to measure the CBF and the oxygen extraction of the brain [3]. Normaly, changes in cerebral perfusion pressure (CPP) have little effect on the CBF due to the autoregulation capacity of the brain. If the CPP decreases the cerebral blood volume (CBV) increases because of the autoregulated vasodilation, thus preserving adequate CBF. Autoregulation fails when the capacity for vasodilation has been exceeded and CBF begins to decline. At that stage, the brain still has the capacity to extract more oxygen increased oxygen extraction fraction (OEF) when oxygen supply has decreased due to diminished CBF. Sufficient augmentation of the blood supply should increase the CBF and decrease the OEF.

However, the conventional STA-MCA bypass only has a limited capacity to increase the blood flow to the brain due to the relatively small size of both donor an recipient bloodvessel. It is possible to create a bypass with a higher capacity by choosing a larger donor vessel, like the more proximal segments of the STA or the external carotid artery (ECA), and/or to interpose a large venous graft between donor and recipient vessel. One of the advantages to use a cortical branch of the MCA as recipient vessel, is that these branches usually have many collaterals. Therefore, it is quite safe to temporarily occlude such a branch in order to create the distal anastomosis of the bypass, using the conventional anastomosis technique originally described by Carrel [5], and improved by Yasargil for use in EC/IC bypass procedures [22, 23]. Even if there are no collaterals, the occlusion of a cortical branch creates temporary ischemia in only a very small part of the brain which may not be clinically relevant. To make a very high capacity bypass to the brain, a larger (more proximal) recipient artery should be chosen [7]. However, these vessels do not have many collaterals, so occlusion will create temporary ischemia in a rather large portion of the brain. Patients at risk for cerebral ischemia usually use their collaterals already at maximum, diminishing even further the window of time during which the surgeon may create a conventional anastomosis. Also, the risk of hyperperfusion after the creation of the bypass increases when choosing a more proximal recipient vessel. So, in order to safely create high flow bypasses to the brain and thus increase the CBF, it is necessary to choose a large donor vessel (i.e. the ECA), to use an interposing vein graft, and to connect that graft to a proximal cerebral artery in a non-occlusive way. In this paper we want to elaborate on the techniques with which we have tried to create such a bypass.

In 1902, Carrel described the principles for creating vascular anastomoses, which have hardly changed during the last century [5]. The recipient artery is temporarily occluded with two clamps. Between them, an opening is cut into the wall. The end of the donor vessel is connected to the recipient vessel with the endothelial layers of both vessels closely approximated. Still the backbone of modern vascular surgery, Carrel's technique has been highly successful. However, its inherent flaw is the temporary occlusion of the recipient vessel. A critically ischemic area may become infarcted during the procedure. As the brain is extremely dependent on a continuous blood supply, Carrel's techniques are almost impossible to use on cerebral arteries. It is therefore surprising that no attempts have been made to develop a non-occlusive anastomosis technique, apart from the animal experiments by Eck and Yahr [6, 21].

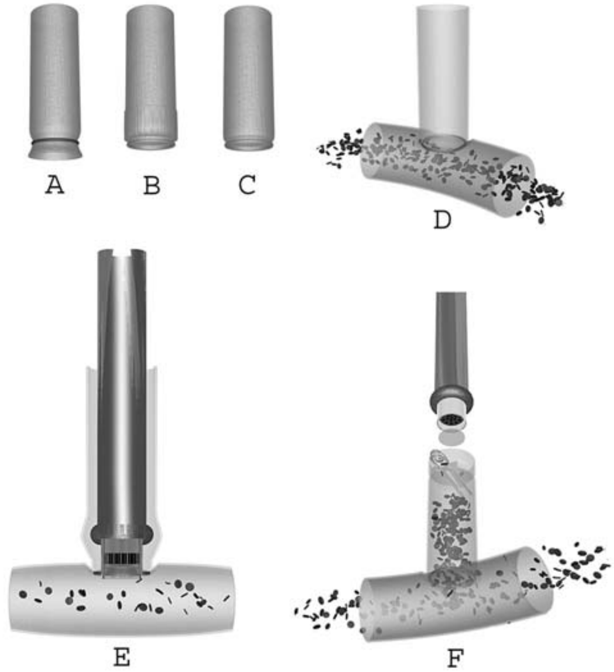

Fig. 1. The ELANA technique. (A) A platinum ring is placed over the end of the donor vessel. (B) The end of the donor vessel is then everted over the platinum ring. (C) The donor vessel is fixated to the platinum ring with several sutures, after which the excessive end of the everted part is cut of. (D) The donor vessel is then attached to the recipient vessel using sutures which pass the platinum ring, completely pass the wall of the donor vessel, and only superficially penetrate the wall of the recipient vessel. (E) The ELANA catheter is introduced into the open end of the donor vessel, so that the tip touches the wall of the recipient vessel inside the platinum ring. Vacuum suction is aplied, ensuring a firm fixation of the laser fibers to the vessel wall. When the laser is activated, a full-thickness portion (flap) of the wall of the recipient artery is cut out. (F) Due to the continued vacuum suction, the flap is recovered when the catheter is withdrawn from the now functional anastomosis

Materials and methods

Twenty-five years ago we started animal experiments in order to make high-flow revascularization procedures of the brain a safe and effective procedure. First, the end of the donor vessel is connected to the recipient artery using sutures, which pass through the wall of the recipient artery superficially, and fully through the wall of the donor vessel. Subsequently, a cutting device, which is introduced into the donor vessel, is used to make a hole in the wall of the recipient artery, leaving part of the adventitial and medial layers of the recipient artery exposed to the blood stream. This is contrary to Carrel's adage that close approximation of the endothelial layers is an absolute prerequisite for a successful anastomosis, which may explain why so few surgeons followed this line of thinking. Exposure of the other layers of the blood vessel to the blood stream would lead to thrombus formation and occlusion.

In many animal experiments we showed that non-occlusive anastomoses will remain patent, thanks to 2 technical innovations [14, 17, 18, 20]. The first was the use of the Excimer laser (Fig. 2E) to cut a full-thickness disc of recipient artery wall at the anastomosis site. The laser catheter consists of two concentric circles of 60 micron fibres arranged around the periphery of a thin-walled catheter with an internal diameter of 2.0 mm. A small metal grid is mounted 0.5 mm from the tip. The catheter is introduced into the donor vessel, so that the tip touches the wall of the recipient artery (Fig. 1E). Vacuum is then induced within the lumen of the catheter, causing a firm fixation of the wall to the grid and the laser fibres. When the laser is activated a full-thickness disc of recipient artery wall is cut out, creating a functional anastomosis. The second innovation is the application of a platinum ring with a diameter of 2.8 mm, which is attached onto the end of the donor vessel (Fig. 1A, B, C). The donor vessel is then connected to the recipient vessel (Fig. 1D), using sutures around the platinum ring, which fully pass through the wall of the donor and superficially pass the wall of the recipient artery. The effect of the platinum ring is fourfold: 1) It flattens the wall inside the ring, which facilitates the penetration of the laser tip over its full circumference;

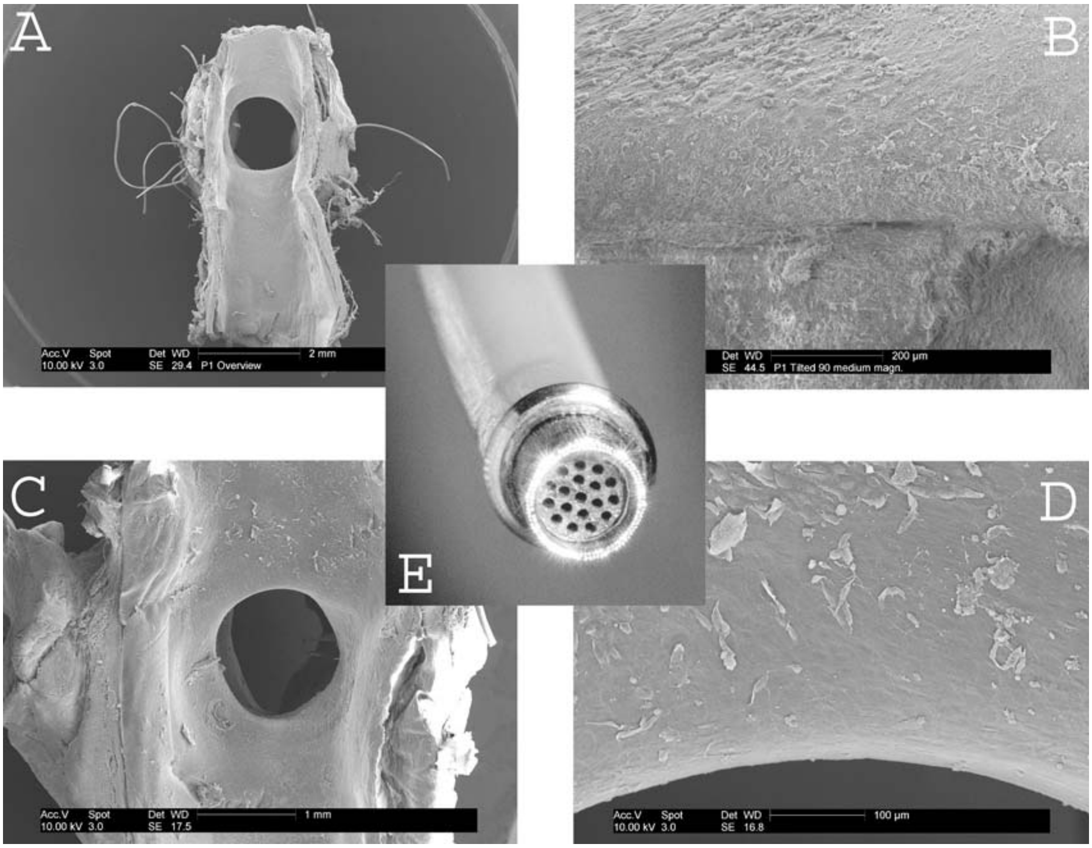

Fig. 2. Scanning electron microscopic *(SEM)* images of 2 anastomoses (A, B, C, D) and an image of the ELANA catheter tip (E). In (A), the inside of the posterior cerebral artery is shown at the site of the anastomosis with the bypass, three weeks after its construction (see text). The bypass is coming towards the camera, and its lumen is clearly visible. A high magnification image of the edge of the vessel wall (B), which has been ablated by the excimer laser (E) shows a smooth surface with re-endothelialization. Similar images of an anastomosis with the intracranial internal carotid artery (C and D) were taken more than 5 years after its construction (see text). The laser edge is very well re-endothelialized in the high magnification image (D)

2) The ring dictates the shape of the anastomosis, which is always round with a diameter of 2.8 mm; 3) It guides the tip to the correct position; 4) The ring prevents the tip from further entering the lumen after penetration of the wall, because it stops the catheter at a circular protuberance, 1.5 mm from the tip.

Results

During the last seven years the excimer laser-assisted non-occlusive anastomosis (ELANA) technique, has been applied in 170 patients with giant intracranial aneurysms, skull base tumours, or progressive brain ischemia [12, 13, 15, 16, 19]. The long term patency was 90% with an average flow in the bypass of 150 ml/min. In one patient with a giant aneurysm of the basilar artery we used the ELANA technique twice to create a connection between the internal carotid artery and the posterior cerebral artery. He died three weeks after the operation because of respiratory failure. Angiography showed that the bypass was patent and at autopsy both anastomoses appeared fully endothelialised, which was later confirmed by scanning electron microscopic evaluation (Fig. 2A, with a high magnification in 2B). Another patient, in whom we ligated the internal carotid artery after the construction of a bypass because of a skull base tumour, died 5 years later because of tumour recurrence. The ELANA anastomosis was removed at autopsy for scanning electron microscopy (Fig. 2C, with high magnification in 2D). The anastomosis site was well endothelialised and the rim of recipient artery wall with the adventitial and medial layers had disappeared.

Our group has published on the clinical results of the ELANA technique in a small series of 15 patients with a high risk of recurrent stroke with promising results [8, 10]. We offer an ELANA EC/IC bypass procedure

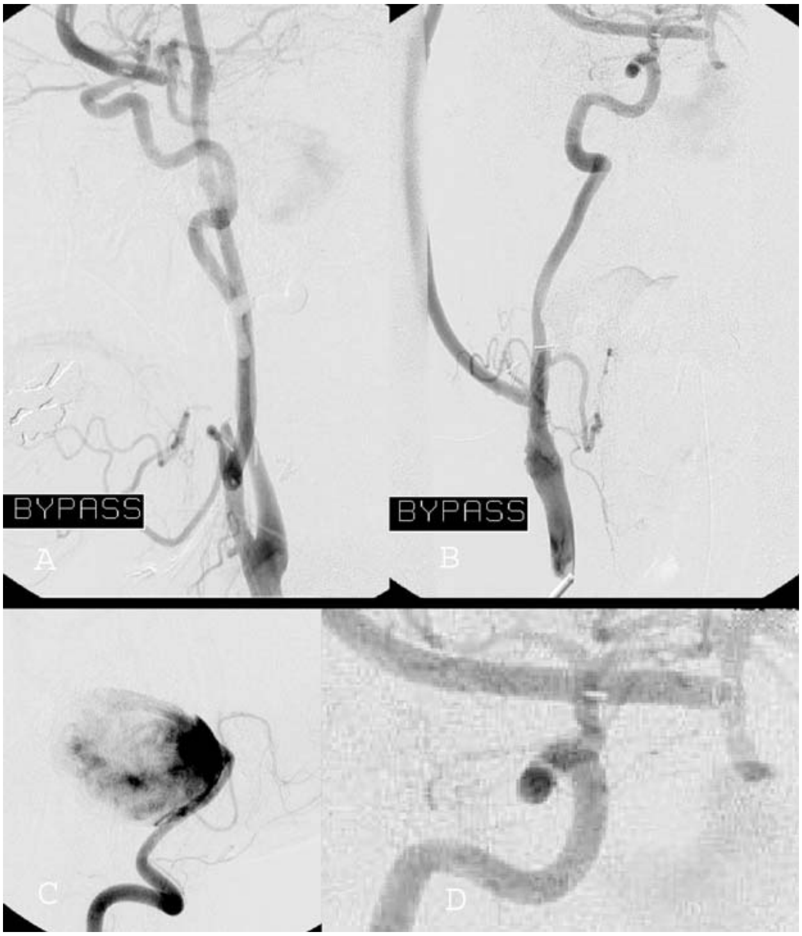

Fig. 3. Pre- and postoperative angiograms of the BA aneurysm and the bypass. In (C) the giant aneurysm is shown. The ECA-BA bypass is shown from a lateral view in (A), and from a frontal view in (B). A closeup of the distal anastomosis to the BA is shown in (D). Note the small platinum ring which has been attached to the distal BA

only to those patients who have ongoing symptoms of cerebral ischemia, after unilateral or bilateral ICA occlusion has been observed, despite antithrombotic treatment and endarterectomy of a contralateral ICA stenosis or ipsilateral ECA, and in whom the symptoms are likely to be of haemodynamic origin. An exception has been made for a patient who presented with repeated episodes of vertebrobasilar ischemia because of vertebral artery occlusion and stenosis. An ICA-posterior cerebral artery segment P1 bypass procedure was performed, effectively creating a new posterior communicating artery [15]. All patients had a proven hypoperfusion of the brain. In this very carefully selected group of patients we have been able to create EC/IC and IC/IC bypasses to all proximal cerebral arteries of the brain, depending on the location and extend of the occlusive vascular lesions. Several times we could not proceed with the ELANA technique because of severe athereosclerosis of the ICA, the proximal MCA, or the proximal ACA. We then created a conventional EC/IC bypass to a non-sclerotic cortical branch of the MCA, because using a sclerotic recipient vessel may lead to rupture of the anastomosis.

So, it is possible to consider every cerebral artery as a recipient artery for bypass surgery. Recently, we treated a patient with a giant VA-BA aneurysm (Fig. 3c), which was increasing in size during the last months. The last two months our patient could not continue his work as a policeman, and suffered from progressive brainstem deficits with dysarthria, swallow problems, vertigo and ultimately a tetraparesis. He obviously had a bad prognosis, and we expected that his life-expectancy would be very short. Clinically, our patient did not tolerate bilateral VA occlusion, in order to reverse the flow in the BA and thus preventing the aneurysm from growing. Therefore, a "jump" bypass was considered between the intracranial ICA and the PCA, like the bypass made in the afore-mentioned patient. We also considered making an ECA-PCA bypass. Both bypasses should than supply sufficient bloodflow to the posterior circulation, while ligation of both VAs would reverse the flow in the aneurysm. We started by occluding the left VA using two endovascular balloons. Our patient tolerated this without problems. We then operated him. Using a pterional approach, we found that the BA-bifurcation was located quite high, and the BA, distally of the aneurysm, looked very healthy and accessible. Of course, creating a conventional anastomosis to the BA was out of the question. In the literature we could find only one case under deep hypothermic circulatory arrest during which a conventional anastomosis to the BA was made [11]. The ELANA technique allowed us to attach a venous graft to the BA through the small opening formed by the ICA, the A1 and the optic nerve, without occuding the BA. A nice flap of BA wall was retracted and this anastomosis was used to create an ECA-BA bypass, through which a flow of 55 ml/min was observed. This flow was observed with the right VA still open. We then ligated also this VA and the flow through the bypass increased to 95 ml/min. Due to the reversed flow in the aneurysm, there was now a high chance that a thrombus will create within the aneurysm, which hopefully would not occlude the BA itself. BA occlusion, however, was not likely to occur because of the continued flow to the PCAs, SCAs and AICAs. Angiography showed that the bypass supplied the posterior circulation (Fig. 3A, B, D), and our patient was improving and started to talk and move his limbs. After the operation his condition stabilized. There were signs of improvement. Two weeks later, MRA and CTA scans showed progression of thrombus formation within the aneurysm. However, there was also some progression of the neurological deficits. Four weeks later, the patient suffered a fatal subarachnoidal haemorrhage, which probably originated from the remnant of the aneurysm.

Discussion

The ELANA technique is an additional tool in the neurosurgical armamentarium. It can be used to attach blood vessels to otherwise inaccessible cerebral vessels, creating high flows. Whether to use this technique in patients endangered for stroke is still undefined. We have selected only those patients who have suffered multiple TIAs or minor stroke due to ICA occlusions inaccessible for endarterectomy, and who have a proven hypoperfusion of the brain. The results of the new EC/IC bypass trial might show that even more patients will improve when treated with revascularization techniques.

Various techniques to apply the platinum ring onto the recipient vessel are under investigation. The latest developments in our laboratory concentrate on the possibility of making a facilitated sutureless ELANA. The first results of animal experiments on rabbits using this method look very promising.

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