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End-to-side anastomosis without occlusion of the recipient artery utilizing the Excimer laser

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ABSTRACT

A new technique has been developed which enables the creation of an end-to-side anastomosis between arteries with no or an extremely short occlusion time (2 min) of the recipient artery for ischemic sensitive areas. The feasibility of the technique was studied in a rabbit model. The right common carotid artery was connected with the exterior of the left common carotid artery. Through an artificial sidebranch, which was connected with the donor artery proximally from the anastomosis, a laser catheter was introduced in contact with the recipient arterial wall. The laser was activated to create a hole in this wall and the artificial sidebranch was subsequently occluded. Meanwhile no occlusion of the donor artery was necessary.
In a series of 100 rabbits using a coated hemispherical contact probe (1.8 or 2.2 mm diameter) coupled to a Nd:YAG laser (one 0.5 s, 18 W pulse) a 95 % patency rate was obtained. In a recent series of 20 rabbits an Excimer-laser (Technolas, XeCl 308 nm, 120 ns, 20 Hz, 25 mJ/pulse) was used. The hole was created with a custom designed multifibercatheter of 2.2 mm diameter consisting 140 laserfibers in a flat circular configuration. A patency rate of 100% was obtained. Scanning Electron Microscopy of the anastomosis site up till 8 weeks showed a perfect endothelialization.
The advantage of the Excimer based multifiber catheter compared with the Nd:YAG based contact probe, is the absence of thermal effects at the site of the anastomosis. A pilot study is in progress in a series of patients, where an extra-intracranial bypass is indicated.

2. INTRODUCTION

In microvascular neurosurgery it is of great advantage when revascularization of the brain can be established without temporary occlusion of the recipient artery, since the intracranial internal carotid artery (ICA) and the main trunks of the anterior, middle and posterior cerebral artery can not be occluded for a period of more than 5 minutes without the risk of brain ischemia.
The extra-intracranial bypass for patients with transient brain ischemia, caused by an occlusion or severe stenosis of the internal carotid artery or the main trunk of the middle cerebral artery (MCA), was extensively studied among others in a multicenter randomized study conducted from London, Ontario, and funded by the N.I.H. (1). The bypass was made between one of the two branches of the superficial temporal artery and a superficially located branch of the middle cerebral artery. The superficial branch of the MCA was selected for safety reasons. When a more proximal MCA branch is occluded for the period of time necessary to create the anastomosis, focal brain ischemia may develop. It goes without

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saying, that an anastomosis with the intracranial portion of the internal carotid artery or the main trunk of the MCA was absolutely contraindicated. It was shown, that the extra-intracranial bypass between a superficial temporal artery branch and peripheral branch of MCA was not effective in preventing another ischemic episode in the ipsilateral cerebral hemisphere (1).
For many years we are trying to develop a new technique for the end-to-side anastomosis, which obviates the necessity to occlude the recipient artery during the procedure. Once established such a technique should enable the neurosurgeon to use as recipient artery in revascularization of the brain the intracranial portion of the internal carotid artery or the main trunk of the middle cerebral artery. It can not be excluded, that such a "high flow" extra-intracranial bypass will protect the brain in case of an occlusion of the ICA or a severe stenosis of the ICA (or MCA) in a more effective way than the "low flow" bypass, that was the subject of the International Randomized Study (2).
In this article we describe the three steps that led in the end to the development of the in our opinion first safe and reliable technique for end-to-side anastomosis without occlusion of the recipient artery.

3. PROCEDURE

First step: (3)
In 100 rats the left common carotid artery was connected with the right common carotid artery in the following way: The left carotid artery was ligated and transected as proximal in the neck as possible. This end of the artery was for 3/4 of its circumference connected with the exterior of the right carotid artery with eight 10.0 interrupted sutures (fig. 1a and 1b).

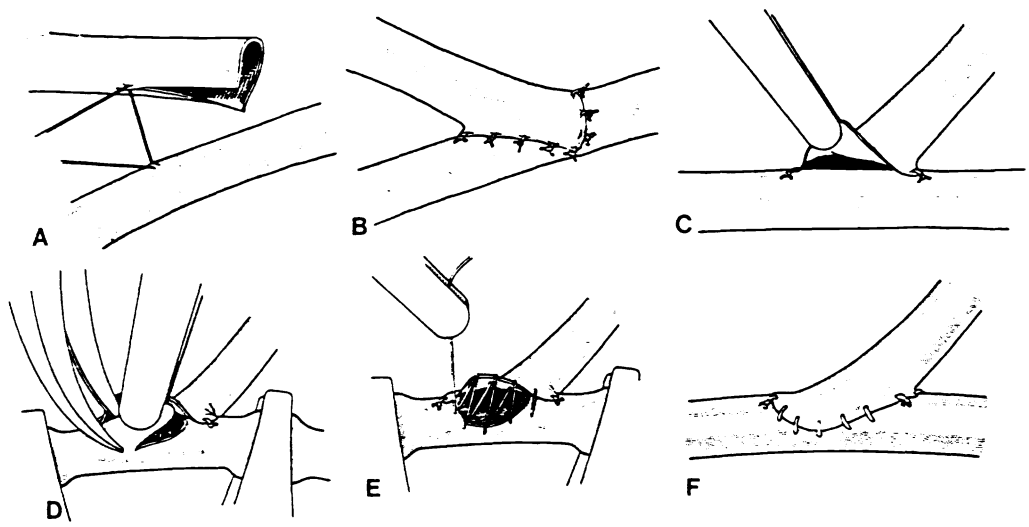

Fig. 1
The end-to-side anastomosis made in our first series of experiments (rats). For explanation see text.

On both sides of the anastomosis a temporary vessel clip is now applied and a hole is cut in the recipient artery (fig. 1c and 1d). The remaining 1/4 of the anastomosis is closed with a running suture 10.0; both temporary vessel clips are removed (fig. 1e and 1f). It goes without saying, that this type of microvascular surgery is performed with the aid of the operating microscope. In the end we were able to perform the end-to-side anastomosis with an occlusion time of the recipient artery of less than 5 minutes. More or less to our surprise the anastomosis stayed nicely open in about 95% of the cases. The anastomosis site was visually inspected in all animals and in 10 rats scanning electron microscopic examination of the anastomosis site was performed. The edge of the hole, cut in the recipient artery, endothelialized perfectly in 2 to 3 weeks. We did not dare to use this technique in patients, since an occlusion time of 5 minutes is still rather long when a main brain artery is used as recipient vessel and, moreover, when the technique has to be performed via a deep narrow tunnel at the base of the brain it is very well possible that the occlusion time necessary to finish the anastomosis will be longer.

Second step: (4).
The ideal to create an end-to-side anastomosis without occlusion of the recipient artery became more close when the Neodymium YAG-laser with the hemispherical contact probe became available at our institution. We performed operations in 65 rabbits. The left common carotid artery was used as the donor vessel and the right as the recipient vessel. The anastomosis was made as follows (fig. 2).

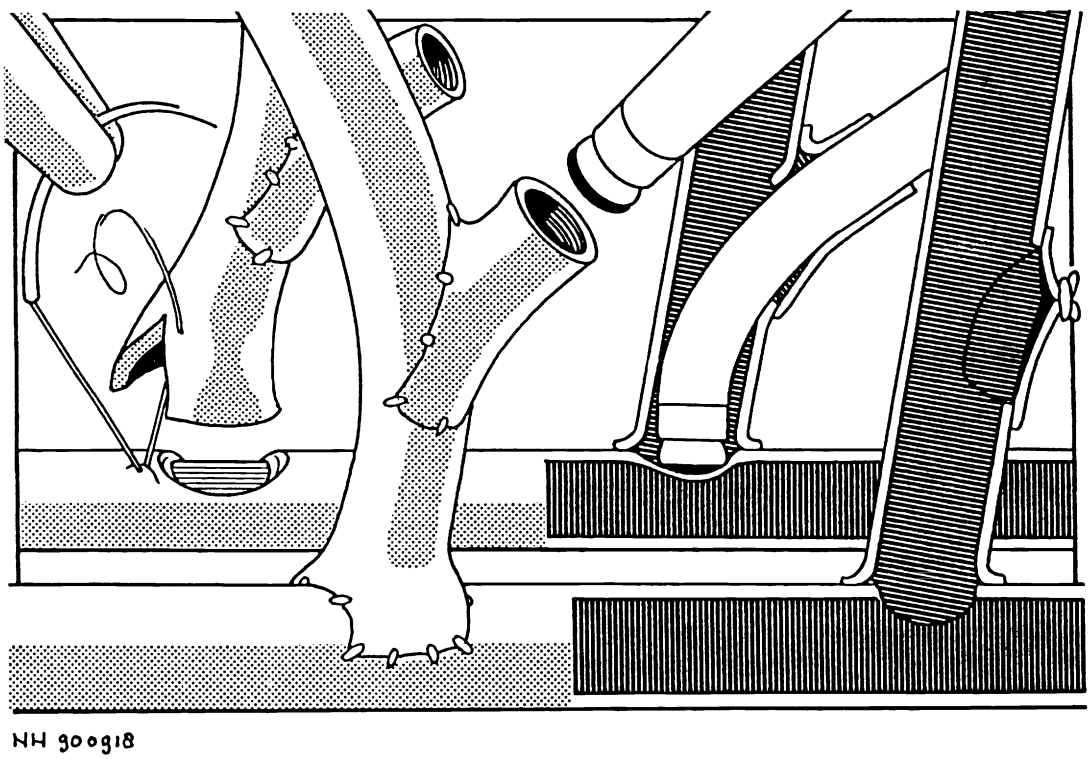

Fig. 2
The end-to-side anastomosis made in our second series of experiments (rabbits) and in 3 patients, where the donor artery was connected with one of the first branches of the M.C.A. For explanation see text.

The transected end of the left common carotid artery was connected for its full circumference with the exterior of the right carotid artery. An average of twelve interrupted sutures 10.0 Ethicon was used. Every suture passed only through the adventitial layer of the recipient artery and passed through the full wall of the donor artery.
Via an artificial side branch on the donor artery (a piece of vein) the Neodymium YAG-laser with the hemispherical contact probe on top (diameter 1.8 mm) was introduced in the donor artery and pushed forward till the tip touched and slightly impressed the wall of the recipient artery. With a laserpulse varying between 0.5-1.0 sec., 15-20 Watt a hole was created in the wall of the recipient artery. The hole had about the same diameter as the contact probe. The catheter was withdrawn and the artificial side branch was occluded with a hemoclip. In the first 35 of the 65 rabbits we achieved a patency rate of 65%. The low patency rate was caused in some cases by too small a hole when a too low laser energy was used or because of the thermal effect on the interior of the recipient and donor artery at the anastomosis site when the laser energy was too high. The control over the laser energy was related to the absorption at the surface of the probe by adhering carbonized particles (ref. RV). The presence of these particles and thus the absorption was hard to predict or to control.
Therefor we improved on this technique in the following way:
In the last 30 experiments we removed the adventitial layer and the muscular layer of the recipient artery at the spot where the anastomosis was planned. With the operating microscope on a high magnification (16 x) the layers were peeled off till the outside of the internal layer remained. With a laserpulse of only 0.5 seconds and 18 Watt a patent anastomosis has been obtained in the far majority of cases (90%). Furthermore, no single laser induced lesion of the vessel wall or the anastomosis itself was observed. The hole, burned with the laser tip, showed the same diameter or was slightly larger than the diameter of the laser tip used (1.8 mm). The patency of the anastomosis was examined by exploration and inspection of the anastomosis site and in 10 cases scanning electron microscopy of the anastomosis site was performed. A nice endothelialization of the edge of the hole in the recipient artery, that took place in 2 to 3 weeks, was observed.
In three patients we made and extra-intracranial bypass between the superficial temporal artery and a second generation middle cerebral artery branch, using this end-to-side anastomosis technique. In one of those patients a post-operative angiogram was performed, which showed a nicely patent anastomosis and a marked increase in diameter of the branch of the superficial temporal artery, that was used at the donor artery.
Despite the fact that it was proven by these clinical cases that the end-to-side anastomosis could be successfully used in patients, we considered the technique still rather complicated and not without risk. The risk is in the removal of the adventitial and medial layer of the recipient artery previous to the creation of the hole with the aid of the Neodymium YAG-laser tip. In the hands of very specialized microvascular neurosurgeons this manoeuvre can be safely performed. However, the risk of penetration of the recipient artery already at this moment is very real.

Third step:
All of a sudden the laser assisted end-to-side anastomosis without occlusion of the recipient artery became a very real clinical possibility when the Excimer laser (Technolas, München, Germany) became available at our institution in the beginning of 1991. The Excimer laser (Xenon chloride, 308 nm) light pulses with a frequency of 10, 20 or 40 Herz ablate the tissue layer by layer. During every pulse a tissue layer with exactly the diameter of the laser fiber and with a depth of about 0.01 mm is ablated. There is

no noticeble thermal effect in the tissue immediately surrounding the fibertip and also in the layer adjoining the ablated layer, that is still not ablated by the next laserpulse.
In 20 rabbits we performed an end-to-side anastomosis between the carotid arteries with the aid of the Excimer laser. A portion of 2.5 cm of the left common carotid artery was taken out and connected by way of two end-to-side anastomoses with the right internal carotid artery. Both anastomoses were made without occlusion of the recipient artery, using the technique as described under step 2 (fig. 2) with two alterations:

1. The Excimer laser is used instead of the Neodymium YAG-laser. The laser catheter tip of the Excimer laser, that was made at our request by the Firm Technolas (München, Germany) for this purpose, had a diameter of 2.2 mm and consisted op 140 laser fibers that were glued together and protruded for 2 mm out of the thin metal ring at the end of the catheter (fig. 3).

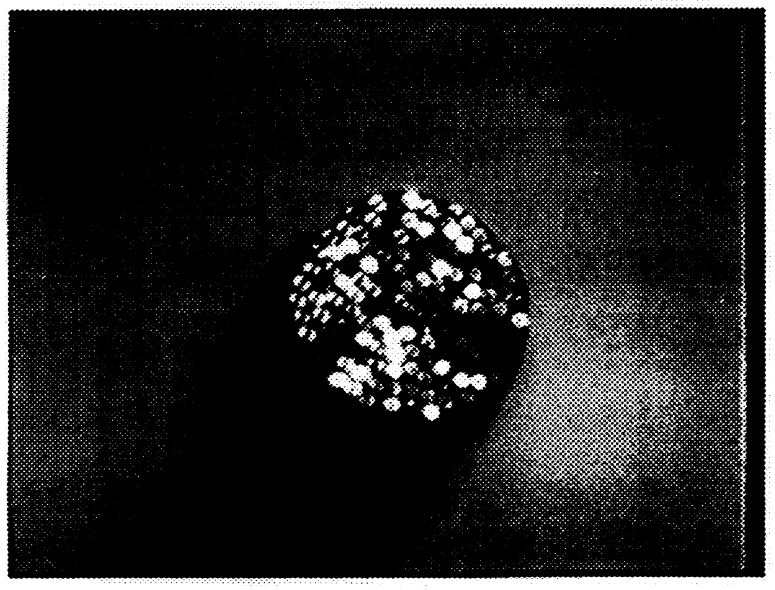

Fig. 3
The tip of the Excimer laser.

In 1 to 2 seconds (20 to 40 pulses) the tip penetrated the wall of the recipient artery, making a perfect round hole with exactly the same diameter as the tip of the catheter. The edge of the hole looks as if it is created by an extremely fine knife. No thermal effect is noted.
2. The adventitial and medial layer were not removed at the spot where the anastomosis was planned. The tip of the Excimer laser penetrated all the layers of the arterial wall in such an easy way without thermal effect, that the rather risky procedure of peeling off the outer layers of the vessel is completely obviated. The anastomoses were studied by direct exploration and inspection in all cases and in 5 cases scanning electron microscopy of the anastomosis site was perfomed. The anastomoses were studied at different time intervals between 2 hours to 2 months after the operation. In two animals an occlusion of the anastomosis site was observed, probably because of mechanical damage of the interior layer of the

donor artery, since in both cases there was a discrepancy between the diameter of the catheter tip (2.2 mm) and the relatively small carotid artery (1.9 mm). In all the other cases a nicely patent anastomosis was observed with a very sharp deliniated hole in the recipient artery in the acute stage (fig. 4a and 4b), that gradually in 2 to 3 weeks became perfectly endothelialized (fig. 5).

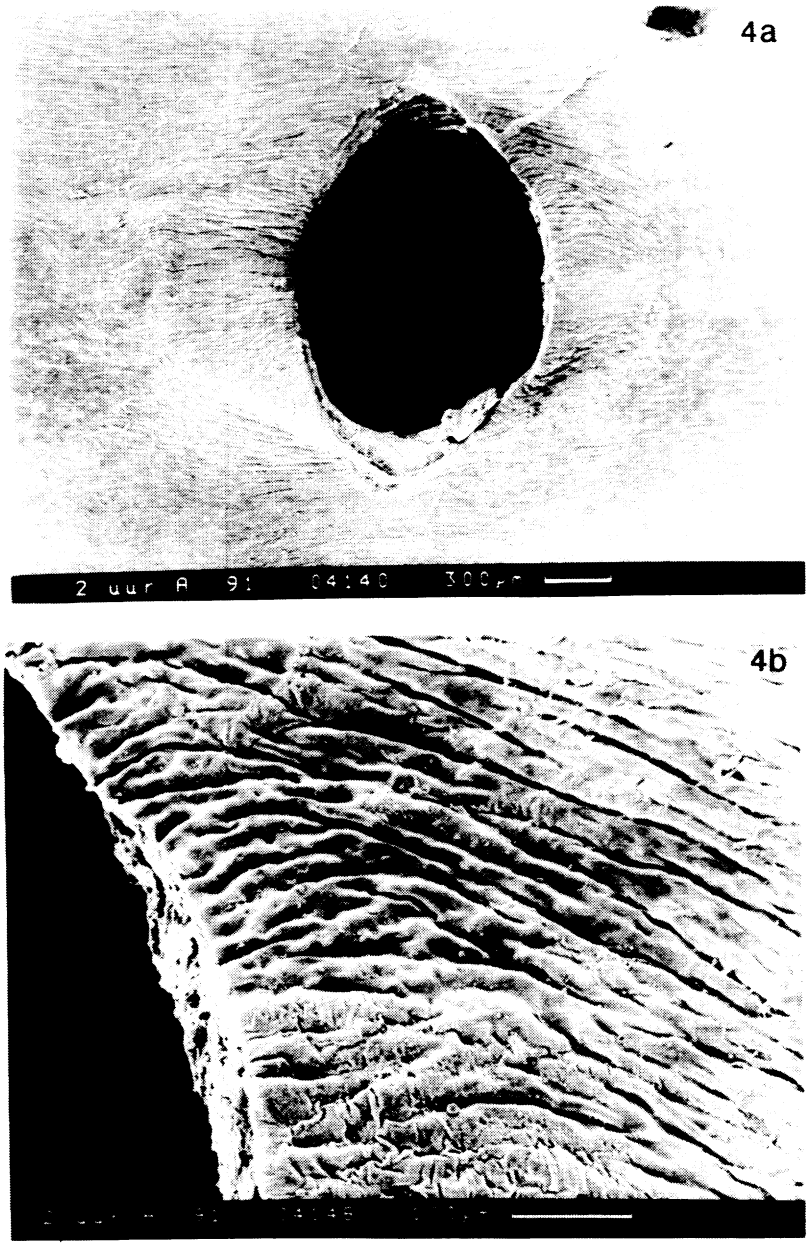

Fig. 4
The hole created by the Excimer laser tip with a diameter of 2.2 mm and consisting of 140 laserfibers, using 30 pulses (20 Herz) - 25 mJ/pulse: a. small magnification; b. large magnification.

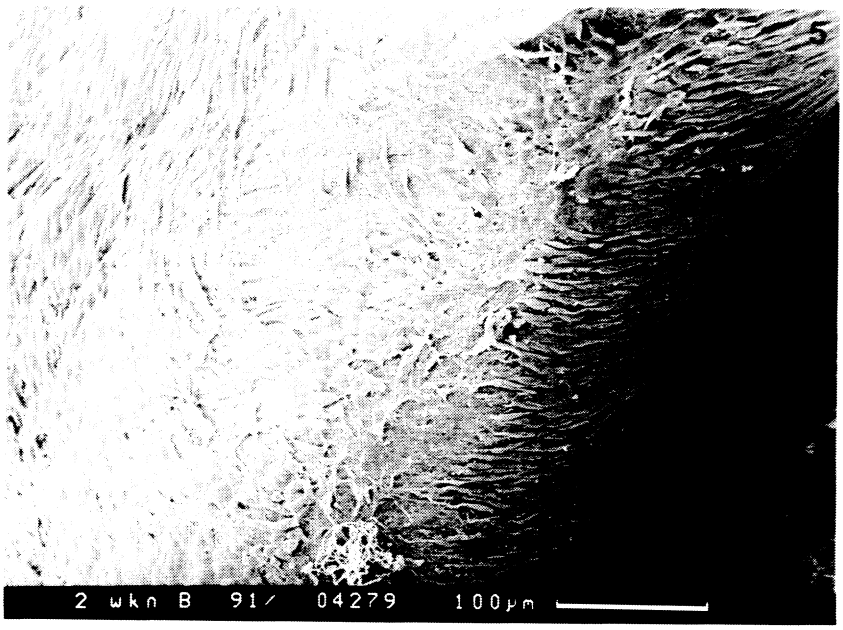

Fig. 5
The edge of the by the Excimer laser induced anastomosis, two months after the operation. The endothelialization of the edge is shown. For comparison with the acute stage see fig. 4a and 4b.

Recently we performed a "high flow" extra-intracranial bypass in two patients with a severe narrowing of the right internal carotid artery in its petrosal portion in one patient and an occlusion of both internal carotid arteries in the other. As recipient artery we used the intracranial internal carotid artery and as an arterial transplant we used the right inferior epigastric artery (length 15 cm) (5).
The proximal end of the epigastric artery (diameter 2.5 mm) was end-to-side connected with the exterior of the intra-cranial internal carotid artery, using all the steps described in the above (fig. 2).
The other end of the inferior epigastric artery was end-to-end connected with the proximal portion of the superficial temporal artery in front of the ear.
When the laser tip penetrated the wall of the internal carotid artery, it was very well possible to feel the drop in resistance when the tip entered the lumen of the internal carotid artery. The surgeon presses the footswitch himself and stops immediately when he feels the penetration. It took 1.5 seconds (30 pulses of 27 mJ) to create the hole in the recipient artery. The patients sustained the operative procedure perfectly.

4. DISCUSSION

In the above we described our efforts in the last 10 years to develop a new end-to-side anastomosis technique, which obviates the necessity of a temporary occlusion of the recipient artery. When the intracranial portion of the internal carotid artery or the main trunk of the middle cerebral artery is used as recipient vessel in the creation of a "high flow" extra-intracranial bypass, this technique is obligatory. Since half a year, when the Excimer laser became available at our institution, we do have a reliable and safe technique as is shown extensively in animal experiments. The anastomosis is constructed between the donor artery and the exterior of the recipient artery and in the end the anastomosis is opened with the aid of the Excimer laser. The tip of the Excimer laser has a diameter of 2.2 mm and consists of 140 fibers. The laser tip penetrates the wall of the recipient artery in 1 to 2 seconds (20 to 40 laser pulses of 27J) and creates a perfect round hole with exactly the same diameter as the tip. There is no noticeble thermal effect in the tissues bordering the hole.
In two patients we constructed a bypass, where the right inferior epigastric artery was interposed between the proximal portion of the superficial temporal artery (in front of the ear) and the intracranial portion of the internal carotid artery. The second anastomosis was made, utilizing the technique described in the above.
It can not be excluded that the Excimer laser assisted anastomosis technique, that obviates occlusion of the recipient artery, does have an indication in general vascular surgery, where occlusion of the recipient artery is less warranted. For example in cases of reconstruction of the cerebro-petal arteries in the neck and in the reconstruction of arteries that are still supplying a hemodynamically very much endangered organ.

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