Predictors of patency of excimer laser–assisted nonocclusive extracranial-to-intracranial bypasses

Clinical article

Jochem P. Bremmer, M.D.,1 Bon H. Verwei, M.D., Ph.D.,1 Catharina J. M. Klijn, M.D., Ph.D.,1 Albert van der Zw, M.D., Ph.D.,1 L. Jaap Kappelle, M.D., Ph.D.,1 and Cornelis A. F. Tulleken, M.D., Ph.D.1

1Departments of Neurosurgery and 2Neurology, Rudolf Magnus Institute of Neuroscience, University Medical Center Utrecht, The Netherlands

Object. Excimer laser–assisted nonocclusive anastomosis (ELANA) is a technique that can be used for extracranial-to-intracranial (EC-IC) bypasses, without the necessity of temporary occlusion of the donor or recipient artery. Information on predictors of patency of EC-IC bypasses in general and the ELANA bypass in particular is sparse. The authors studied 159 ELANA EC-IC bypasses to find predictors of patency.

Methods. From a prospective database of patients who underwent EC-IC bypass surgery, 143 consecutive patients who underwent a total of 159 ELANA bypasses were studied. The associations of patient characteristics, surgical aspects, and technical aspects specific to the ELANA technique with intraoperative and postoperative bypass patency were studied using logistic regression analysis.

Results. At the end of the operation, 146 (92%) of the 159 bypasses were patent. A first attempt to create a bypass was almost 8 times more likely (OR 7.6, 95% CI 2.1–27.5; p = 0.02) to result in a patent bypass than a second attempt. Administration of a small amount of heparin during the operation was also associated with bypass patency (OR 5.2, 95% CI 1.1–24.9; p = 0.04). One hundred twenty-three (77%) of the 159 bypasses were functional at patency assessments during the 1st month after the operation. Older age (OR 1.043 for every year of increase in age, 95% CI 1.010–1.076; p = 0.01), male sex (OR 2.9, 95% CI 1.3–6.5; p = 0.01), and high intraoperative bypass flow (OR 1.017 for every milliliter per minute increase in flow, 95% CI 1.004–1.030; p = 0.01) were associated with postoperative bypass patency.

Conclusions. Attempts to create a second EC-IC ELANA bypass after the first one are more likely to fail, whereas administration of heparin to the patient during the procedure increases the intraoperative bypass patency rate. Postoperative patency results are better in male and in older patients. Intraoperative bypass flow measurements are essential because high bypass flow is an important determinant of postoperative patency.

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Key Words • anastomosis • bypass patency • cerebral revascularization • ELANA technique • extracranial-to-intracranial bypass

Revascularization by means of EC-IC bypass surgery may benefit 2 groups of patients. The first group consists of patients with an aneurysm in 1 of the intracerebral arteries that cannot be treated by endovascular coil embolization or by neurosurgical clip placement. Bypass surgery may be needed in these patients if occlusion of the artery is not tolerated. The second group consists of patients with recurrent transient ischemic attacks or nondisabling ischemic stroke that is associated with an occlusion of the ICA or MCA. These patients may have a high risk of recurrent stroke in cases of hemodynamic compromise of the intracerebral circulation.9 The efficacy of bypass surgery in preventing stroke in patients in this second group is currently being tested in 2 ongoing randomized clinical trials, the American Carotid Occlusion Study (COSS)10 and the Japanese EC-IC bypass trial (JET study).12,13

The main risk of conventional EC-IC bypass surgery is the occurrence of an ischemic stroke when the recipient artery is temporarily clipped for the creation of the distal anastomosis. This risk is low with a conventional superficial temporal artery-to-MCA bypass, during which an anastomosis is made with a small cortical branch of the
The ELANA Technique

The ELANA technique has been described previously. In summary, a platinum ring is sutured into the end of a vein graft (Fig. 1A and B). After a fronto-temporal craniotomy is performed according to standard procedures, the graft (with the platinum ring) is sutured to the wall of the recipient artery (Fig. 1C). The size of the platinum ring can be 2.6, 2.8, or 3.0 mm, depending on the size of the recipient artery.

Subsequently, the excimer laser catheter is introduced into the lumen of the graft until its tip touches the flattened wall of the recipient artery within the platinum ring. High vacuum suction is applied for 2 minutes to affix the catheter to the wall of the recipient artery. After 2 minutes of vacuum suction, the XeCl excimer laser (308 nm, 100 ns, 10 mJ, 40 Hz; Medolas MAX 10 or 20, Coherent-Tuilaser, or CVX-300; Spectranetics International B.V.) is activated for 5 seconds to ablate a full-thickness disc out of the wall of the recipient artery (Fig. 1D). The laser catheter is then removed from the graft together with the disc of vessel wall (flap) that stays attached to the tip of the catheter due to the continued vacuum suction. A temporary clip is placed to prevent backflow bleeding from the graft. This graft is then connected, using conventional end-to-end anastomosis techniques, to a previously prepared graft that is first connected to a donor artery using conventional end-to-side anastomosis techniques.

Over the years, the ELANA technique has been adapted with respect to the suturing of the platinum ring and handling of an anastomosis in case no flap can be retrieved. Initially, the platinum ring was first sutured onto the end of the graft, and then this graft-ring combination was sutured onto the recipient wall (Fig. 1). In later years, the ring was first sutured onto the recipient vessel wall and subsequently the graft was sutured onto the recipient artery, on top of the platinum ring. Using this method the flattened vessel wall inside the platinum ring could be easily inspected. This method, however, required a larger number of sutures to be placed intracranially, and hemostasis at the anastomosis site tended to be more difficult. For these reasons the ELANA suturing protocol has been changed back to the original suturing method (suturing the ring into the graft first).

When we started using the ELANA technique in patients at the beginning of the 1990s, abandoning the anastomosis if no flap was retrieved was the standard safety procedure. Later, intraoperative ultrasonography flow measurements (as described later) were introduced and intraoperative decision making about bypass function in case a flap was not retrieved was based on the ultrasonography flow measurements.

Patients and Data Collection

Between October 1993 and December 2005, one of us (C.A.F.T.) performed EC-IC bypass operations in 182 patients using the ELANA technique for the distal anastomosis. In the current study we included 143 of these 182 patients. Thirty-nine patients were excluded because information on postoperative patency of the bypass was not available. In 10 of the 39 excluded patients, the bypass was used to enable clipping of an aneurysm after which the bypass was no longer used. In 16 of the 39 excluded patients, bypass patency was not assessed after the operation. In the remaining 13 excluded patients, the ELANA procedure was abandoned during the operation directly after the laser procedure, because a full-thickness disc of the recipient artery (flap) could not be retrieved (in accordance with our safety procedure at the beginning of the 1990s as described previously).

Patient characteristics (age, sex, and indication for the operation) were obtained from medical records. The following general bypass-related characteristics were obtained from the surgical reports or the medical files: positioning of the bypass; function of the bypass at the end of surgery; complete artery replacement (replacement of an occluded ICA) or placement parallel to existing circulation (during aneurysm treatment while endovascular occlusion is being planned); first or second bypass attempt; use of intraoperative heparin; intraoperative bypass flow (the last measurement of bypass flow reported in the surgical report); and postoperative antithrombotic medication. From the surgical report we obtained the following characteristics specific for the ELANA: size of the platinum ring used, technique of suturing (ring onto recipient artery or ring into graft), and retrieval of a full-thickness disc out of the wall of the recipient artery (flap).

Antiplatelet therapy was discontinued ≥ 5 days before surgery. In general, 500–1000 IU of heparin was given intraoperatively, directly after the laser procedure was performed. For the remaining duration of the surgery, 500–1000 IU of heparin per hour was administered.

Postoperatively, 2 different medical regimens were used during the study period. From 1993 until 2002, 50 g of dextran-40 every 24 hours was given combined with intraoperative heparin,
Predictors of patency of ELANA EC-IC bypasses

with low-dose acetylsalicylic acid (30–100 mg) and low-dose nadroparin (2850 IU/day or 5700 IU/day if the patient weighed > 80 kg) for 3 days after surgery (protocol 1; 93 bypasses). From 2002 until 2005, 15000 IU of heparin was administered every 24 hours combined with low-dose aspirin (30–100 mg), and low-dose nadroparin was given for 3 days (protocol 2; 14 bypasses). In some patients only low-dose acetylsalicylic acid was given because anticoagulant therapy was contraindicated (protocol 3; 26 bypasses); anticoagulant therapy could be contraindicated if a bypass was made for the treatment of an aneurysm that had recently caused a subarachnoid hemorrhage. All patients were treated with low-dose acetylsalicylic acid from the 4th day forward. In 8 bypasses the medical regimen did not follow a specific protocol, and in 18 bypasses the medical regimen data were missing.
Assessment of Intraoperative Patency

Intraoperative patency of the bypasses was assessed using 3 different methods. Initially, the patency was manually checked by the surgeon (28 bypasses, 18%) or using the Doppler ultrasonic flow meter (6 bypasses, 4%; Mini Dopplex, Huntleigh Healthcare L.L.C.). Later, the ultrasonic flow meter (Transonic Systems, Inc.) was used in 125 bypasses (79%).

Assessment of Postoperative Patency

Postoperative bypass patency was defined as evidence of patency during the 1st month after the operation. Assessment of postoperative patency varied with respect to the timing and technique applied, depending on the condition of the patient and the type of treatment. If > 1 patency assessment was performed during the 1st month, the last measurement was recorded. If patency was assessed > 1 month after surgery, this measurement was used as proof that the bypass was patent at the end of the 1st month after the operation.

Thirteen (8%) bypasses were found to be occluded at the end of the operation. In 5 bypasses (3%) patency was assessed within 24 hours after the operation and not thereafter. In 4 of these 5 bypasses the bypass was found to be occluded and later assessments were considered not useful. In 73 bypasses (46%) patency was assessed between Day 1 and Day 7 postoperatively, and in 33 bypasses (21%) patency was assessed between Day 7 and Day 30 after the operation. In 35 bypasses (22%) the last bypass patency measurement was performed > 30 days after surgery.

Of the 146 assessments of postoperative patency, 88 (60%) were performed using angiography according to Seldinger,19 42 (29%) using MR angiography or CT angiography, 3 (2%) using duplex ultrasonography, and 13 (9%) using only clinical examination (auscultation and palpation). In 5 of these 13 patients a suspected occlusion of the bypass was confirmed during a subsequent operation.

Data Analysis

The association of patient characteristics, general bypass characteristics, and characteristics specific to the ELANA technique with intraoperative and postoperative bypass patency was analyzed using univariate logistic regression analysis and expressed as ORs with 95% CIs. In addition, probability values are given. Characteristics with an association and a probability value < 0.10 were entered in a multivariate logistic regression analysis. The amount of intraoperative bypass flow was plotted against postoperative bypass patency. Patency of bypasses with a postoperative flow < 40 ml/min was compared with patency of bypasses with postoperative flow ≥ 40 ml/min using the Fisher exact test. Finally, we analyzed the effect of successful flap retrieval on intraoperative bypass flow. Statistical significance was accepted for probability values < 0.05. All analyses were performed using SPSS Version 14 (SPSS Inc.).

Results

The mean age (± SD) of the patients was 54 years (± 12 years). Seventy (49%) of the 143 patients were male. Eighty-seven patients (61%) underwent ELANA bypass surgery because of an aneurysm, and 47 patients (33%) were operated on because of transient ischemic attacks or ischemic stroke associated with occlusion of the ICA. In 8 patients (6%) an ELANA bypass was used in the treatment of a tumor, and 1 patient was operated on because of a malformation of the ICA.

A total of 159 ELANA EC-IC bypasses were created; in 16 patients (11%) the first ELANA bypass was not functional and a second ELANA bypass was performed. In 3 of these 16 patients a new ELANA bypass was constructed in the same surgical session, and in the other 13 patients a second ELANA bypass was created during a second operation. The positioning of the proximal and distal anastomosis of the 159 bypasses is shown in Table 1.

In 155 bypasses (97%), a part of the greater saphenous vein was used as graft, in 1 patient the radial artery was used, and in another patient the epigastric artery was used. The type of graft was not reported in 2 patients. In all patients the ELANA technique was used for the distal intracranial anastomosis, whereas the proximal extracranial anastomosis was made using the conventional end-to-side technique.

Intraoperative Patency

In 146 (92%) of the 159 ELANA bypass procedures a patent bypass could be constructed. Of the 13 bypasses (8%) that were occluded at the end of the operation, 7 bypasses occluded spontaneously. Three of these 7 bypasses showed complete occlusion during the operation, and in 4 bypasses the flow slowly decreased during the operation and occlusion of the bypass was confirmed after the operation. In 6 of the 13 occluded bypasses the procedure was terminated by the surgeon, once because of rupture of the recipient artery at the site of the distal ELANA and 5 times because the flow in the bypass was stable but
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Table 2 shows the associations between patient characteristics, general bypass characteristics, specific ELANA characteristics, and intraoperative bypass patency. A bypass performed as a first attempt remained patent more often during the operation than a bypass made as a second attempt (OR 7.6, 95% CI 2.1–27.5; p = 0.02). If patients received heparin during the operation, the bypass remained patent more often than in the absence of heparin during the operation (OR 5.2, 95% CI 1.1–24.9; p = 0.04). We refrained from further multivariate analysis because in 35% of the cases information on ≥ 1 of the characteristics was missing.

Postoperative Patency

One hundred twenty-three (77%) of the 159 bypasses were functional at patency assessments during the 1st month after the operation. The associations of patient characteristics, general bypass characteristics, and characteristics specific for the ELANA technique with postoperative patency are shown in Table 3. Older age,
TABLE 3: Summary of the associations between patient and bypass characteristics and postoperative bypass patency

<table>
<thead>
<tr>
<th>Variable</th>
<th>All</th>
<th>Yes</th>
<th>No</th>
<th>OR (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
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<tr>
<td><strong>bypasses</strong></td>
<td>159</td>
<td>123 (77)</td>
<td>36 (23)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>patient characteristics</strong></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>age (years ± SD)</td>
<td>53 ± 12</td>
<td>55 ± 12</td>
<td>49 ± 13</td>
<td>1.043 (1.010–1.076)</td>
<td>0.01</td>
</tr>
<tr>
<td>male</td>
<td>75</td>
<td>65 (87)</td>
<td>10 (13)</td>
<td>2.9 (1.3–6.5)</td>
<td>0.01</td>
</tr>
<tr>
<td>female</td>
<td>84</td>
<td>58 (69)</td>
<td>26 (31)</td>
<td></td>
<td></td>
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<tr>
<td><strong>indication</strong></td>
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<tr>
<td>aneurysm</td>
<td>98</td>
<td>73 (74)</td>
<td>25 (26)</td>
<td>0.4 (0.1–1.0)</td>
<td>NS†</td>
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<tr>
<td>ischemia</td>
<td>51</td>
<td>45 (88)</td>
<td>6 (12)</td>
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</tr>
<tr>
<td>ICA malformation</td>
<td>1</td>
<td>1 (100)</td>
<td>0 (0)</td>
<td></td>
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<tr>
<td>tumor</td>
<td>9</td>
<td>4 (44)</td>
<td>5 (56)</td>
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<td><strong>general bypass characteristics</strong></td>
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<td>first bypass attempt</td>
<td></td>
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</tr>
<tr>
<td>yes</td>
<td>143</td>
<td>113 (79)</td>
<td>30 (21)</td>
<td>2.3 (0.8–6.7)</td>
<td>NS</td>
</tr>
<tr>
<td>no</td>
<td>16</td>
<td>10 (62)</td>
<td>6 (38)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>intraoperative heparin‡‡</td>
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<td></td>
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</tr>
<tr>
<td>yes</td>
<td>91</td>
<td>74 (81)</td>
<td>17 (19)</td>
<td>1.9 (0.5–7.0)</td>
<td>NS</td>
</tr>
<tr>
<td>no</td>
<td>13</td>
<td>9 (69)</td>
<td>4 (31)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bypass function at end of surgery§§</td>
<td></td>
<td></td>
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<tr>
<td>artery replacement</td>
<td>77</td>
<td>68 (88)</td>
<td>9 (12)</td>
<td>1.4 (0.9–2.2)</td>
<td>NS</td>
</tr>
<tr>
<td>parallel to existing circulation</td>
<td>66</td>
<td>53 (80)</td>
<td>13 (20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean bypass flow (ml/min ± SD)¶¶</td>
<td>75 ± 42</td>
<td>80 ± 39</td>
<td>57 ± 47</td>
<td>1.017 (1.004–1.030)</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>postoperative medication</strong>†**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>protocol 1</td>
<td>93</td>
<td>75 (81)</td>
<td>18 (19)</td>
<td>0.3 (0.4–2.6)</td>
<td>NS††</td>
</tr>
<tr>
<td>protocol 2</td>
<td>14</td>
<td>13 (93)</td>
<td>1 (7)</td>
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<tr>
<td>protocol 3</td>
<td>26</td>
<td>20 (77)</td>
<td>6 (23)</td>
<td>1.4 (0.5–3.9)</td>
<td>NS‡‡</td>
</tr>
<tr>
<td>different protocol</td>
<td>8</td>
<td>5 (62)</td>
<td>3 (38)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>specific ELENA characteristics</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>platinum ring size (mm)§§</td>
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<td></td>
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<tr>
<td>2.6</td>
<td>48</td>
<td>36 (75)</td>
<td>12 (25)</td>
<td>0.3 (0.0–20.0)</td>
<td>NS§¶</td>
</tr>
<tr>
<td>2.8</td>
<td>78</td>
<td>62 (79)</td>
<td>16 (21)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>15</td>
<td>12 (80)</td>
<td>3 (20)</td>
<td></td>
<td></td>
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<tr>
<td>suturing§</td>
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<td></td>
</tr>
<tr>
<td>ring(s) onto recipient first</td>
<td>80</td>
<td>64 (80)</td>
<td>16 (20)</td>
<td>1.5 (0.7–3.1)</td>
<td>NS</td>
</tr>
<tr>
<td>ring(s) into graft first</td>
<td>71</td>
<td>52 (73)</td>
<td>19 (27)</td>
<td></td>
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<tr>
<td>flaps retrieved b</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>yes</td>
<td>138</td>
<td>110 (80)</td>
<td>28 (20)</td>
<td>2.5 (0.9–7.0)</td>
<td>NS</td>
</tr>
<tr>
<td>no</td>
<td>18</td>
<td>11 (61)</td>
<td>7 (39)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Unless otherwise specified, values given are number of bypasses (%).
† Logistic regression analysis between aneurysm and ischemia.
‡ Not available for 55 bypasses; because of the variance in the total heparin dose given in this protocol, we analyzed the effect of any heparin versus no heparin given during the operation.
§ Not available for 16 bypasses.
¶ Not available for 37 bypasses; the OR is again given per ml flow increase. The interpretation is explained with the following example: if the flow through the EC-IC bypass increases by 1 ml, the odds of a patent bypass increases by a factor 1.017, meaning that if the flow through the bypass is 10 ml higher, the odds of a patent bypass increase by 18% (95% CI 4–34%).

(continued)
male sex, and a high intraoperative bypass flow all significantly increased the odds of a functional bypass in the 1st month after the operation. If we included the amount of flow through the bypass at the end of the operations and age and sex in a multivariate analysis, the association between high bypass flow (OR 1.01 for every milliliter flow increase, 95% CI 1.00–1.03; p = 0.01), older age (OR 1.05 for every year, 95% CI 1.01–1.09; p = 0.01), and postoperative bypass patency remained essentially the same, whereas male sex was no longer associated with postoperative bypass patency (OR 1.79, 95% CI 0.67–4.74; p = 0.24). Further analysis showed that the mean bypass flow in male patients (mean 85 ± 43 ml/min) was significantly higher (p = 0.03) than the bypass flow in female patients (mean 68 ± 39 ml/min; 95% CI 1–31; mean difference 17). We refrained from further multivariate analysis because in 28% of the cases the information in one of the characteristics was missing.

The effect of intraoperative bypass flow on postoperative bypass patency is shown in Fig. 2. Bypasses with a medium to high (≥ 40 ml/min) intraoperative bypass flow remained patent significantly more often (p = 0.007) than bypasses with a low flow (< 40 ml/min). The bypass flow tended to be higher (p = 0.08) when the flap was successfully removed (mean 77 ± 42 ml/min; 95% CI 1–31; mean difference 19) compared with the bypass flow when the flap was left behind (mean 58 ± 40 ml/min; 95% CI −3 to 42; mean difference 19).

**Discussion**

This study shows that an initial ELANA bypass attempt has a greater chance of resulting in a patent bypass at the end of the operation than a second attempt, and that administration of heparin (500–1000 IU/hour) to the patient after the bypass is created also increases the odds of a patent bypass at the end of the operation. Older age, male sex, and high intraoperative flow are associated with postoperative patency.

A possible explanation for the negative effect on intraoperative patency of a new attempt to create a bypass could be selection; a subsequent attempt after the first bypass could be hampered by the same problems as the first bypass attempt, such as poor graft quality or poor quality of the recipient artery. A new bypass attempt could also be hampered by a decreased quality of the remaining available grafts in the patient.

We could confirm the positive effect of heparin on intraoperative bypass patency, which has been described previously, but we could not find an effect on postoperative bypass patency. It should be noted that the amount of heparin we administered (500–1000 IU after the laser procedure followed by 500–1000 IU every hour) is relatively small compared with the administration of 4000–5000 IU that has been reported by others. The effect of postoperative antiplatelet therapy could not be studied because low-dose acetylsalicylic acid was given to all patients. The effectiveness of antiplatelet therapy on postoperative bypass patency has been widely accepted in vascular and cardiovascular surgery. In a trial in 407 patients who underwent aortocoronary bypass surgery, the combination of acetylsalicylic acid and dipyridamole therapy was shown to improve patency compared with placebo. Studies comparing the potential risk of postoperative hematoma or hemorrhagic conversion of an ischemic stroke with the potential benefit of antiplatelet and anticoagulant therapy have not been performed. We could not find associations between the postoperative anticoagulation and antiplatelet protocols and bypass patency, but the antiplatelet and anticoagulant protocol was not standardized and the number of patients receiving 2 of the 3 protocols was small.

The finding that a bypass was more likely to remain patent postoperatively in older patients is difficult to explain. A possible reason could be that the adaptive potential of collateral pathways in older patients is less than in younger patients. In younger patients collateral pathways can perhaps be recruited more effectively than in older patients. Recruitment of collateral pathways can shunt blood away from the bypass, thus decreasing bypass flow and therefore increasing the risk of occlusion.

The increased risk of occlusion of the EC-IC bypass in female patients is associated with a lower bypass flow in these patients. According to Poiseuille’s law, a small vessel diameter in females will result in a lower flow, and low bypass flow again is a risk factor for postoperative bypass occlusion.

The finding that a higher bypass flow during the operation increased the chance of a patent bypass postoperatively is in accordance with the cardiovascular experience. In 1 EC-IC bypass study, which included 202 conventional saphenous vein–grafted EC-IC bypasses, occlusion of the bypass was more frequent when the flow was < 50 ml/min.

We found a trend toward lower bypass flow if a flap could not be retrieved. In current clinical practice, we use the ELANA technique for the creation of the bypass even if we do not obtain the flap, but only when we find a high and stable bypass flow through the bypass during the op-

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**TABLE 3: Summary of the associations between patient and bypass characteristics and postoperative bypass patency (continued)**

*Not available for 18 bypasses.
†† Logistic regression analysis comparing protocol 1 and protocol 2.
‡‡ Logistic regression analysis comparing protocols 1 and 2 combined versus protocol 3.
§§ Not available for 18 bypasses.
¶¶ Logistic regression analysis between 2.6 and 2.8 mm.
* Not available for 8 bypasses.
* Not available for 3 bypasses.
than postoperative patency (84%) in the medium- to high-flow group (F ≥ 40 ml/min) was significantly lower (p = 0.007; 2-tailed Fisher exact test) than postoperative patency (59%) in the low-flow group (F < 40 ml/min). Flow data was not available in 21 bypasses.

postoperative patency may have been influenced by selection: 13 of the 39 excluded patients were not included because our safety policy in the beginning of the 1990s was to abandon the ELANA if the flap could not be retrieved.

Postoperative patency rate of the EC-IC bypasses in our study (77%) is lower than the patency results of EC-IC bypass surgery using saphenous vein grafts as reported by Regli et al. (86% after 30 days). This difference may be explained by the larger number of patients who underwent operations because of aneurysms in our study. In aneurysm treatment the positioning of the intracranial ELANA is mostly defined by the position of the aneurysm. The ELANA is usually made directly distal to the aneurysm, often an MCA M2 segment or the anterior cerebral artery A2 segment. The flow territory of these distal branches is small, and according to Poiseuille’s law the small diameter of these distal branches leads to a low blood flow, which leads to a low bypass flow. Another reason for the low bypass flow in patients who underwent operations because of aneurysms could be the fact that the parent artery harboring the aneurysm was not always occluded intraoperatively, but often a couple of days thereafter. Finally, some patients may have been able to sustain occlusion of the parent artery via their existent collateral blood vessels. At present, we routinely perform test occlusions with venous phase monitoring to evaluate whether an EC-IC bypass is needed, but such test occlusions were not routinely performed at the beginning of the 1990s.

This study has several limitations inherent to its retrospective design. Over the long study period, postoperative assessment of patency and the postoperative medical regimen have not remained the same. In addition, some technical aspects of the procedure have varied over time. However, in the present study we were able to assess a relatively large group of bypasses all performed in 1 center by a single experienced vascular neurosurgeon. This is the first report of determinants of intraoperative and postoperative patency of all ELANA EC-IC bypasses performed since the method was first developed and without selecting patients according to bypass indication. A further limitation of this study is that the influence of the choice of graft and surgical handling of an interposed graft on patency as discussed in the literature could not be studied, because only a few grafts other than greater saphenous veins were used in the studied patients. Data about surgical handling of grafts were not routinely reported, but there have not been different protocols for surgical handling of grafts in the study period.

In the present study, intraoperative angiograms or the recently developed near-infrared indocyanine green video angiography were not used, but both techniques may be of benefit in checking the anastomoses for imperfections that can hamper blood flow and may lead to stenosis of the bypass.

Based on the results of this study and our clinical experience, we recommend a detailed check of the anastomoses if the flow in the bypass is found to be unexpectedly low during the operation. This detailed check of the anastomoses should involve the ELANA, the conventional end-to-side anastomosis, and the end-to-end anastomosis in the venous graft. When the flap cannot be retrieved, the ELANA might be the culprit. If a flap is successfully retrieved and the bypass flow is still low, the end-to-end or the end-to-side anastomosis is most likely obstructing the bypass flow. The end-to-end anastomosis between the 2 venous parts of the bypass is mostly located at the area where the bypass enters the skull and is made with an angle of ~ 60° to prevent kinking at this site. This anastomosis is relatively simple but should still be made with utmost precision to prevent stenosis. Furthermore, bypass flow can be low if the aneurysm is not trapped intraoperatively. Based on the data in this study we are more likely to consider immediate intraoperative entrapment of the aneurysm instead of postoperative endovascular balloon occlusion.

Conclusions

Bypasses performed using the ELANA technique can be effectively used to create bypasses to large cerebral arteries without the necessity of temporary occlusion of the donor or recipient artery. Attempts to create an EC-IC ELANA bypass after the first one are more likely to fail, and administration of heparin to the patient during the procedure, even at a relatively low dose, increases the intraoperative bypass patency rate. Postoperative patency results are better in male patients and in older patients.
Predictors of patency of ELANA EC-IC bypasses

Intraoperative bypass flow measurements are essential, not only to evaluate the patency of the bypass during the operation, but also because high bypass flow is an important determinant of postoperative patency.

Disclosure

Cornelis A. F. Tulleken, M.D., Ph.D., is a consultant to ELANA BV, producer of the ELANA catheter used for the ELANA technique. ELANA BV was not involved in the design and conduct of this study. ELANA BV assisted with the collection of patient files for the database, but management, analysis, and interpretation of the data were performed by the authors.

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