Effect of the Extra-Intracranial (STA-MCA) Arterial Anastomosis on EEG and Cerebral Blood Flow

A Controlled Study of Patients with Unilateral Cerebral Ischemia

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SUMMARY A prospective study of the changes in the EEG and rCBF in 20 patients with unilateral cerebral ischemia was carried out. Two identical groups of 10 patients were studied: one group of patients received an STA-MCA anastomosis, the other 10 served as controls. Computer analysis of the EEG was performed, using Fast Fourier Transformation. Two parameters of the alpha rhythm and one parameter of the delta activity in the temporal regions were chosen to evaluate the serial examinations of these patients. The rCBF in the distribution area of the middle cerebral artery was measured using the $^{133}$Xe inhalation method. The Initial Slope Index and the Initial Slope Index asymmetry, i.e. the relative difference in the mean Initial Slope Index between the two hemispheres, were used as parameters. All patients underwent two examinations 3 months apart. Furthermore the surgical patients were also studied 10 days after the operation.

In both groups of patients more improvement than deterioration was seen in the parameters of the alpha rhythm; however, only minor differences were found between the surgical and the control patients. A slight deterioration of the EEG was noted in some cases 10 days after the operations; subsequent improvement of the EEG was demonstrated in all of these patients at 3 months. In both groups similar changes in the neurological condition were noted after 3 months. In 14 of the 20 patients ISI asymmetry diminished; however, there were no differences in the rCBF parameters between the two groups after 3 months. Thus serial examination of the EEG and rCBF showed only minor differences between patients with an STA-MCA anastomosis and similar patients who did not undergo surgery.

Since the introduction of the extra-intracranial arterial anastomosis (STA-MCA anastomosis), the efficacy of this operation for patients with unilateral cerebral ischemia has been a subject of controversy. The "Cooperative Study of the Extracranial-Intracranial Arterial Anastomosis" may provide a well-documented evaluation of the clinical aspects of this problem.

Theoretically the STA-MCA anastomosis leads to an increase in cerebral blood flow (CBF); however the results of measurements taken in various centers before and after surgery differ to such an extent that there is as yet no consensus of opinion in this respect. 2-5

Electroencephalography (EEG) plays a role in the diagnosis of unilateral cerebral ischemia; after the cerebrovascular accident spontaneous improvements in the EEG can be measured with the aid of computer analysis of the EEG (qEEG). 6-8 To date the effect of the STA-MCA anastomosis on this spontaneous improvement in the EEG has not been studied.

As part of an investigation into the influence of (surgical) intervention on cerebral dysfunction in patients with disturbed circulation, a prospective controlled study was carried out to determine the changes in the EEG and CBF after the introduction of an STA-MCA anastomosis. The results of this study are presented here.

Patients

Twenty patients with unilateral cerebral ischemia were studied; 10 patients received an STA-MCA anastomosis and the other 10 formed the control group. The two groups did not differ essentially in either age or severity of the ischemia (see table 1). Seventeen patients were on thrombocyte aggregation inhibitors (acetylsalicylic acid and dipyridamole); 3 patients from the control group received oral anticoagulants (acenocoumarol).

Methods

EEG Registration and Data Processing

All EEGs were registered with the patient in a state of quiet attentiveness with eyes closed. A montage with $C_{3}$ (10–20 system) as a common reference point was used. Fast Fourier Transformation was applied to two 100 s segments of the EEG. For each pair of corresponding derivations from the right and left hemisphere power spectra were computed. Several data on spectral maxima (i.e. frequency, amplitude and – 3dB frequency values of the spectral peaks) were calculated. The details of this method have been published elsewhere. 9 The estimated power spectrum (range 0.5–35.2 Hz) was divided into 9 adjacent frequency bands. The total power for each of these frequency bands was calculated. On the basis of the results of the study of Van Huffelen et al.,9 parameters of the alpha rhythm and slow activity in the temporal regions were chosen for the serial EEG investigation of the patients (fig. 1):
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TABLE 1 Patients

<table>
<thead>
<tr>
<th>STA-MCA anastomosis</th>
<th>Reference group</th>
</tr>
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<tbody>
<tr>
<td>10 patients 8 m, 2 f</td>
<td>10 patients 9 m, 1 f</td>
</tr>
<tr>
<td>age: x 51 yrs; S.D. 12.7 yrs</td>
<td>age: x 54 yrs; S.D. 9.5 yrs</td>
</tr>
<tr>
<td>range 30-70 years</td>
<td>range 35-64 yrs</td>
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Type of stroke:
—reversible deficit
(RIND or TIA):
2
—partial non-progressive stroke:
6
—completed stroke:
2

1. Alpha Peak Frequency (fa)

The spectral peak in the alpha range (7.5–12.4 Hz) with the highest amplitude in the occipital, parietal and posterior temporal regions in both hemispheres. The mean alpha peak frequency was calculated as the mean of the peak frequencies in one hemisphere (normal: > 8.0 Hz).

2. Relative Alpha Power (Ra2)

Power in the alpha, (10.0–12.4 Hz) band relative to the power in the total alpha (7.5–12.4 Hz) band (α2/α1 + α2) in the occipital, parietal and posterior temporal regions (normal range: 0.01–0.9).

3. Delta Power Asymmetry (RAδ2)

Relative difference in power in the delta2 (2–3.4 Hz) band between the two mid-temporal regions: | (R – L)/(R + L) |, in which R is the power in this band in the right channel and L the same in the left channel (normal: < 0.143).

Measurement of the rCBF

The regional CBF (rCBF) was measured using the Obrist10 133Xe inhalation technique with a Novo-Cerebrograph. 133Xe gas mixed with air was inhaled for one minute by means of a close-fitting face mask or mouthpiece. The 133Xe clearance curves, which were derived from the detectors placed over the head and from the end-tidal air, were recorded throughout the next 10 minutes. From these curves the Initial Slope Index (ISI) was calculated, as described by Risberg et al.11 The rCBF in the distribution area of the middle cerebral artery was calculated as the mean of the ISI measured by 8 detectors in this area in each hemisphere. For serial examinations of the patients the following parameters were used (fig. 1):

1. Initial Slope Index (ISI)

Mean ISI of 8 detectors over the distribution area of the middle cerebral artery in each hemisphere (normal: 38–65).

2. Initial Slope Index asymmetry (RA ISI)

Relative difference | (R – L)/(R + L) | in the mean ISI for the distribution area of the middle cerebral artery between the two hemispheres (normal: < 0.025).

**FIGURES 1A AND 1B.** Changes in the EEG and rCBF after an STA-MCA anastomosis. Patient 1 (fig. 1a). STA-MCA anastomosis on the right side after a completed stroke on this side. An initial decrease in ISI asymmetry (RA ISI) to a normal value was followed by an increase in RA ISI 3 months after the operation. These variations in rCBF contrast with the changes in the EEG: in both hemispheres an initial deterioration (fa ↓ and Ra2 ↓) preceded improvement at 3 months (fa ↑ and Ra2 ↑).

Patient 2 (fig. 1b). STA-MCA anastomosis on the left after a partial non-progressive stroke on this side. Parallel EEG and rCBF parameters. An initial increase in RA ISI and deterioration of the EEG was followed 3 months later by a decrease in RA ISI to a normal value and improvement of the EEG in both hemispheres.
The end-tidal pCO₂ was recorded for each measurement of the CBF. However, no attempt was made to correct the calculated ISI for the consecutive measurements of the end-tidal pCO₂. Estimation of the arterial pCO₂ from the end-tidal pCO₂, which in addition may also affect the ischemic and non-ischemic cerebral tissues differently, is not sufficiently reliable and might lead to a misinterpretation of the changes in the rCBF.

Timing of the Examinations

The time between the EEG and measurement of the rCBF was less than 24 hours. The surgical patients were examined three times: before the operation and 10 days and 3 months after surgery; the control patients underwent 2 examinations 3 months apart. The first examination for both groups took place several days after the occurrence of cerebral ischemia (STA-MCA anastomosis group: range 9–85 days, median 29 days; control group: range 2–90 days, median 13 days).

Neurological and Other Supplementary Examinations

The patients were examined neurologically at the time of each EEG and rCBF study; the aim of this follow-up examination was to detect changes in motor and sensory function and to detect new cerebrovascular disturbances. Doppler and/or angiographic examinations demonstrated that in all cases the STA-MCA anastomosis was still patent 3 months after the operation.

Case Histories

In figure 1 the changes in several of the selected EEG and rCBF parameters are shown for two patients with an STA-MCA anastomosis. For patient 1, there was a discrepancy between the changes on the EEG and those in the rCBF. Upon the examination of this patient 10 days after surgery an improvement in the rCBF was found together with a deterioration of the EEG. Three months after surgery the EEG had improved considerably with respect to the preoperative recording, whereas the rCBF was less and the ISI asymmetry was greater than before surgery. In patient 2 the changes in the EEG paralleled those in the rCBF parameters. Ten days after surgery there was deterioration of the EEG as well as a decrease in the rCBF; 3 months after the operation both sets of parameters showed improvement with respect to the preoperative values.

Results

EEG

Comparison of the Two Groups at 3 Months

a. Alpha Peak Frequency. Almost all patients showed a change in the alpha peak frequency in the course of 3 months; however, between the two groups of patients no significant differences existed in the number of channels which exhibited an increase in the alpha peak frequency (table 2). The mean alpha peak frequency per hemisphere increased in 6 patients in each group. In these 12 patients the increase in mean alpha peak frequency occurred in both hemispheres. In the course of the 3-month interval there was no significant difference in the changes in mean alpha peak frequency per hemisphere between the two groups (distribution free test of Kolmogorov-Smirnov; for details see: 12).

b. Relative Alpha₂ Power. At the end of three months an increase in relative alpha₂ power was noted in most patients of the surgical group than of the control group (table 3). This difference in the increase in power in the high alpha frequencies would seem to indicate greater improvement in the EEG of the surgical patients.

c. Delta₂ Power Asymmetry in the Mid-temporal Region. On the initial EEG this parameter was abnormal for 5 patients who were to undergo surgery and 4 patients of the control group, indicating more delta activity in the mid-temporal region of the ischemic hemisphere than in the corresponding region of the non-ischemic hemisphere. Three months later there was no change in this significant preoperative delta₂ power asymmetry for either the 4 control patients or the 5 surgical patients; out of the 5 surgical patients without significant delta₂ power asymmetry before surgery, 2 showed asymmetry after surgery. The changes noted for the latter 2 patients were probably attributable to the effect of the skull defects on the EEG, and have no clinical significance.

Short-term Influence of the Operation on the EEG

The ten patients who underwent surgery were examined 10 days and 3 months after they received the anastomosis. For 6 patients the EEG on the 10th day showed a decrease in the mean alpha peak frequency per hemisphere; in all cases, however, the EEG at 3 months showed some recovery and in 3 cases the mean alpha peak frequency per hemisphere was even higher than before surgery (see case histories and figure 1).

<table>
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<tr>
<th>Table 3</th>
<th>Changes of Relative Alpha₂ Power After 3 Months</th>
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<tr>
<td></td>
<td>Relative alpha₂ power (Rα₂) (3 derivations/hemisphere)</td>
</tr>
<tr>
<td></td>
<td>Increase</td>
</tr>
<tr>
<td>Operated patients</td>
<td>30</td>
</tr>
<tr>
<td>Reference group</td>
<td>18</td>
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</table>

Significantly (X² = 8.56; p < 0.025) more increase (improvement) of Rα₂ in operated patients.
This short-term change in the EEG is probably caused by the anesthetics used and is not related to the nature of the operation itself.

Measurements at 10 days and 3 months showed that the changes in the relative alpha power during this interval were not significant. The delta power asymmetry also did not undergo any further changes in the period between 10 days and 3 months after surgery.

**rCBF**

**ISI**

In 19 of the 20 patients investigated changes occurred in the rCBF in the 3 months following the initial measurement. In all cases there was a positive correlation between the changes in the ISI for both cerebral hemispheres: an increase in the rCBF in one hemisphere was always accompanied by an increase in the rCBF in the other. Moreover a decrease in the rCBF always occurred in both hemispheres.

The rCBF increased in 5 out of the 10 surgical patients and decreased in the other 5 patients. Of the 10 patients of the control group there was also a decrease in the ISI for 5 patients. In both groups at three months there was no significant change in the average rCBF with respect to the initial values (table 4).

**ISI Asymmetry (fig. 2)**

In 14 of the 20 patients studied there was a decrease in the ISI asymmetry after 3 months, i.e. a decrease in the difference between the rCBF found for each hemisphere. In 4 cases the ISI asymmetry decreased from a pathological value to a value in the normal range. There was an increase in ISI asymmetry in only 2 patients of the surgical group and 3 patients of the control group; in one case ISI asymmetry did not change at all during the 3-month interval. In 4 of these 6 patients with an increased or unchanged ISI asymmetry after 3 months, the changes in this parameter of the rCBF occurred within the normal range and are probably only of slight significance.

Between the two groups of patients, there appeared to be no difference in the changes in ISI asymmetry measured over the 3-month interval (distribution free test, Kolmogorov-Smirnov).

As was the case for the parameters of the EEG, the changes in the rCBF in the surgical patients measured

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Changes of rCBF After 3 Months</th>
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<tr>
<td>rCBF (ISI)</td>
<td>Increase</td>
</tr>
<tr>
<td>Operated patients</td>
<td>5</td>
</tr>
<tr>
<td>Reference group</td>
<td>4</td>
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</table>

<table>
<thead>
<tr>
<th>Mean changes of ISI (SD in brackets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic hemisphere</td>
</tr>
<tr>
<td>Operated patients</td>
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<tr>
<td>Reference group</td>
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</table>

**FIGURE 2.** ISI asymmetry (RA ISI). RA ISI: relative difference | (R - L) | (R + L) | in mean ISI for distribution area of middle cerebral artery between the two hemispheres (normal: < 0.025). Decrease in RA ISI for 6 of the 10 controls; decrease in RA ISI for 8 of the 10 surgical patients at 3 months. No significant difference between the two groups. Decrease in RA ISI for 7 of the surgical patients when measured 10 days after the operation. No significant difference in the changes in RA ISI measured 10 days and 3 months after the operation. A = patient 2 in fig. 1B. B = patient 1 in fig. 1A.

10 days and 3 months after surgery were compared. It appeared that in the period between 10 days and 3 months there were no changes in the average ISI asymmetry (distribution free test, Kolmogorov-Smirnov; fig. 2).

**Clinical Phenomena**

Five of the surgical patients showed no changes in neurological condition; in the other 5 improved motor and/or sensory function could be demonstrated. In this group neither deterioration nor a new cerebrovascular accident occurred. In the control group one patient suffered a TIA four times after the initial examination; his EEG had deteriorated after 3 months and the rCBF remained the same. Of the remaining patients in the control group 7 exhibited no change in neurological condition and 2 showed improvement. No relation could be demonstrated between the change in neurological condition on the one hand and the EEG and rCBF on the other.

**Discussion**

Serial examination of patients should preferably be carried out by means of non-invasive methods which do not affect the patient. Both the EEG examinations and the CBF measurements according to the inhalation technique satisfy these requirements. Computer analysis of the EEG makes it possible to detect and in particular quantify the changes in cerebral functions in the course of time.

Intra-arterial injection of $^{133}$Xe is to be preferred for measurement of the CBF in small regions and can be used to determine slight changes in the regional circulation resulting from external stimuli. $^{13}$ The non-invasive inhalation technique, highly suitable for serial examinations of a patient, is perhaps less precise for the determination of these small local changes in the
CBF but do provide a clear insight into the circulation and the changes in the course of time within a fairly large region, such as the distribution area of the middle cerebral artery.

Arterial pCO$_2$ (paCO$_2$) has a pronounced influence on the CBF. Moreover the CBF is also affected by such factors as the state of mind of the patient, external stimuli such as noises in the examination room and visual stimuli during the examination. Since these factors are not the same for every CBF examination the evaluation of the serial examinations of our patients was based on changes in ISI asymmetry. This parameter of the rCBF is independent of all external factors. In addition the influence of paCO$_2$ on the CBF is then also eliminated — with the exception of a slight difference in reactivity of the CBF in ischemic and non-ischemic brain tissue.

The serial examination of the rCBF in patients with an STA-MCA anastomosis has as yet only been carried out by several authors. Austin et al.$^2$ Schmiedek et al.$^4$ Grubb et al.$^{18}$ and Nakajima et al.$^5$ found an improvement in the rCBF, predominantly in the region where the STA-MCA anastomosis was created. Thomas et al.$^{15}$ were not able to demonstrate any changes in the rCBF. None of these authors included a control group of comparable patients who did not undergo surgery. Tolonen et al.$^7$ studied the changes in the rCBF in patients with unilateral cerebral ischemia who did not undergo surgery. They found no changes in the rCBF in the three months following ischemia. The findings of Tolonen et al.$^7$ appear to agree with the results of our investigation of the group of control patients as well as the surgical group. In these two groups the average rCBF did not increase; when improvement occurred, it was only a decrease in the difference between the two hemispheres.

As in the case of an STA-MCA anastomosis, an improvement could theoretically be expected after desobstruction of the carotid artery. There is no consensus of opinion regarding the effect of this operation on the rCBF. Engell et al.$^{16}$ and Sundt et al.$^{17}$ examined their patients before and immediately after surgery and demonstrated an increase in the rCBF, mainly in patients with a severe stenosis. By measuring the rCBF before and about 6 weeks after carotid endarterectomy Herrschaft et al.$^{18}$ demonstrated an increase in the rCBF in patients with either a severe stenosis or kinking of the internal carotid artery. In contrast to these findings, the measurements of Waltz et al.$^{19}$ and Jennet et al.$^{20}$ did not show an increased rCBF after such an operation.

The effect of vascular surgery, both intracranial and extracranial, on the rCBF appears therefore to be highly variable and dependent on as yet unexplained factors that do not seem to be related to the procedure itself. A change in the rCBF in one hemisphere was always accompanied in our patients by a comparable change in the rCBF in the other hemisphere. From a theoretical point of view, one would assume that an increase in the rCBF would benefit mainly the ischemic region or only the ipsilateral hemisphere. In their study, Schmiedek et al.$^4$ found a similar regional improvement in the rCBF. A bilateral improvement in the rCBF was demonstrated by Nakajima et al.$^5$ in the months following an STA-MCA anastomosis; Meyer et al.$^{21}$ reported similar results for their investigation of a group of patients with mild cerebral ischemia without surgical intervention. Hitchon et al.$^{22}$ in their study of dogs with an STA-MCA anastomosis found that the rCBF in both hemispheres was influenced by this unilateral vascular anastomosis.

The quantification of the EEG offers a good opportunity to carry out serial examinations of patients with cerebral ischemia. Van Huffelen et al.$^8$ and Tolonen et al.$^7$ reported that some of their patients with unilateral cerebral ischemia showed a spontaneous bilateral improvement in the EEG, and that these improvements could be quantified with the aid of computer analysis of the EEG. Pfurchscher and Auer$^{23}$ investigated the quantitative changes in the EEG of the centrotemporal region after creation of an STA-MCA anastomosis. These authors found an improvement in the EEG in the region of the STA-MCA anastomosis. In our study too, an improvement in the EEG was seen in both hemispheres in patients who underwent surgery; however improvements were also demonstrated in non-surgical patients. Only one of the parameters of the EEG, namely the presence of rapid alpha activity, the relative alpha power, improved more in surgical patients than in the control patients. In our 20 patients there were therefore only slight differences between the two groups of patients; thus it appears that the additional effect on the EEG of the STA-MCA anastomosis — i.e. in addition to the spontaneous improvement already occurring — was very small.

**Conclusion**

Nineteen of the 20 patients studied showed some improvement, neurologically and/or on the EEG. In general the rCBF did not change although a change was sometimes noted in the difference between the rCBF in the two hemispheres. Comparison of the two groups of patients showed that during the interval of 3 months there was no difference between the two groups in the changes of rCBF. The EEGs of the group of patients with an anastomosis improved slightly more than those of the control group. On the basis of these results the STA-MCA anastomosis apparently contributes little to the improvement of the rCBF and the EEG; it would appear that the value of this operation can only be evaluated on the basis of the long-term clinical results. The conclusions of the "Cooperative Study of Extracranial-Intracranial Arterial Anastomoses" should cast some light in this direction.

**References**

3. Heilbrun MP, Reichman OH, Anderson RE, Roberts TS: Regional cerebral blood flow studies following superficial temporal-middle
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