Factors disposing to morbidity in surgery of intracranial aneurysms with special regard to deep controlled hypotension

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In 200 cases of intracranial saccular aneurysm a technique of short-term deep blood pressure reduction, as a rule induced with halothane, was used during the ligation of the aneurysm. The systolic blood pressure was reduced in most cases to about 50 mm Hg. This hypotension gives great advantages in the operative procedure. The vascular tree becomes more mobile, which facilitates the final phase of the dissection. The aneurysmal sac becomes softer, diminishing the risk of rupture when the ligature is being applied, and facilitating control of hemorrhage should it occur. The disadvantage of deep blood pressure reduction is the risk of anoxic damage. The surgical morbidity and mortality were therefore analyzed in detail with respect to the probable cause. In all but one case the symptoms or death could be attributed to one or more other factors (cerebral edema, vascular spasm, surgical trauma, etc.)

KEY WORDS: intracranial aneurysm, morbidity, controlled hypotension

Hypotensive anesthesia was used extensively during the 1950's and is still employed in a modified form for operations on intracranial aneurysms; prolonged hypotension has been replaced by deep reduction of the blood pressure during a relatively short portion of the operation when its effect is of maximal value. The technique has gradually been changed and improved. Originally, arteriotomy was used to lower the blood pressure by decreasing the blood volume. Pharmacologically-induced hypotension soon became the dominant method, and trimetaphane and halothane the popular drugs. A number of other methods for deliberately producing temporary hypotension are described.

The risks with hypotension are obvious. Decreased cardiac output, oxygen transport, and low perfusion pressure expose the tissues to the risk of hypoxia, which may aggravate the effects of the circulatory disturbance present in the brain after rupture of an aneurysm. The risks increase further when the brain is exposed to pressure from retractors during the operation. Complicating conditions such as hypertension, arteriosclerosis, or elevated body temperature are of great importance when judging the risks of hypotension in the individual case. The assumption that in deep anesthesia the metabolic rate and oxygen transport need to decrease with tissue perfusion favors the use of halothane.
In this clinic we have used planned deep hypotension during operations for intracranial arterial aneurysms in 200 patients during a direct surgical attack on the aneurysm. In most of these cases hypotension was induced with halothane, which we have found to be a simple and reliable drug. The purpose of this study was to find out the cause of complications in each of these 200 cases and thus to estimate the risk of the hypotension procedure *per se*.

**Patients and Methods**

The study was performed in 237 patients with an angiographically verified intracranial aneurysm. All were treated surgically by direct attack on the aneurysm with the aim of occluding it. In 200 patients, deep hypotension was induced for a short period during the operation. The other patients were operated on under normotension; these served as controls.

The hypotension series is presented in Table 1. The operations were performed at greatly varying times following the subarachnoid hemorrhage, and the series was therefore divided into an early group and a late group. The borderline between the groups was placed at 11 days since it was known from isotope studies that in most cases the circulation improves by the middle of the 2nd week after the hemorrhage; this improvement is due to regression of the cerebral edema and vascular spasm. The series was divided further into groups according to Botterell, et al., with respect to the preoperative condition of the patient.

The majority of the patients underwent operation in a good clinical condition and at a time later than 11 days after the hemorrhage. In 43 patients a combination of hypotension and hypothermia (29° to 31° C) was used.

During the surgical procedure the major part of the dissection of the aneurysm was performed before the hypotension was initiated, in order to shorten the hypotensive period. Although hypotension was induced with trimetaphane in a small number of patients, halothane was used in most. Ventilation of the patient was controlled, and a moderate hyperventilation with 100% oxygen was used. The EEG was monitored and blood pressure was followed through an intraarterial catheter. Blood gases and acid-base balance were usually checked before, during, and after (30 to 60 min) hypotension.

In trimetaphane hypotension an initial intravenous dose was given followed by a rapid trimetaphane drip. In halothane hypotension the halothane concentration in the respiratory gas was increased to 4%, sometimes higher. If there were no contraindications against a low blood pressure, a systolic level near 50 mm Hg was the objective. In 25% of the patients the systolic pressure did not drop below 60 mm Hg; in 27.5% it was below 60 mm Hg for 1 to 5 minutes, in 25.5% for 6 to 10 minutes, and in 26% for more than 10 minutes. The longest period below 60 mm Hg was 45 minutes in normothermia and 50 minutes in hypothermia. The average of the mean arterial pressures for the whole series was

**TABLE 1**

*Summary of clinical data in 200 patients operated on under controlled hypotension*

<table>
<thead>
<tr>
<th>Site of Aneurysm</th>
<th>Total No.</th>
<th>Operation</th>
<th>Botterell Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0–11 Days</td>
<td>&gt;11 Days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>after Bleeding</td>
<td>after Bleeding</td>
</tr>
<tr>
<td>carotid artery anterior</td>
<td>64</td>
<td>17 (27%)</td>
<td>47 (73%)</td>
</tr>
<tr>
<td>communicating</td>
<td>65</td>
<td>19 (29%)</td>
<td>46 (71%)</td>
</tr>
<tr>
<td>middle cerebral</td>
<td>56</td>
<td>24 (43%)</td>
<td>32 (57%)</td>
</tr>
<tr>
<td>pericallosal</td>
<td>8</td>
<td>5 (63%)</td>
<td>3 (37%)</td>
</tr>
<tr>
<td>vertebral</td>
<td>7</td>
<td>2 (29%)</td>
<td>5 (71%)</td>
</tr>
<tr>
<td>total no.</td>
<td>200</td>
<td>67 (34%)</td>
<td>133 (66%)</td>
</tr>
</tbody>
</table>

Rune Hugosson and Seth Högström
Value of hypotension in aneurysm surgery

close to 40 mm Hg, and there was no significant difference between the trimetaphane, halothane, or hypothermia groups.

The patients were also observed for the possibility of postoperative myocardial infarction, renal shutdown, and liver damage.

Results

Technical Advantages

During the hypotensive period three effects may be noted in the operative field: 1) the entire vascular tree which has to be dissected free around the aneurysm becomes more mobile, facilitating the final phase of the dissection; 2) the aneurysm becomes softer, which reduces the risk of rupture of its stalk and increases the possibility of ligating a broad-based aneurysm; and 3) if a rupture occurs in spite of the hypotension the hemorrhage is more easily controllable than under normotension. These three effects facilitate the operation from a technical aspect and very probably improve the end result.

In our series, satisfactory ligation or clipping was accomplished in 86% of the patients. In 11% the ligation was technically unsatisfactory and in 3% completely impossible despite the hypotension. A ligature occluding only part of the aneurysmal sac was regarded as unsatisfactory. In 16 patients (8%) ruptures of varying magnitude occurred at the base of the aneurysm during the hypotensive phase; in 14 of these the hemorrhage was controlled and the ligation was completely satisfactory. The other two patients developed neurological deficits. In 12 patients the aneurysm ruptured before the hypotension had been induced; five of these had neurological deficits and one of them died.

Surgical Morbidity and Mortality in the Hypotension Series

Risk Factors Present at the Time of Operation. The most serious factors leading to morbidity in patients who survived a subarachnoid hemorrhage are cerebral edema, arterial spasm, and intracerebral hematoma. A surgical complication is usually caused by one of these conditions or by some disorder of the general circulation (e.g., arteriosclerosis, hypertension). In addition there is the risk factor attributable to operative trauma, including temporary deep blood pressure reduction. Recurrent hemorrhage was not taken into account as a risk factor in this study; only those risks involved during and immediately following the operation itself were considered.

The incidence of different risk factors in the 200 surgically treated patients are presented in Table 2. Altogether 121 patients (60%) showed one or more of these factors. Arterial hypertension has been included as a possible risk factor outside the brain. The investigation also covered cardiopulmonary and renal diseases, but none of the patients showed serious manifestations of these diseases.

Association of the Surgical Morbidity and Mortality with Specific Risk Factors. All symptoms manifested after the operation were analyzed with respect to their probable cause (Table 3). The most common symptoms were hemiparesis, aphasia, and mental confusion. Transient symptoms were also included in the analysis. Some patients developed general physical and mental defects which became permanent; these were included in the surgical morbidity except in patients where the preoperative brain damage could have been sufficient to cause the condition. To risk factors already present preoperatively were added those involving the operative procedure (trauma) itself, including operative vascular spasm and cerebral hypoxia during the period of hypotension. New symptoms developed after the operation in 38 patients (19%), 10 of whom died. In many cases several factors played a role in the development of

TABLE 2

<table>
<thead>
<tr>
<th>Morbidity-Producing Factor</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>considerable brain swelling</td>
<td>15%</td>
</tr>
<tr>
<td>preoperative vascular spasm</td>
<td>16%</td>
</tr>
<tr>
<td>intracerebral hematoma</td>
<td>13%</td>
</tr>
<tr>
<td>arterial hypertension</td>
<td>29%</td>
</tr>
<tr>
<td>local arteriosclerosis</td>
<td>10%</td>
</tr>
</tbody>
</table>
TABLE 3
Causes of morbidity and mortality in the hypotension series

<table>
<thead>
<tr>
<th>Cause</th>
<th>Morbidity (no.)</th>
<th>Mortality (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>brain swelling</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>vascular spasm</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>intracerebral hematoma</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>surgical trauma</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>postoperative bleeding</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>induced deep hypotension</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>total</td>
<td>28</td>
<td>10</td>
</tr>
</tbody>
</table>

symptoms or in the fatal outcome. Always, however, one specific factor could be distinguished as being the predominant cause of the symptoms, and the classification could therefore be made with a high degree of certainty. This analysis showed that arterial spasm and surgical trauma predominated as causes of the surgical morbidity, while cerebral edema and intracerebral hematoma were the principal causes of death. Cerebral hypoxia resulting from the hypotension led to death in one patient. Arterial hypertension and cerebral arteriosclerosis were contributory factors in several cases but were never the main cause of any symptoms or death.

The following details may be added to the information given in Table 3. Each of the four patients with cerebral edema was in poor preoperative condition (Botterell Groups 3 to 5), was operated on at an early stage, and cerebral edema was the most striking finding at operation and autopsy. The cerebral edema in the patient who survived was aggravated by infectious encephalitis.

Of the 16 patients with postoperative vasospasm, 10 underwent early operation. As a rule the spasm was induced during the operation by the mechanical manipulations of the blood vessels, or was already evident from the start. The symptoms did not appear immediately after the operation but within the first 24 hours postoperatively. In the patients undergoing late operations the neurological symptoms caused by the spasm appeared somewhat later on the 2nd or 3rd day, and the spasm was verified angiographically. Of the total 16 patients, five recovered completely and two died.

Each of the patients in whom intracerebral hematoma was the cause of death underwent operation in a comatose condition (Botterell Groups 4 and 5). One patient developed permanent hemiparesis after evacuation of the hematoma and ligation of the aneurysm; reexploration revealed a CSF block in the basal cistern which was probably important in the development of symptoms.

Two of the 10 patients with evidence of surgical trauma developed kinking of the parent vessel during application of the ligation. In seven patients the aneurysm ruptured and the hemorrhage could only be controlled by ligation or constriction of the parent vessel. One elderly patient with hypertension, arteriosclerosis, and refractory postoperative wound infections developed mental and physical debility; although there were several contributory factors the main cause of this development was probably the surgical trauma.

The one patient who died as a result of the blood pressure reduction was a 44-year-old man who underwent operation in good condition on the 22nd day after his subarachnoid hemorrhage. From a technical aspect the operation was completely free of complications and no morbidity-inducing factors were evident. He did not regain consciousness after the operation, however, and died on the following day. Autopsy revealed areas of tissue softening and petechial hemorrhages in the brain stem. The operative field showed nothing of note.

The presence of one or more of the factors listed in Table 2 was established in 81% of the patients who developed surgical complications as compared to 60% in the whole series. The distribution among the Botterell groups was 67% in Groups 1 and 2, 22% in Group 3, and 11% in Groups 4 and 5. A comparison with the figures for the whole series (see Table 1) thus showed that these patients were in a poorer preoperative condition than the average. Among the patients with postoperative symptoms, 22 (60%) underwent early operation, which meant that every third patient operated on before the 11th day ran a risk of postoperative morbidity or mortality. This risk was 11% in the late group. It should be pointed out, however, that patients with large
intracerebral hematomas must be operated on promptly and that these patients have a poor prognosis. Of the patients who died, 90% were in the group operated on early.

**Frequency of Surgical Morbidity and Mortality in Relation to Aneurysm Site.** Postoperative symptoms occurred in approximately the same frequency among the patients regardless of the site of the aneurysm. The symptoms were, however, of a much more serious nature in the groups with anterior communicating (four deaths) and middle cerebral (three deaths) aneurysms. With regard to the cause of the postoperative symptoms, there was a clear differentiation between the different types of aneurysm. In patients with a carotid aneurysm, vascular spasm predominated as the causative factor; in those with an anterior communicating aneurysm, surgical trauma predominated; and in those with a middle cerebral aneurysm, the main cause of the symptoms were spasm and intracerebral hematoma (Table 4).

**Moderate Hypothermia.** Controlled hypotension supplemented with moderate hypothermia was used in 43 cases. Of these, seven (17%) developed postoperative symptoms; this may be compared with a complication figure of 19% in operations using hypotension alone. Thus, no evidence was obtained in this study that an increased risk is involved if the hypotension is combined with hypothermia.

**Control Series**

In 37 patients the entire operation was performed under normotension; the purpose was a direct attack on the aneurysm with the aim of ligating it. In a few patients the aneurysm was in fact occluded, but in most cases this was not possible for one reason or another, and instead the aneurysmal sac was coated with plastic. The usual reason for this was that the aneurysm was not saccular in shape but was of the fusiform type, or that adhesions between the stalk of the aneurysm and surrounding blood vessels were impossible to divide.

The distribution of the patients into early and late operations and into Botterell's risk groups can be seen in Table 5. There was no appreciable difference in these respects as compared with the hypotension series (see Table 1). Morbidity disposing factors were found in 60% of this control series, the same figure as in the hypotension series.

Symptoms appearing after the operation were analyzed in the same way in the two series. The frequency of surgical morbidity and mortality was 22% in the control series.

**TABLE 4**

*Relation of causes of morbidity and mortality to aneurysm site in hypotension series*

<table>
<thead>
<tr>
<th>Aneurysm Site</th>
<th>Morbidity (no.)</th>
<th>Mortality (no.)</th>
<th>Main Causes of Morbidity and Mortality (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Brain Swelling</td>
</tr>
<tr>
<td>carotid artery</td>
<td>12</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>anterior communicating</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>middle cerebral</td>
<td>8</td>
<td>3</td>
<td>--</td>
</tr>
<tr>
<td>pericallosal</td>
<td>2</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>vertebral</td>
<td>--</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>total</td>
<td>28</td>
<td>10</td>
<td>4</td>
</tr>
</tbody>
</table>

**TABLE 5**

*Summary of clinical data in 37 patients operated on under normotension*

<table>
<thead>
<tr>
<th>Operation</th>
<th>Botterell Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Cases</td>
<td>1 and 2</td>
</tr>
<tr>
<td>0 to 11 Days</td>
<td>&gt;11 Days</td>
</tr>
<tr>
<td>after Bleeding</td>
<td>27 (73%)</td>
</tr>
<tr>
<td>14 (38%)</td>
<td>23 (62%)</td>
</tr>
</tbody>
</table>
and 19% in the hypotension series. This close agreement supports the view that controlled deep hypotension played a very minor role in the development of symptoms, fatal or otherwise.

Laboratory Findings (Hypotension Series)

During the operations no clinically significant changes in acid-base balance occurred; the mean decrease in Stand-HCO₃ and base excess was near 1 mEq/l. The urine production was followed carefully pre- and postoperatively, but in no case were pathological values noted.

The serum creatinine concentration was determined both before and after the operation in 96 patients. Pathological values were found postoperatively in six patients, but all of these were also abnormal before the operation.

Transaminases (GOT and GPT) were determined pre- and postoperatively in 60 patients. Pathological values were obtained postoperatively for GOT in three patients and for GPT in four patients, all of whom had normal values before the operation. The increases were so moderate, however, that no treatment was required in any of the patients.

No clinical signs of myocardial infarction were observed during the postoperative period, and only insignificant changes were recorded on the ECG. No alarming ECG changes were observed during the hypotensive period.

Discussion and Conclusions

The advantages of deep controlled hypotension in the surgical treatment of intracranial aneurysms are obvious to the surgeon but difficult to prove with figures. Statistics indicating satisfactory occlusion of the aneurysm under controlled hypotension have been reported, but have not been compared to control series operated on under normotension. It was striking, however, how this technique made it possible to ligate an aneurysm which probably would have ruptured under normotensive surgery. The results obtained by Paterson in the surgical management of posterior communicating aneurysms support this observation. He had one death in 24 cases using hypotension, but seven deaths in 53 patients operated on under normotension. In our hypotension series there were no deaths caused by rupture of the aneurysm during the hypotensive period and in only two of these 16 cases was it necessary to ligate a parent vessel.

Hypotension was induced in all cases where we saw an anatomical possibility of ligating the aneurysm; occlusion was successful in 86% of these patients. After the postoperative angiographic examinations this figure decreased somewhat as the ligature had slipped off in some cases. If we add to this series those cases in which hypotension was not used and the aneurysm was treated by plastic coating, the frequency of satisfactory ligatures was 72%.

Spasm was the most important cause of postoperative complications. This diagnosis was made either during the operation, when the spasm could be observed directly, or postoperatively, when owing to deterioration of the patient, either the operative field was reexplored or angiography was performed. We are aware of the possibility that a combination of arterial spasm and deep hypotension can be especially deleterious for the nutrition of the cerebral tissue. In patients where spasm was found or occurred during the operation, we therefore avoided extreme hypotension, and pressure from a retaining spatula was limited to a minimum. Further, we bathed the spastic vessels in warm xylocaine, which in many cases gave at least temporary vasodilatation. During the short hypotensive phase the oxygen supply was also greatly increased. If the hypotension played any decisive role in producing the neurological deficits in these cases, these should have come directly after operation. Instead, they appeared after a delay of 1 to 3 days which strongly suggests that the spasm was the causative factor.

The other causes of postoperative morbidity and mortality were easily established. Surgical trauma plays a very important role in this connection, and it is chiefly rupture of the aneurysm and constriction of a major vessel that cause the damage. The risk is much greater if the aneurysm ruptures during the dissection before hypotension has
been induced, since a large hemorrhage is
difficult to control in a deep, restricted
operative field. We do not consider it
advisable, however, to use effective hypoten-
sion during the whole time that it takes to
free the aneurysm, as this would certainly
increase the risk of hypoxic damage.

There was complete correspondence be-
tween the control and the hypotension series
with regard to the preoperative clinical
condition of the patients. However, the
degree of surgical trauma was not completely
comparable in the two series. The
decision to use plastic coating may be
reached early in the operation; sometimes
this same decision may not be reached until
after a long dissection. In any case plastic
coating requires complete exposure of the
aneurysmal sac to be effective, a dissection
that is not always possible owing to the risk
of rupturing the aneurysm. It is true that the
special risks associated with ligation of an
aneurysm are not involved here, but the
general risks of dissection are identical. It
was found, in fact, that the surgical
morbidity and mortality were almost identical in the two series. This finding supports
our opinion, based on a thorough analysis of
a large amount of material, that the
hypotension technique is a low-risk proce-
dure.

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