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Correlation between angiographic findings and the ischaemia of head injury

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SUMMARY The carotid angiograms of 96 patients who had died from non-missile head injury were reviewed and assessed for evidence of arterial spasm, slowing of the cerebral circulation, and the presence of intracranial haematoma. As bilateral angiography had been done in 44 cases the results are based on a correlation between the angiographic appearances and the presence or absence of ischaemic brain damage in the cortex of 140 cerebral hemispheres. There was a significant relationship between spasm alone, the presence of intracranial haematoma alone, or their combination, and ischaemic damage in the ipsilateral cortex. Apart from an association between the more severe grades of spasm and slowing of circulation in the group with ischaemia within arterial territories, there was none between slowing of the circulation or the combination of slowing with either spasm or haematoma and ischaemic brain damage.

We have reported previously the association between ischaemic brain damage and arterial spasm or slowing of the cerebral circulation in a series of 33 fatally head-injured patients (Macpherson and Graham, 1973). We have now extended the series by a further 63 cases and, in addition, have investigated the possible role of intracranial haematoma in the genesis of ischaemic brain damage in the total 96 patients.

Methods

The series comprised 96 patients who died in the Institute of Neurological Sciences in Glasgow as a result of non-missile head injury, on whom carotid angiography had been carried out before any surgical treatment and on whom a full neuropathological examination was performed subsequently. There were 79 males and 17 females, aged from 8 months to 73 years, and with a survival time after injury ranging from six hours to seven months.

ANGIOGRAPHY

The technique used was that described previously (Macpherson and Graham, 1973). The patients were induced with thiopentone sodium, intubated, and moderately hyperventilated to give a $PaCO_2$ in the range 30–35 mmHg. Anaesthesia was maintained with 30% O_2/70% N_2O supplemented with fentanyl (Sublinaze), pentazocine (Fortral), or thiopentone. Contrast medium was injected by hand into the common carotid artery, and serial films were taken on a Barr and Stroud manual cassette changer. Arterial spasm was considered to be present when there was smooth, circumferential, tapered narrowing, with the sites of branching being relatively less affected. The severity of the spasm was determined by relating the calibre to that of the nearest area of apparently normal vessel, though in some cases where a long section was involved, an estimate had to be made. Where the reduction in calibre was less than one-third it was classified as grade 1, between one-third and two-thirds grade 2, and greater than two-thirds grade 3. The distribution of spasm was recorded in each case.

"The general arterial circulation time" (Leeds and Taveras, 1963) was judged by the persistence of contrast medium in the cerebral arteries. If present for more than 2.5 seconds after the injection this was recorded as slightly prolonged; if more than 3.75 seconds, moderately prolonged; and if more than 5 seconds, markedly prolonged. With one exception where no record was available,

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all cases had a recorded systolic blood pressure of over 80 mmHg at the time of angiography.

Displacement across the midline of the internal cerebral vein or branches of the anterior cerebral artery or both was also recorded. If the shift was not obviously due to an extracerebral haematoma, reference was made to the operative notes to establish whether or not an intracerebral haematoma had been identified, thus ensuring that the intracerebral space-occupying lesion, at least in part, was due to a haematoma and not wholly to infarction with brain swelling.

NEUROPATHOLOGY

The brains were fixed by immersion for at least three weeks in 10% formol saline before dissection. Large bilateral blocks were taken from the cerebral and cerebellar hemispheres and from the brainstem. They were embedded in celloidin, and sections, cut at 30 μm and stained by the method of Nissl using cresyl violet and by Woelke's modification of Heidenhain's method for myelin, were examined by conventional light microscopy.

STATISTICAL EVALUATION

Levels of statistical significance were determined by the chi^2 test.

Results

FREQUENCY OF ABNORMAL RESULTS

Bilateral carotid angiography was carried out in 44 of the 96 patients giving 140 angiograms for analysis, so that the results are based on a correlation between the angiographic appearances and the presence or absence of ischaemic damage in the cortex of 140 hemispheres. There was arterial spasm in 54 (39%) of the 140 hemispheres: the distribution is shown in Table 1 and the severity in Table 2. There was slowing of the circulation in 86 (61%): the degree is shown in Table 3. Spasm combined with slowing was present in 40 (29%). In only 38 (27%) was there neither spasm nor slowing. Intracranial (intra or extracerebral or both) haematomas were present in 67 (48%), haematoma combined with spasm in 35 (25%) and haematoma with slowing in 47 (34%).

There was focal ischaemic damage in the cortex of 47 of the 140 hemispheres (excluding infarction related to contusions, cardiorespiratory arrest, status epilepticus, cerebral fat embolism, and that within the distribution of the posterior cerebral artery secondary to tentorial herniation). In three there were multiple foci of necrosis, in 16 there was infarction within the distribution of the anterior or middle cerebral arterial territories or both, and in 28 there was infarction in the boundary zones between the distribution of the major cerebral arteries.

Using the criteria defined by Adams and Graham (1976), there was evidence of raised intracranial pressure in 80 of the 96 patients, in 32 of whom there was ischaemic damage in the cortex.

There was a variable amount of atheroma in the intracranial and extracranial arteries but in none was there evidence of occlusion. Similarly, no occluded vessel was seen at angiography, and there was no appreciable atheromatous stenosis. In one case there was grade 3 "narrowing" of the internal carotid artery associated with fracture at the base of the skull, and in two cases it appeared that the distal internal carotid artery was being compressed with grade 3 "narrowing" against the dorsum sellae.

CORRELATIONS (TABLE 4)

Arterial spasm Of the 54 hemispheres with spasm, there were 24 in which ischaemic damage

Table 1 *Incidence and distribution of arterial spasm identified in hemispheres with and without ischaemic brain damage*

Cases	*Total hemispheres*	*Spasm*	*Basal*	*ACA alone*	*MCA alone*	*ACA and MCA*	*Basal and ACA*	*Basal and MCA*	*Basal and ACA+MCA*
With IBD in cortex									
MF 3	3	1	1	0	0	0	0	0	0
AT 14	16	9	3	0	0	1	1	2	2
BZ 19	28	14	10	0	0	0	1	1	2
36	47	24	14	0	0	1	2	3	4
Without IBD									
60	93	30	15	1	0	0	6	1	7

IBD = ischaemic brain damage; MF = multiple focal; AT = arterial territory; BZ = boundary zone; Basal = distal internal carotid artery and/or proximal anterior and middle cerebral arteries; ACA = peripheral anterior cerebral artery; MCA = peripheral middle cerebral artery.

Table 2 *Severity of arterial spasm identified in hemispheres with and without ischaemic brain damage*

	Hemispheres with spasm	Grade of spasm		
		1	2	3
With IBD in cortex				
MF	1	0	1	0
AT	9	2	5	2
BZ	14	9	4	1
	24	11	10	3
Without IBD	30	13	14	3

Abbreviations as in Table 1.

was present in the cortex. Of the 47 hemispheres with ischaemia, there was arterial spasm in 24 (51%) as compared with the 30 (32%) with spasm in the 93 hemispheres without ischaemia ($P<0.05$). There was no correlation between the distribution and severity of spasm and the pattern of ischaemic brain damage (Tables 1 and 2). Even though seven of nine hemispheres with infarction within arterial territories had the more severe grades of spasm, this was not statistically different from the other groups.

Slowing of the circulation Of the 86 hemispheres with slowing of the cerebral circulation, there were 28 in which ischaemic damage was identified. Therefore, there was slowing of the circulation in 28 (60%) of the 47 ischaemic hemispheres as compared with 58 (62%) of the 93 hemispheres without ischaemia. There was no correlation between the degree of slowing and the pattern of ischaemic brain damage.

Arterial spasm and slowing of the circulation There were 40 hemispheres in which both angiographic appearances were present and of these there was ischaemic damage in 16. Both features were present in 16 (34%) of the 47 ischaemic hemispheres as compared with 24 (26%) of the 93 non-ischaemic hemispheres. There was no correlation between the combination of spasm and slowing of the circulation and ischaemic brain damage. However, in the group with infarction within arterial territories, grade 2 and 3 spasm were present in the seven with slowing, while grade 1 spasm was present in the two hemispheres without slowing ($P<0.005$).

Intracranial haematoma Of the 67 hemispheres with intracranial haematoma, there were 28 with ischaemic damage in the cortex. In 28 (60%) of the 47 hemispheres with ischaemia there was an ipsilateral haematoma as compared with 39 (42%) of the 93 non-ischaemic hemispheres in which a haematoma was not present ($P<0.01$). When the different distribution patterns of ischaemic brain damage are considered, an even greater significance is seen when the 13 hemispheres in which a haematoma coexisted with arterial territory ischaemia are compared with the 39 hemispheres with haematoma but without ischaemia ($P<0.005$). There is no statistical significance between infarction in the boundary zones and intracranial haematoma.

Arterial spasm and intracranial haematoma This combination was present in 35 of the 140 hemispheres, and of these there was ischaemic damage in 17. Therefore, of the 47 ischaemic hemispheres there were 17 (36%) with spasm and an intracranial haematoma as compared with 18 (19%) in the 93 non-ischaemic hemispheres ($P<0.05$). Again a greater significance is seen when the nine hemispheres in which the combination of spasm and haematoma coexisting with arterial territory ischaemia are compared with the 18 cases in which the combination occurred but in whom there was no ischaemia ($P<0.005$). There was no correlation between the distribution of the spasm in the cases combined with haematoma and the occurrence of infarction. In all the hemispheres in which spasm was associated with arterial territory infarction, there was an ipsilateral haematoma. Of the 14 hemispheres in which spasm was associated with boundary zone infarction, only seven had ipsilateral haematoma. Of these 14 the grading of the spasm was similar whether a haematoma was present or not.

Slowing of the circulation and intracranial haematoma This combination was present in 47 of the 140 hemispheres, and of these there was ischaemic damage in 16. Therefore, of the 47 ischaemic

Table 3 *Incidence and degree of slowing of the cerebral circulation identified in hemispheres with and without ischaemic brain damage*

	Total	Slowing	Slight	Moderate	Marked	Pseudo-occlusion
With IBD in cortex	47	28	8	5	14	1
Without IBD in cortex	93	58	24	7	23	4

Abbreviations as in Table 1.

Table 4 *Association between arterial spasm, slow circulation, intracranial haematoma, and ischaemic brain damage*

Cases	*Raised ICP*	*Total hemispheres*	*Vasospasm*	*Slow circulation*	*Vasospasm and slow circulation*	*Neither spasm nor slow circulation*	*Intracranial haematoma*	*Vasospasm and haematoma*	*Neither vasospasm nor haematoma*	*Slow circulation and haematoma*	*Neither slow circulation nor haematoma*
With IBD in cortex											
MF 3	3	3	1	2	1	1	1	1	2	1	1
AT 14	14	16	9	9	7	4	13	9	3	7	1
BZ 19	15	28	14	17	8	4	14	7	6	8	5
36	32	47	24 (51%)	28 (60%)	16 (34%)	9 (19%)	28 (60%)	17 (36%)	11 (23%)	16 (34%)	7 (15%)
Without IBD in cortex 60	48	93	30 (32%)	58 (62%)	24 (26%)	29 (31%)	39 (42%)	18 (19%)	41 (44%)	31 (33%)	27 (29%)
Chi^2 test with IBD and without			$P < 0.05$	NS	NS	NS	$P < 0.05$	$P < 0.05$	$P < 0.025$	NS	NS
AT damage alone and without IBD			NS	NS	NS	NS	$P < 0.005$	$P < 0.005$	NS	NS	NS

ICP intracranial pressure; NS = not significant; other abbreviations as in Table 1.

hemispheres, there were 16 (34%) with slowing and haematoma compared with 31 (33%) in the 93 non-ischaemic hemispheres.

The above findings show a significant relationship between the presence of arterial spasm and ischaemic damage in the ipsilateral cortex. Whereas the more severe grades of spasm were associated with slowing of the circulation in the group with ischaemia within arterial territories, there was none between slowing of the circulation or a combination of spasm and slowing with ischaemic damage.

They show also a significant relationship between the presence of intracranial haematoma and ipsilateral ischaemic damage, particularly in arterial territory distributions. There was a significant relationship between the combination of spasm and haematoma and ischaemic damage, but none between the combination of slowing with haematoma and cortical ischaemia.

Discussion

The incidence of spasm of the cerebral vessels in cases of head injury has been found to vary from 2–31% (Suwanwela and Suwanwela, 1972). In a selected group of fatally head-injured patients, on whom angiography had been carried out before any surgical treatment and on whom a full neuropathological examination was subsequently performed, we (Macpherson and Graham, 1973) found evidence of arterial spasm in 57%. Using the same criteria, the present larger study, which includes 63 new patients, has shown a reduction in the incidence of spasm to 41%.

There are considerable clinical data implicating vasospasm as a factor of major importance in the overall morbidity associated with subarachnoid haemorrhage due to rupture of a berry aneurysm (Heros *et al.*, 1976) when it may also be responsible for severe ischaemic brain damage (Tomlinson, 1959; du Boulay *et al.*, 1972). However, Millikan (1975) suggested that cerebral vasospasm had no effect on the mortality from subarachnoid haemorrhage due to ruptured aneurysm, and that there was no relationship between the frequency and severity of the complications from surgical or conservative treatment and the presence or absence of vasospasm. Adams *et al.* (1976) considered that the presence of vasospasm on preoperative angiograms did not relate to the presence of postoperative vasospasm or the clinical result, but that the development of generalised postoperative vasospasm correlated with a poor outcome from surgery, and indeed was the cause of

death in nine of 100 patients, and probably contributed to the death of another. Drake (1976) has reviewed the problem and concluded that the evidence is still too tenuous to abandon vasospasm as an important radiological phenomenon.

Information on the relationship between vasospasm and ischaemic brain damage in head-injured patients is generally lacking although Wilkins and Odom (1970) have shown that arterial spasm after head injury may be associated with a neurological deficit, and Macpherson and Graham (1973) suggested that there might be some correlation between arterial spasm and ischaemic damage in the cerebral cortex of fatally head-injured patients. The present study on a larger number of such patients is the first time that a statistical correlation between vasospasm and ipsilateral ischaemic brain damage has been found.

A slow cerebral circulation may be due to a number of factors (Schechter and Zingesser, 1966), and Bergeron and Rumbaugh (1974) suggest that the most common cause of a slow cerebral circulation in patients with head injury is a combination of increased intracranial pressure and decreased systemic blood pressure. In this study none of the patients was known to be hypotensive at angiography, none had evidence of atheromatous stenosis, and in only three was there a suggestion of compression of the internal carotid artery. It would, therefore, seem reasonable, in the majority of the 63% of patients (61% of the hemispheres) with a prolonged circulation time, to attribute the angiographic appearances to raised intracranial pressure, especially as there was neuropathological evidence of raised intracranial pressure in 83% of the cases. As in our previous study there was in general no apparent correlation between a prolonged circulation time, either singly or in combination with cerebral vasospasm or intracranial haematoma, and ischaemic brain damage. However, in the group with infarction within arterial territories, the more severe grades of spasm were associated with slowing of the cerebral circulation.

We have also found for the first time a statistically significant correlation between intracranial haematoma, either singly or in combination with vasospasm, and ischaemic brain damage particularly in the distribution of arterial territories. This suggests that mechanical factors generated by the distortion and displacement of an intracranial space-occupying lesion can reduce regional cerebral blood flow to critical levels, particularly in vessels which have been affected by spasm. That such a correlation is not present in cerebral hemispheres with ischaemic damage in the arterial boundary zones is in keeping with the finding that such brain damage is due to a profound, though transient, episode of hypotension (Graham, 1977).

Although the present study has shown that arterial spasm is associated with ischaemic brain damage, infarction is more likely to be a consequence either of an intracranial haematoma or a combination of haematoma and cerebral vasospasm in fatally head-injured patients.

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