Moderately Elevated Intracranial Pressure Produces Greater Cross-Filling of the Anterior Communicating Artery

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SUMMARY – *This study aimed to investigate whether moderately elevated intracranial pressure is associated with greater cross-filling of the anterior communicating artery on diagnostic cerebral angiography. A retrospective study of 12 patients with subarachnoid hemorrhage was performed. Data on sequential cerebral angiograms and clinical data were used to indirectly estimate intracranial pressure (ICP). Cross-filling of the anterior communicating artery (ACom) was recorded according to our scoring system. Our study included 12 patients with mean age 43 ± 11 yrs. Six patients demonstrated greater ICP associated with greater cross-filling of the ACom on initial angiogram. One patient had greater ICP with greater cross-filling on follow-up angiogram secondary to infarction and midline shift. Two patients had lower ICP yet greater cross-filling on follow-up angiogram due to higher injection rate and volume. One patient with no change in ICP demonstrated the same degree of cross-filling. A markedly elevated ICP is traditionally associated with no cross-filling across the ACom. We propose a counter-intuitive model in which moderately elevated ICP produces greater cross-filling of the ACom. This diagnostic angiographic finding should make the angiographer consider that the patient has moderately elevated ICP, and facilitate more timely clinical management.*

Introduction

Satisfactory cross-filling of the anterior communicating artery (ACom) during cerebral angiography is crucial for the early detection of intracranial aneurysms in patients presenting with subarachnoid hemorrhage (SAH) ¹⁻³. An understanding of the hemodynamics of carotid angiography with particular attention to cross-filling of the ACom is an important step towards improving patient outcomes.

Intracranial pressure (ICP) is a dynamic measurement that can change rapidly during the clinical course of SAH ⁴. Although ICP remains acutely elevated following aneurysm rupture, it subsequently decreases over the days following

rupture in the absence of complications such as hydrocephalus or arterial spasm ⁵. Historically, angiographers recognized that in the setting of severely elevated ICP approaching mean arterial pressure, contrast did not traverse beyond the carotid siphon ⁶⁻⁸ and no cross-filling of the ACom was observed. Based on data from these patients with extremely elevated ICPs, neuroangiographers extrapolated a linear inverse relationship between ICP and cross-filling ⁵. Angiographers often modified technical factors such as catheter size, injection rate and injection volume ⁹⁻¹¹ with the intention of producing greater cross-filling in patients with elevated ICP. In addition, cross-compression of the contralateral carotid artery was also employed.

Figure 1 Angiogram grading scale for cross-filling of the ACom.

Although using techniques to produce greater cross-filling of the ACom may be necessary in the case of severely elevated ICP, we present an alternative scheme where a moderately elevated ICP well below mean arterial pressure actually improves cross-filling without the need to increase injection rates or employ manual cross-compression. This reduces the risk of procedural complications such as distal emboli resulting from dislodged carotid artery thrombus or plaque. In cases where increased cross-filling is incidentally noted on cerebral angiography from moderately elevated ICP, the angiographer may facilitate timely management.

Materials and Methods

Patients

We conducted this study with the approval of the St. Luke's-Roosevelt Hospital IRB (IRB 12-075X). This is a retrospective study of patients who had two sequential cerebral angiograms after presenting with signs and symptoms suggestive of subarachnoid hemorrhage (SAH). Fifteen patients were identified from a computer database over a six-year period. Two patients were excluded due to marked vasospasm during their follow-up angiogram, and one due to an aplastic anterior communicating artery. The 12 remaining patients were equally divided between men and women, and had mean age of 43 years (± 11 yrs).

Image Acquisition

CT

Each patient had an initial CT scan for detection of possible SAH. A follow-up CT was performed to evaluate possible progression or improvement of SAH. All CT scans were per-

formed on a conventional scanner at our institution. Contiguous axial images were obtained at 5 mm intervals from the skull base to the vertex without intravenous contrast.

Cerebral Angiography

Initial diagnostic conventional cerebral angiograms were performed. Initial angiograms were performed at mean 0.41 days from admission with a range of 0 to 1 day. Follow-up angiograms were obtained at a mean 19.8 days. After excluding one patient with 161 days between angiograms, the adjusted mean was 7.0 days with a range of four to 14 days.

Angiography was performed with a single plane digital subtraction angiography unit (Integris, Philips Medical Systems, Netherlands) by one of five board certified radiologists with the assistance of an interventional radiology fellow or a radiology resident. During the initial angiogram, selective catheterizations of the bilateral common and/or internal carotid arteries and unilateral vertebral artery were achieved in all patients. In the follow-up studies, six patients had bilateral carotid artery injections and six had unilateral carotid artery injections on the side of pathology.

Injections were performed with a power injector (Medrad Mark V Plus, Indianola, PA, USA) using standard injection rates and volumes: common carotid artery 8cc/s for 10-12 cc, internal carotid artery 6-8 cc/s for 8-10 cc, and vertebral artery 3-4 cc/s for 6-8 cc. Contrast agents were administered as per our institutional guidelines with nonionic contrast (Iopamidol 300, Isovue; Bracco Diagnostic, Princeton, NJ, USA).

Data Interpretation

A single board-certified and Certificate of Added Qualification-certified neuroradiologist reviewed the CT scans obtained immediately

prior to initial angiography and prior to follow-up angiography without knowledge of the original reports. The neuroradiologist graded the degree of subarachnoid hemorrhage according to the Fisher scale, and the degree of hydrocephalus as none, minimal, mild, moderate or severe¹⁵⁻¹⁷. Degree of hydrocephalus was then converted to a numerical value as follows: 0-none, 1-minimal, 2-mild, 3-moderate, 4-severe. Hunt-Hess scores were obtained from a review of the patients' medical charts in conjunction with a neurologist attending¹².

The degree of cross-filling was determined by evaluation of angiogram images and was graded from 0 to 4 according to the following scale: 0-no cross-filling, 1-filling of the ACom, 2-filling of the contralateral A2 segment of the anterior cerebral artery, 3-filling of the contralateral A1 segment of the anterior cerebral artery and 4-filling at the M1 segment of the contralateral middle cerebral artery (MCA) (Figure 1).

Each patient's numerical ICP score was obtained by adding the Hunt-Hess grade, the Fisher grade, and the degree of hydrocephalus. The ICP score served as a basis for comparison between initial and follow-up angiograms.

Results

Positive correlation between ICP and cross-filling of ACom

Seven patients had elevated ICPs with associated increased cross-filling of ACom (Table 1). Of those, six patients (Patient 1-6) exhibited this phenomenon on initial angiogram (Figure 2). There was no change in injection rate or volume during initial and follow-up angiograms. In four patients, bilateral catheterizations were performed both on initial and follow-up angiograms. In two patients (Patients 1 and 3), catheterization was in fact more selective on follow-up, with catheterization of the common carotids during initial study and of the internal carotids on follow-up. One patient (Patient 3) demonstrated no change in degree of cross-filling on the left despite having a more selective catheterization on follow-up examination (cross compression was ultimately used to visualize the ACom region).

One patient (Patient 7) demonstrated elevated ICP and increased cross-filling on follow-up angiogram (Figure 3). We surmise that ICP rose on follow-up due to interval development of a MCA territory infarct with midline shift.

Table 1 Cross-filling of the anterior communicating artery during initial and follow-up angiograms.

Patient	Age	Sex	Angio Injection initial	Angio Injection follow-up	Hunt-Hess initial	Hunt-Hess follow-up	Fisher initial	Fisher follow-up	Hydrocephalus initial	Hydrocephalus follow-up	Cross Filling initial	Cross Filling follow-up
1	53	F	RCCA	RICA	II	0	4	2	0	0	1	0
2	30	F	LICA	LICA	II	II	2	1	0	0	3	0
3	59	M	RCCA	RICA	II	I	3	1	2	1	1	0
			LCCA	LICA							1	1
4	35	M	RICA	RICA	II	II	4	2	1	1	4	2
			LICA	LICA							4	1
5	26	M	RICA	RICA	I	I	4	2	2	0	3	1
			LICA	LICA							3	1
6	48	M	RICA	RICA	III	III	4	4	3	2	1	0
			LICA	LICA	III	III	4	4	3	2	4	2
7	49	F	LICA	LICA	III	I	4	1	2	1	1	2
8	43	M	RICA	RICA	V	IV	4	2	2	2	1	2
9	42	F	RICA	RICA	I	I	3	2	0	0	1	2
			LICA	LICA							0	1
10	35	F	LICA	LICA	0	0	1	1	0	0	0	0
11	36	F	LCCA	LCCA	II	I	1	1	0	0	1	1
12	61	M	RCCA	RICA	I	I	4	1	2	0	2	2
			LCCA	LICA							2	2

Figure 2 Initial and follow-up CT and angiograms of Patient 6. Top: A) Initial axial non-contrast head CT of Patient 6 demonstrates SAH in the left Sylvian fissure with intraventricular hemorrhage consistent with Fisher grade 4; dilated ventricles consistent with moderate hydrocephalus. B) Follow-up axial non-contrast head CT of Patient 6 four days later again demonstrates Fisher grade 4 intraventricular hemorrhage; new ventricular shunt with no hydrocephalus. ICP was determined to have decreased. Bottom: A) Initial angiogram of the intracranial arteries of Patient 6 shows grade 4 cross filling in the contralateral MCA. B) Follow-up angiogram of intracranial arteries of Patient 6 demonstrates grade 2 cross-filling in the contralateral A2.

Figure 3 Initial and follow-up CT and angiograms of Patient 7. Top: A) Initial axial non-contrast head CT of Patient 7 on admission demonstrates SAH in the right hemispheric cisterns and sulci, IVH in the right occipital horn of the lateral ventricle, and mild hydrocephalus consistent with Fisher grade 4. B) Follow-up axial non-contrast head CT of Patient 7 six days later demonstrates right frontal infarction in the MCA territory with edema, mass effect, and midline shift consistent with Fisher grade 1; IVH resolved. Bottom: A) Initial angiogram of intracranial arteries of Patient 7 demonstrates grade 1 cross-filling in the ACom. B) Follow-up angiogram of intracranial arteries of Patient 7 demonstrates grade 2 cross-filling in the contralateral A2.

Figure 4 Schematic diagram of the nonlinear relationship between ICP and cross-filling of the ACom.

Negative correlation between ICP and cross-filling of ACom

Patients 8 and 9 had decreased ICP yet increased cross-filling of the ACom on follow-up angiogram. We attribute this relationship to higher injection rates and volumes used: 7cc/s (total 7cc) on initial angiogram vs. 8cc/s (total 8cc) on follow-up angiogram.

No change in cross-filling on initial and follow-up angiogram

The remaining three patients demonstrated no change in degree of cross-filling. Patient 10 had normal initial and follow-up CT scans, as well as normal Hunt-Hess scores with no change in ICP. Patient 11 had a slight decrease in her ICP score. However, both her CT studies were normal, with a decrease in Hunt-Hess score from II to I. Patient 12 had a significant drop in his ICP score on follow-up. However, catheterization was more selective on the follow-up angiogram.

Discussion

Cross-filling of the anterior communicating artery in cerebral angiography is determined by a combination of technical parameters and clinical variables. Technical parameters include injection volume, injection rate, filming rate, catheter position, and catheter-associated vessel spasm. Greater injection volume and injection rate lead to increased cross-filling. Greater filming rate yields more images per second, and provides increased opportunity to document maximum cross-filling. Catheter placement in a location that induces vessel spasm can create a temporarily closed system at the catheter tip spasm site which, at the time of contrast injection, will transmit a full, unidirectional pressure wave upward and

across the Acom¹³. This increase in pressure creates greater cross-filling, and hence greater angiographic visualization, at the risk of possible aneurysm rupture or vessel damage.

Clinical variables affecting cross-filling include phasicity of the cardiac cycle and the ICP. When contrast injection occurs together with systole, the summation of cephalad systolic blood flow and cephalad contrast injection leads to greater cross-filling compared to the summation of the flow vectors in diastole.

ICP likewise plays a significant role in cross-filling. An extreme increase in ICP has been historically associated with decreased cross-filling in cases where ICP approached mean arterial pressure¹³. Our study expands on this relationship by examining the degree of cross-filling in the setting of a moderately elevated ICP. Our results show a positive correlation between moderately elevated intracranial pressure and cross-filling of the ACom. Although ICP is not directly measured, we infer that ICPs of our study patients are far below mean arterial pressure (MAP) because ICP at that level is fatal when sustained for more than a few minutes¹⁴. The six patients who had higher ICPs on initial angiogram also demonstrated greater cross-filling of the ACom on initial angiogram. The one patient who had a higher ICP on follow-up angiogram also had greater cross-filling upon follow-up. In addition, technical factors such as higher contrast injection volume and rate in two patients were associated with greater cross-filling despite lower ICPs on follow-up angiogram.

Our results appear counter-intuitive to prior research on elevated ICP in the setting of brain death. Earlier cerebral angiography findings demonstrated a cessation of cerebral blood flow when the ICP approached MAP^{7, 15-17}. Therefore, there was no observed cross-filling of the ACom at markedly elevated ICPs. While this negative correlation between ICP and cross-filling may be applicable to cases of extreme ICP such as

brain death, we propose a nonlinear relationship between moderately elevated ICP and cross-filling of the ACom (Figure 4).

One possible mechanism is vasoconstriction of the vascular beds that leads to exiting of contrast via the path of least resistance through the contralateral arterial system. In the immediate period following subarachnoid hemorrhage, there is a decrease in nitric oxide availability and a resulting increase in unopposed vasoconstriction¹⁸. Cerebral arteries also contract in response to blood products such as serum, erythrocytes, and platelets¹⁸. Cerebrovascular resistance is, therefore, increased in the vascular beds. During angiography, contrast will preferentially fill the contralateral arterial system over filling the cerebral vascular beds with higher resistance.

An understanding of the relationship between ICP and cross-filling has a significant impact on the management and outcome of SAH patients. Greater cross-filling of the ACom in the setting of elevated ICP alerts the angiographer to avoid cross-compression maneuvers which reduces the risk of plaque or thrombus dislodgement associated with manipulations of the carotid artery. Furthermore, an unexpected enhancement in cross-filling of the anterior communicating artery with possible contrast reflux into the vertebral-basilar circulation would alert the angiographer to the

setting of an increased ICP. This allows immediate clinical assessment of ICP, and facilitates timely collaboration with clinicians for appropriate management.

Limitations to our study include the small sample size of SAH patients at our institution who had initial and follow-up angiograms. Technical factors such as contrast volume and injection rates also varied across angiograms due to the retrospective nature of our study. Furthermore, our assessment of ICP is indirect, and is based on select criteria including the Fisher grade and Hunt Hess score. Future prospective studies using probes inserted into brain parenchyma or lateral ventricles to directly measure ICP would be of interest.

Conclusions

Markedly elevated ICP is traditionally associated with no cross-filling across the anterior communicating artery as cerebral blood flow ceases when ICP approaches MAP. We propose a counter-intuitive model in which moderately elevated ICP produces greater cross-filling of the anterior communicating artery. This diagnostic angiographic finding should make the angiographer consider that the patient has moderately elevated ICP, thereby leading to more timely clinical management of the elevated ICP.

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