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Clinical Study

Transcranial doppler study of cerebral arteriovenous malformations after gamma knife radiosurgery

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ABSTRACT

The aim of this study was to evaluate the clinical value of the Transcranial Doppler (TCD) in follow-up examinations after gamma knife radiosurgery (GKS) for arteriovenous malformations (AVM). We performed TCD after GKS in 18 patients who had cerebral AVMs to evaluate the hemodynamic effects of the procedure. Ten patients underwent TCD within 12 months after GKS, and eight between 12 and 24 months. The mean blood velocity (Vm) and pulsatility index (PI) were primarily analyzed in the feeding arteries (FAs) and non-FAs. Fifteen healthy volunteers served as control patients. The Vm values in the FAs after GKS ranged from 31 cm/s to 90 cm/s, with PI values ranging from 0.48 to 1.03. The Vm values in the comparable normal arteries ranged from 28 cm/s to 87 cm/s, and the PI values in these arteries ranged from 0.62 to 1.02. The Vm and PI values in every FA in all patients were normal compared to the values in the non-FAs ($p = 0.67$ and 0.38, respectively). Our results suggest that AVM vessels with high Vm and low PI values return to normal as the nidus of the AVM is obliterated after GKS. Although there was a trend toward a reduction of the Vm values after obliteration, this trend was not significant, except when the < 12 month subgroup was compared to the 12-24 month subgroup. In our limited study, TDC proved to be a reliable, safe and non-invasive method to monitor the outcome of GKS for cerebral AVMs.

1. Introduction

Cerebral arteriovenous malformations (AVMs) are vascular anomalies that cause blood to be shunted from the arterial system to the venous system.[1] AVMs manifest most frequently by bleeding, and the primary goal of treatment is, therefore, to prevent the bleeding caused by rupture of the pathological vessel connections. Treatment options for AVMs include microsurgery, embolization, stereotactic radiosurgery, or a combination of these three.[2] Gamma knife radiosurgery (GKS) is usually recommended when safe and radical open surgery cannot be performed or when patients choose to undergo this procedure.[3] However, it is not possible to obliterate AVMs after GKS immediately after treatment – it usually takes 1 to 3 years for AVMs to completely disappear after GKS.[4] To accurately evaluate the treatment outcome, regular follow-up examinations need to be maintained prior to the final investigation.

Transcranial Doppler (TCD) provides a non-invasive and useful method to detect blood flow velocity in the basal cerebral arteries.[5] Recently TCD has been used frequently to examine cerebral vasospasm subsequent to subarachnoid hemorrhage, to detect intracranial stenosis and to evaluate AVMs.[6–8] Hassler and Lindegaard showed that TCD measurements in patients with AVMs demonstrated an elevated mean blood velocity (Vm) and a decreased pulsatility index (PI).[9,10] Chioffi showed that the high Vm and low PI observed in the feeding arteries (FAs) of patients who were treated by embolization or surgery returned to normal as the shunt was obliterated.[11] After radiosurgical treatment of AVMs, the gradual obliteration of the AVM nidus can be hemodynamically monitored by TCD examinations of the related feeders.[12] Thus TCD might be a valuable and safe method for follow-up studies after GKS for cerebral AVMs. However, the clinical value of TCD as a tool to monitor the hemodynamic effects of GKS for cerebral AVMs has not been fully explored. Therefore, we aimed to evaluate the clinical efficacy of TCD on a preliminary basis for the follow-up of patients treated for cerebral AVMs after GKS.

2. Materials and methods

2.1. Patients

TCD ultrasonography was performed on 18 consecutive patients (10 males, 8 females) treated with GKS for cerebral AVMs at our hospital between January 2005 and December 2006. Two neurosurgeons treated 18 patients. The criteria for inclusion in the study were: (i) an AVM at the time of GKS as demonstrated by angiography; (ii) TCD examinations with a visible ultrasonic window

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performed after GKS; and (iii) MRIs performed after GKS, to follow-up the AVM nidus and exclude intracranial complications. The clinical course and outcomes were also evaluated in these 18 patients with an average follow-up of 351.8 days (range 89–707 days). Table 1 shows the demographic data of the patients, the angiographic characteristics of the AVMs and the TCD values. The control group consisted of 15 healthy volunteers (8 males, 7 females). We compared the TCD values obtained from the non-FA and the control group.

2.2. Angiograms

Bilateral carotid and vertebral angiography were available for all patients. Angiograms were used to evaluate the FAs, the venous drainage and the size of the AVMs. The Spetzler-Martin Grade was determined. The volume of the AVM was calculated. We used an arbitrary classification of small, medium and large lesions: 16 patients had small lesions (volume < 14 cm^3) and two patients had medium-sized lesions (15 cm^3–65 cm^3).

2.3. Gamma knife technique

Stereotactic radiosurgery was carried out using a Gamma Knife Model C (Elekta Instruments, Stockholm, Sweden). A stereotactic frame was fixed to the head of the patient under local anesthesia and the position of the frame was adjusted on the head according to the location of the AVM; this maneuver brought the nidus of the AVM closer to the center of the stereotactic system. Angiography with MRI was used for the stereotactic localization of the AVMs. The T_2-weighted MRI or three-dimensional time-of-flight MR angiograms were crucial for outlining the AVM nidus. The Leksell Gamma Plan planning system (Elekta Instruments) was used to plan the GKS for all patients. Based on the available data, a dose of 25 Gy was applied to the AVM periphery whenever possible to maximize the probability of total obliteration.

2.4. Transcranial Doppler recordings

A pulsed, range-gated 2-MHz TCD device (EME 2020, Eden Medizinische Elektronik, Überlingen, Germany) was used to measure the Vm and PI in the FAs and non-FAs at the transtemporal, transmandibular and suboccipital ultrasonic windows at various depths. We regarded the TCD value of the non-FA, in the contralateral hemisphere, as the normal reference value for the TCD.[13] All TCD measurements were obtained by the same technician. We used the standard examination procedure.[5] When possible, we examined all major arteries of the circle of Willis: the intracranial internal carotid artery (ICA), the middle cerebral artery (MCA), the anterior cerebral artery (ACA), and the posterior cerebral artery (PCA). The corresponding vessels on both sides were simultaneously insonated by two TCD probes that were fixed over the temporal bones using a headband. The MCAs and ACAs were insonated as close to the ICA bifurcation as possible. The PCAs were insonated at their P1 segments (flow toward the probe).

We chose to analyze Vm, because this value depends less on central cardiovascular factors (such as heart rate, contractility, total peripheral resistance, aortic compliance) than do the systolic and the diastolic velocities.[14] Vm is an absolute value that is measured in centimeters per second using the TCD. The PI, an index of downstream vascular resistances, is a ratio value, determined by the equation: ([systolic blood velocity − diastolic blood velocity] / Vm). We were not interested in testing the vasoreactivity of the AVMs in this study, and therefore the partial pressure of carbon dioxide was not monitored. Ten patients underwent TCD within 12 months after the GKS, and eight additional patients were assessed between 12 and 24 months after the GKS.

2.5. Statistical analysis

Analysis of variance (ANOVA) using the Statistical Package for the Social Sciences v. 11.5 for Windows (SPSS, Chicago, IL, USA) was calculated for mean value differences of the subgroups and compared to the control group. The Student's *t*-test was used to analyze the differences between the control group and the non-FA groups. The Vm and PI values of the FAs were compared with those in the non-FAs in the healthy contralateral hemisphere using the Student's *t*-test for dependent samples. We used a p value < 0.05 for denote statistical significance. Statistics are expressed as mean ± standard deviation (SD).

3. Results

3.1. Patient and control groups

Table 1 shows the locations of the AVMs and the Spetzler-Martin grade. The maximum diameter of the AVM nidus ranged between 0.7 and 4.4 cm, with a median diameter of 2.4 cm. The median volume of the AVM nidus was 3.1 cm^3. The number of

Table 1
Cerebral arteriovenous malformations in 18 patients treated by gamma knife radiosurgery

Sex / age (y)	Location	Feeding arteries	Nidus volume (cm^3)	Spetzler-Martin grade	Feeding arteries		Non-feeding arteries	
					Vm (cm/s)	PI	Vm (cm/s)	PI
M/58	Thalamus	PCA	3.2	3	42	0.95	37	0.93
M/23	Corpus callosum	ACA	22.3	2	90	0.48	87	0.62
F/17	Parietal	MCA	2.0	2	71	0.70	79	0.84
F/45	Cerebellum	PCA	1.3	2	31	0.68	28	1.02
F/36	Frontal	ACA	2.1	2	58	0.76	51	0.86
M/58	Temporal	PCA	2.0	1	46	0.58	34	0.91
F/17	Thalamus	PCA	5.3	3	42	1.03	51	0.88
M/21	Frontal	ACA	3.1	1	62	0.71	88	0.62
F/36	Temporal	MCA	5.7	1	56	0.62	61	0.72
M/59	Frontal	ACA	8.9	2	50	0.61	74	0.68
F/42	Parietal	PCA	3.8	2	48	0.51	34	0.63
M/49	Frontal	ACA	3.7	1	88	0.52	82	0.52
F/30	Frontal	ACA	6.5	2	86	0.68	87	0.69
F/32	Thalamus	PCA	0.6	3	41	0.92	43	0.73
M/34	Corpus callosum	ACA	2.8	1	71	0.69	73	0.67
M/26	Thalamus	PCA	1.7	3	41	0.67	53	0.71
M/16	Temporal	MCA	1.4	4	72	0.96	89	1.01
M/52	Parietal	ACA	16.7	2	87	0.68	83	0.55

ACA = anterior cerebral artery, F = female, M = male, MCA = middle cerebral artery, PCA = posterior cerebral artery, Vm = mean blood velocity, PI = pulsatility index.