Dynamic cerebral autoregulation in carotid stenosis before and after carotid stenting

Sung-Chun Tang, MD,[a,b] Yu-Wen Huang, MD,[a] Jiann-Shing Shieh, PhD,[d] Sheng-Jean Huang, MD,[c] Ping-Keung Yip, MD,[a] and **Jiann-Shing Jeng, MD, PhD,[a]** *Taipei, Douliu, and Tao-Yuan, Taiwan*

Background: **Impaired dynamic cerebral autoregulation (DCA) has been shown in patients with severe (≥70%) internal carotid artery (ICA) stenosis, but DCA in moderate (50% to 69%) ICA stenosis, especially its response to carotid revascularization, has rarely been reported. Our study aimed to characterize DCA in severe and moderate ICA stenosis before and after carotid stenting.**

Methods: **This study included 21 patients with ICA stenosis ≥50% who received carotid stenting. Data of arterial blood pressure and cerebral blood flow velocity of the middle cerebral artery, measured by transcranial Doppler, were collected for 10 minutes ≤24 hours before and after stenting. The DCA index, represented as aMx, was assessed by calculating the Pearson product-moment correlation coefficient of spontaneous arterial blood pressure and cerebral blood flow velocity fluctuations. The relationship between aMx and stenotic severity and also alternations of aMx before and after stenting were assessed.**

Results: **Carotid stenting was effective to improve the DCA in the stenting side but not in the contralateral nonstenting side. In considering individual ICAs, the average aMx (mean ± SD) increased significantly from ICA stenosis <50% (0.117 ± 0.091) to 50% to 69% (0.349 ± 0.144), 70% to 99% (0.456 ± 0.147), and total occlusion (0.557 ± 0.210; $P <$ .05, $P <$ .01, and $P <$ .01, compared with 50% to 69%, 70% to 99%, or total occlusion with <50% stenosis). The correlation between the degree of ICA stenosis and the aMx was also significant ($r = 0.693$, $P <$ .005). The aMx improved significantly in the stented side after carotid stenting in both moderate and severe ICA stenosis, and this finding was not affected by age, sex, risk factors, or clinical symptoms.**

Conclusions: **In addition to patients with severe carotid stenosis, patients with moderate carotid stenosis may also have impaired DCA that can be restored after carotid stenting. (J Vasc Surg 2008;48:88-92.)**

Cerebral autoregulation is an intrinsic mechanism to maintain stable cerebral blood flow within a given range of systemic blood pressure.[1] In some pathologic conditions, this ability may be impaired or lost, rendering the patients vulnerable to either cerebral ischemia or hyperperfusion injury. Previous studies in patients with carotid stenosis suggested that reduced cerebrovascular reactivity is a marker of increased risk of stroke and that evaluation of cerebral hemodynamics might help in the decision of whether to do vascular revascularization, especially in asymptomatic patients.[2-4]

In general, two types of cerebral autoregulation can be distinguished: a "static" change of cerebral blood flow under the manipulation of blood pressure to obtain the upper and lower limits of the cerebral autoregulation plateau, or a "dynamic" more rapid change by physiologic oscillations of blood pressure.[5,6] Recent studies showed that the status of dynamic cerebral autoregulation (DCA) could be obtained without manipulation of blood pressure,[7-9] thus DCA testing is more feasible for patients with internal carotid artery (ICA) stenosis in clinical practice. Impairment of DCA has been shown in patients with severe ICA stenosis (70% to 99%),[10-14] and revascularization by either carotid endarterectomy or stenting could restore its function effectively.[13,14] However, the status of DCA in moderate stenosis, especially after carotid revascularization, has not been well investigated so far.[10,13] In this study, we measured DCA in patients with a wide range of carotid stenosis and repeated the measurements after carotid stenting.

METHODS

Patients were recruited if they had at least one side of ICA stenosis ≥50% by carotid duplex ultrasound scanning and were admitted to the Stroke Center, National Taiwan University Hospital, for scheduled intervention of carotid stenting. Selection criteria for carotid stenting were patients with symptomatic ICA stenosis ≥50% or asymptomatic ICA stenosis ≥60%.[15,16] Patients with total occlusion of the ICA did not undergo intervention. Symptomatic ICA stenosis was defined as occurrence of transient ischemic attack or ischemic stroke before intervention of the ipsilateral ICA. Patients were categorized into three groups: group 1, unilateral ICA stenosis ≥50% and receiving carotid stenting; group 2, bilateral ICA stenosis ≥50% or occlusion and receiving one side carotid stenting; and

From the Stroke Center and Departments of Neurology,[a] and Surgery,[c] National Taiwan University Hospital, Taipei; Department of Neurology,[b] National Taiwan University Hospital, Yun-Lin Branch, Douliu; Department of Mechanical Engineering,[d] Yuan Ze University, Tao-Yuan; and Section of Neurology,[e] Department of Internal Medicine, Far Eastern Memorial Hospital, Taipei, Taiwan.

This work was supported by grants NSC-93-2314-B-002-248 and NSC-94-2314-B-002-108 of the National Science Council, Taiwan.

Competition of interest: none.

Reprint requests: Jiann-Shing Jeng, MD, PhD, Department of Neurology, National Taiwan University Hospital, No. 7 Chung-Shan South Rd, Taipei 100, Taiwan (e-mail: jsjeng@ntu.edu.tw).

0741-5214/$34.00

doi:10.1016/j.jvs.2008.02.025

group 3, bilateral ICA stenosis ≥50% and receiving bilateral carotid stenting.

Ultrasound measurements were assigned with standard ultrasound criteria.[17,18] Both maximum systolic flow velocity of >1.25 m/s and area reduction of >75% identified the degree of stenosis of >50%. Carotid stenosis of ≥70% was defined as maximum systolic flow velocity of >2.50 m/s. Absence of both color flow and Doppler signal of the ICA indicated total occlusion of the artery.

The severity of carotid stenosis was further classified into mild stenosis (<50%), moderate stenosis (50% to 69%), severe stenosis (70% to 99%), and total occlusion on conventional angiography according to the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria.[15]

After the carotid stenting, patients were sent to the intensive care unit for overnight monitoring of hemodynamic and neurologic status, and systolic blood pressure was carefully maintained within 100 to 140 mm Hg.[19]

Patients with poor acoustic temporal bone window, cardiac arrhythmia, or intolerance of the examination were excluded. This study was approved by the ethics committee of the National Taiwan University, College of Medicine.

All patients received assessment of DCA ≤24 hours before and after carotid stenting. The DCA was accessed while patients were in the supine position with mild elevation of the upper body. Cerebral blood flow velocity (CBFV) of the middle cerebral artery was measured through the temporal bone window by transcranial Doppler equipped with a 2-MHz transducer and a head fixation frame (EZ-Dop, DWL, Compumedics Germany GmbH, Singen, Germany).[20] Arterial blood pressure (ABP) was directly measured and continuously recorded using a radial artery fluid-coupled system. Accurate assessment of cerebral blood flow is difficult in clinical applications; therefore, measurement of flow velocity instead of cerebral blood flow by transcranial Doppler is often used as a surrogate marker that is considered being proportional to cerebral blood flow.

The ABP and CBFV were monitored simultaneously for a mean duration of 864.3 ± 14.8 seconds (range, 10-30 minutes). These two waveforms were captured digitally, with a sampling rate of 100 Hz using a data acquisition card (National Instruments (Austin, Tex) on a bedside laptop computer. We designed the software of this data collection, and it has been patented (Patent No. I 256572) in Taiwan, Republic of China. The mean values of ABP and CBFV in time domains were averaged for 3-second periods offline. Consecutively, from every 20 such values (ie, 60-second periods), separate Pearson product-moment correlation coefficients between the mean ABP and CBFV were calculated.[21] The resulting sets of 1-minute correlation coefficients were then averaged for the whole measurement period and labeled as the minimally invasive autoregulatory index, aMx.

Theoretically, if DCA was preserved, a decrease in ABP would provoke compensatory vasodilatation, an increase in cerebral blood volume, and then increased CBFV.[1] Therefore, with intact DCA, aMx is near zero or negative. Conversely, if DCA fails, a decrease in ABP would produce no active vascular response and would reduce cerebral blood volume and velocity.[1] Therefore in this state, changes in ABP and CBFV would be in the same direction, rendering aMx positive. The value of aMx is a correlation coefficient and thus is standardized between 1 and −1.[7,8] One advantage of this index is that it reflects DCA between completely normal autoregulation at one end and a maximally vasodilated or nonresponsive vascular bed at the other, with a graded range of dysfunction in-between; not just "present" or "absent."

The correlation between the severity of ICA stenosis and aMx was assessed by the Pearson product moment correlation method. A paired Student *t* test was used to estimate the significance of changes after carotid stenting in symptomatic and asymptomatic patients, as well as patients with a different degree of carotid stenosis. A logistic regression analysis was applied to evaluate factors affecting aMx after carotid stenting. Statistical analyses were done with SPSS 12.0 software (SPSS Inc, Chicago, Ill).

RESULTS

The study included 21 patients (42 carotid arteries; 19 men), with a mean age of 69.1 ± 9.5 years. Of these patients with ≥50% carotid stenosis, 13 were symptomatic and 8 were asymptomatic. For asymptomatic patients, all had at ≥60% carotid diameter reduction, with the average stenosis of 77.7% ± 14.0%.

Eight patients were in group 1, nine in group 2, and four in group 3. Before carotid stenting, the aMx in group 1 patients was significantly higher in the stenotic side than the nonstenotic side (0.365 ± 0.118 vs 0.117 ± 0.091, $P < .001$). After stenting, the stented side of the aMx decreased significantly compared with before stenting in all three groups (all $P < .05$; Table I). Except for one patient (aMx from 0.77 to 0.02) in group 2, all patients in group 1 and most patients in group 2 showed no obvious change of aMx in the contralateral side of the ICA between before and after stenting ($P = .811$ and $P = .741$, respectively).

Considering the individual ICA status in a total of 42 carotid arteries from 21 patients before the stenting, the aMx increased significantly from ICA stenosis <50% in 8 arteries (aMx, 0.117 ± 0.091), 50% to 69% in 10 (aMx, 0.349 ± 0.144), 70% to 99% in 19 (aMx, 0.456 ± 0.147), and total occlusion in 5 (aMx, 0.557 ± 0.210; $P < .05$, $P < .01$, and $P < .01$, respectively, compared with 50% to 69%, 70% to 99%, or total occlusion with <50% stenosis). There was a significant correlation between the severity of ICA stenosis and the values of the aMx (Pearson $r = 0.693$; $P < .005$; Fig).

Carotid stenting was done on 25 ICA, and the aMx decreased significantly after stenting from 0.421 ± 0.158 before stenting to 0.211 ± 0.087 after stenting ($P < .001$). The effect of carotid stenting on the reduction of aMx was significant not only in severe carotid stenosis in 17 arteries (aMx from 0.359 ± 0.144 to 0.221 ± 0.087, $P < .001$) but also in moderate carotid stenosis in eight (aMx

Table I. Effect of carotid stenting on dynamic cerebral autoregulation index in patients with unilateral or bilateral internal carotid artery stenosis

	Group 1 (n = 8)[a]		*Group 2 (n = 9)*[b]		*Group 3 (n = 4)*[c]
Effect	*Stenting*	*Nonstenting*	*Stenting*	*Nonstenting*	*Stenting*
50%-69%, No.	4	0	2	2	2
70%-100%, No.	4	0	7	7	6
aMx1 (before stenting)	0.365 ± 0.118	0.117 ± 0.091	0.398 ± 0.180	0.482 ± 0.205	0.512 ± 0.115
aMx2 (after stenting	0.172 ± 0.046	0.104 ± 0.078	0.216 ± 0.100	0.379 ± 0.213	0.245 ± 0.101
P (aMx1/aMx2)	<0.001	.811	.018	.312	.001

aMx, Autoregulatory index.
[a]Unilateral ≥50% internal carotid artery stenosis.
[b]Bilateral ≥50% internal carotid artery stenosis or occlusion of the contralateral internal carotid artery with one side stenting.
[c]Bilateral ≥50% internal carotid artery stenosis with carotid stenting at both sides.

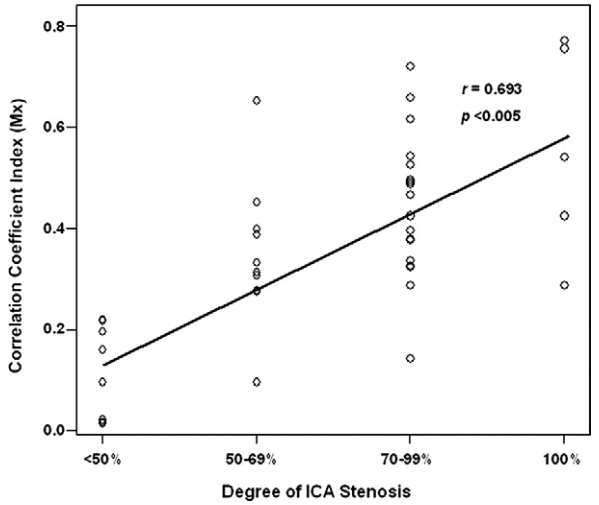

Fig. Before carotid stenting, the value of the dynamic cerebral autoregulation index *(Mx)* significantly increased with the degree of internal carotid artery *(ICA)* stenosis (Pearson $r = 0.693$; $P < .005$).

Table II. Multivariate regression analysis of factors affecting dynamic cerebral autoregulation after carotid stenting in study patients

Factor	β	*95% CI*	*SE*	P
	0.026	−0.301 to 0.352	0.160	.873
Age, years	0.002	−0.003 to 0.007	0.002	.365
Male sex	−0.057	−0.202 to 0.087	0.071	.427
Left side vs right side	−0.011	−0.095 to 0.073	0.041	.793
Symptomatic ICA stenosis	−0.018	−0.125 to 0.090	0.053	.740
Carotid stenting	−0.170	−0.324 to −0.016	0.076	.032
ICA stenosis before stenting				
<50%	1.0	—	—	—
50%-69%	0.229	0.051 to 0.408	0.088	.013
70%-99%	0.291	0.116 to 0.465	0.086	.002
100%	0.254	0.098 to 0.410	0.077	.002

CI, Confidence interval; *ICA*, internal carotid artery; *SE*, standard error.

from 0.362 ± 0.150 to 0.195 ± 0.094, $P < .001$). Multivariate linear regression analysis showed that the degree of ICA stenosis and carotid stenting were independent factors, but not age, sex, lesion side, or symptomatic ICA stenosis, in the effect on poststenting aMx values (Table II).

DISCUSSION

Previous studies have shown that the status of DCA could be represented as Mx based on the correlation coefficient between slow spontaneous fluctuations of cerebral perfusion pressure, which is the difference between ABP and intracranial pressure, and CBFV measured with transcranial Doppler.[22-24] However, there are several other clinical conditions in which assessment of DCA would be valuable, such as stroke,[25] hypertensive encephalopathy,[26] liver failure,[27] and carotid stenosis.[2-4] It is not necessary to have an intracranial pressure monitor to study Mx. Hence, DCA can also be estimated noninvasively by nMx by calculating the correlation coefficient between slow changes of noninvasive ABP using a finger plethysmograph and slow changes of CBFV with transcranial Doppler.[8,25] However, the noninvasive ABP with a finger plethysmograph is a highly expensive machine that is not used in routine clinical monitoring. Attention has therefore turned to a low cost, routine monitoring, and not to a so highly invasive vital sign monitoring that can reflect the hemodynamic changes. Obviously, the low cost, routine monitoring, and minimally invasive ABP would be a good candidate. Fortunately, according to previous studies,[7] the aMx was calculated by correlating CBFV and ABP and constantly shifted a mean value. The results have been shown that minimally invasive aMx and nMx were contradictory in 6 of 167 recordings from 145 patients and the sensitivity of both methods to detect impaired cerebral autoregulation was 0.73. Hence, in this study, the aMx was calculated by correlating CBFV and ABP, rather than CBFV and cerebral perfusion pressure and noninvasive ABP to investigate DCA.

DCA has been suggested as an important prognostic factor in patients with head injury.[22,23,28] Previous study

has also showed that DCA was impaired in patients with severe carotid stenosis or total occlusion[11,29] and was related to long-term functional outcome.[4] One study assessed the values of Mx in 58 patients with severe unilateral ICA stenosis undergoing carotid endarterectomy or stenting. It showed that DCA was clearly impaired ipsilaterally compared with contralateral sides preoperatively, and early normalization of DCA was noted postoperatively.[14]

DCA has also been obtained by other methods, including (1) transfer function analysis of spontaneous fluctuation of ABP and CBFV,[9,10] or (2) autoregulation index values obtained from a sudden stepwise drop in ABP by the thigh cuff test and analyzed the rate of return of ABP and CBFV to baseline.[12,13] Both methods were used in previous studies to demonstrate the impairment of cerebral hemodynamics in patients with severe ICA stenosis. One study also showed that the autoregulation index returned to normal after carotid endarterectomy in patients with severe impairment of DCA.[12] However, only a few works have addressed patients with moderate ICA stenosis. Previous studies had showed a good correlation between the impairment of DCA and degree of stenosis[10,12,13]; thus, patients with moderate ICA stenosis might have poorer DCA than the normal controls. To our knowledge, however, its response to carotid revascularization has not been investigated so far.

Our study proved that carotid stenting was an effective way to improve the DCA in the stented side in patients with either unilateral or bilateral ICA stenosis but not in the contralateral nonstented side. In considering individual carotid arteries, a significant correlation exists between aMx and the degree of ICA stenosis before carotid stenting. Severe and moderate ICA stenosis both showed clearly poorer DCA compared with <50% ICA stenosis. After stenting, similar with the previous articles, significant reduction of aMx in severe ICA stenosis was noted. In addition, our study further demonstrated that impaired DCA in moderate ICA stenosis could be repaired by carotid stenting. Multivariate analysis confirmed that moderate ICA stenosis was an independent factor associated with impaired DCA; therefore, our study provides direct evidence that DCA is impaired in most patients with moderate ICA stenosis and that carotid revascularization can improve the DCA as well.

Previous studies had linked patients with impaired DCA with being more vulnerable for acute strokes[30] or chronic disorders such as vascular dementia.[31-34] From this point of view, if low procedurally related complication could be achieved, revascularization might be considered as a therapeutic alternative for patients with moderate ICAS stenosis and impaired DCA. However, owing to the small sample size and lack of data of functional outcome, the clinical impact of our study is uncertain. It cannot provide strong support for the concept that measurement of DCA could help in the selection of patients for revascularization in moderate ICA stenosis as well. Further studies with a larger sample base and long-term follow-up will be very valuable to verify this point in the future.

By the way, it is noteworthy that most patients who received carotid stenting in our study had impaired DCA before the procedure, but no definite hyperperfusion syndrome resulted after the procedure. The strategy of strictly maintaining systolic blood pressure within 100 to 140 mm Hg before and after carotid stenting in our group may be one important factor,[35] and the small sample size and nonrandomized case selection in our study may be another one. Nevertheless, our study demonstrated the feasibility of measuring aMx in patients with ICA stenosis before the revascularization, which could help in identifying patients with relative high risk for hyperperfusion syndrome after the procedure.[36,37]

Our study has some potential limitations. First, we only included patients who were eligible for transcranial Doppler monitoring, so patients with poor temporal acoustic bone windows were excluded. In our previous study, 20.7% of Asians had at least one side of poor temporal acoustic bone window,[38] which might result in case selection bias and also limit clinical application.

Second, this is a cross-section study and did not include for comparison patients with carotid stenosis but not receiving carotid stenting; thus, the long-term prognostic value of the aMx in moderate carotid stenosis cannot be analyzed. Actually, it could be the most important issue to demonstrate any clinical benefit of carotid revascularization in moderate ICA stenosis.

Finally, because this is a hospital-based study and our hospital is a medical center, the case selection bias may be considered for the findings of a high percentage of impaired DCA in patients with moderate ICA stenosis.

CONCLUSIONS

We applied the aMx measurement in patients with ICA stenosis before and after carotid stenting. Our results indicated that both severe and moderate ICA stenosis could have impaired DCA that could be readily and effectively improved by carotid revascularization. Further studies should be done to investigate if assessment of DCA in patients with ICA stenosis could provide valuable data in consideration of therapeutic strategies.

AUTHOR CONTRIBUTIONS

Conception and design: ST, JS, HS, JJ
Analysis and interpretation: ST, YH, JJ
Data collection: ST, YH
Writing the article: ST, JS, JJ
Critical revision of the article: HS, PY, JJ
Final approval of the article: JJ
Statistical analysis: ST, JJ
Obtained funding: JJ
Overall responsibility: JJ

REFERENCES

1. Chillon JM, Baumbach GL. Autoregulation: arterial and intracranial pressure. In: Edvinsson L, Krause DN, eds. Cerebral blood flow and metabolism. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2002. p. 395-412.

2. Markus H, Cullinane M. Severely impaired cerebrovascular reactivity predicts stroke and TIA risk in patients with carotid artery stenosis and occlusion. Brain 2001;124:457-67.
3. Gur AY, Bova I, Bornstein NM. Is impaired cerebral vasomotor reactivity a predictive factor of stroke in asymptomatic patients? Stroke 1996;27:2188-90.
4. Silvestrini M, Vernieri F, Pasqualetti P, Matteis M, Troisi E, Passarelli F, et al. Impaired cerebral vasoreactivity and risk of stroke in patients with asymptomatic carotid artery stenosis. JAMA 2000;238:2122-7.
5. Panerai RB. Assessment of cerebral pressure autoregulation in humans–a review of measurement methods. Physiol Meas 1998;19: 305-38.
6. Dawson SL, Blake MJ, Panerai RB, Potter JF. Dynamic but not static cerebral autoregulation is impaired in acute ischaemic stroke. Cerebrovasc Dis 2000;10:126-32.
7. Schmidt B, Czosnyka M, Raabe A, Yahya H, Schwarze JJ, Sackerer D, et al. Adaptive noninvasive assessment of intracranial pressure and cerebral autoregulation. Stroke 2003;34:84-9.
8. Lavinio A, Schmidt EA, Haubrich C, Smielewski P, Pickard JD, Czosnyka M. Noninvasive evaluation of dynamic cerebrovascular autoregulation using Finapres plethysmograph and transcranial Doppler. Stroke 2007;38:402-4.
9. Kuo TB, Chern CM, Sheng WY, Wong WJ, Hu HH. Frequency domain analysis of cerebral blood flow velocity and its correlation with arterial blood pressure. J Cereb Blood Flow Metab 1998;18:311-8.
10. Hu HH, Kuo TB, Wong WJ, Luk YO, Chern CM, Hsu LC, et al. Transfer function analysis of cerebral hemodynamics in patients with carotid stenosis. J Cereb Blood Flow Metab 1999;19:460-5.
11. Reinhard M, Müller T, Guschlbauer B, Timmer J, Hetzel A. Dynamic cerebral autoregulation and collateral flow patterns in patients with severe carotid stenosis or occlusion. Ultrasound Med Biol 2003;29: 1105-13.
12. Panerai RB, White RP, Markus HS, Evans DH. Grading of cerebral dynamic autoregulation from spontaneous fluctuations in arterial blood pressure. Stroke 1998;29:2341-6.
13. White RP, Markus HS. Impaired dynamic cerebral autoregulation in carotid artery stenosis. Stroke 1997;28:1340-4.
14. Reinhard M, Roth M, Muller T, Guschlbauer B, Timmer J, Czosnyka M, et al. Effect of carotid endarterectomy or stenting on impairment of dynamic cerebral autoregulation. Stroke 2004;35:1381-7.
15. Barnett HJ, Taylor DW, Eliasziw M, Fox AJ, Ferguson GG, Haynes RB, et al. Benefit of carotid endarterectomy in patients with symptomatic moderate or severe stenosis. North American Symptomatic Carotid Endarterectomy Trial Collaborators. N Engl J Med 1998;339:1415-25.
16. Executive Committee for the Asymptomatic Carotid Atherosclerosis Study. Endarterectomy for asymptomatic carotid stenosis. JAMA 1995; 273:1421-8.
17. de Bray JM, Glatt B. Quantification of atheromatous stenosis in the extracranial internal carotid artery. Cerebrovasc Dis 1995;5:414-26.
18. Sidhu PS, Allan PL. Ultrasound assessment of internal carotid artery stenosis. Clin Radiol 1997;52:654-8.
19. Kao HL, Lin MS, Wang CS, Lin YH, Lin LC, Chao CL, et al. Feasibility of endovascular recanalization for symptomatic cervical internal carotid artery occlusion. J Am Coll Cardiol 2007;49:765-71.
20. Tang SC, Huang SJ, Chiu MJ, Yip PK. Impaired cerebral autoregulation in a case of severe acute encephalitis. J Formos Med Assoc 2007; 106:S7-12.
21. Glantz SA. Primer of biostatistics. 6th ed, Singapore: McGraw-Hill Inc; 2005.
22. Czosnyka M, Smielewski P, Piechnik S, Steiner LA, Pickard JD. Cerebral autoregulation following head injury. J Neurosurg 2001;95:756-63.
23. Czosnyka M, Smielewski P, Kirkpatrick P, Laing RJ, Menon D, Pickard JD. Continuous assessment of the cerebral vasomotor reactivity in head injury. Neurosurgery 1997;41:11-19.
24. Lang EW, Mehdorn HM, Dorsch NW, Czosnyka M. Continuous monitoring of cerebrovascular autoregulation: a validation study. J Neurol Neurosurg Psychiatry 2002;72:583-6.
25. Reinhard M, Roth M, Guschlbauer B, Harloff A, Timmer J, Czosnyka M, et al. Dynamic cerebral autoregulation in acute ischemic stroke assessed from spontaneous blood pressure fluctuations. Stroke 2005; 36:1684-9.
26. Oehm E, Hetzel A, Els T, Berlis A, Keck C, Will HG, Reinhard M. Cerebral hemodynamics and autoregulation in reversible posterior leukoencephalopathy syndrome caused by pre-/eclampsia. Cerebrovasc Dis 2006;22:204-8.
27. Strauss GI, Hansen BA, Herzog T, Larsen FS. Cerebral autoregulation in patients with end-stage liver disease. Eur J Gastroenterol Hepatol 2000;12:767-71.
28. Steiner LA, Coles JP, Johnston AJ, Chatfield DA, Smielewski P, Fryer TD, et al. Assessment of cerebrovascular autoregulation in head-injured patients: a validation study. Stroke 2003;34:2404-9.
29. Reinhard M, Roth M, Muller T, Czosnyka M, Timmer J, Hetzel A. Cerebral autoregulation in carotid artery occlusive disease assessed from spontaneous blood pressure fluctuations by the correlation coefficient index. Stroke 2003;34:2138-44.
30. Novak V, Chowdhary A, Farrar B, Nagaraja H, Braun J, Kanard R, et al. Altered cerebral vasoregulation in hypertension and stroke. Neurology 2003;60:1657-63.
31. Blass JP, Ratan RR. "Silent" strokes and dementia. N Engl J Med 2003:27;348:1277-8.
32. Vicenzini E, Ricciardi MC, Altieri M, Puccinelli F, Bonaffini N, Di Piero V, et al. Cerebrovascular reactivity in degenerative and vascular dementia: a transcranial Doppler study. Eur Neurol 2007;58:84-9.
33. Ohtani R, Tomimoto H, Kawasaki T, Yagi H, Akiguchi I, Shibasaki H. Cerebral vasomotor reactivity to postural change is impaired in patients with cerebrovascular white matter lesions. J Neurol 2003;250:412-7.
34. Schroeter ML, Bucheler MM, Preul C, Scheid R, Schmiedel O, Guthke T, et al. Spontaneous slow hemodynamic oscillations are impaired in cerebral microangiopathy. J Cereb Blood Flow Metab 2005;25:1675-84.
35. Abou-Chebl A, Reginelli J, Bajzer CT, Yadav JS. Intensive treatment of hypertension decreases the risk of hyperperfusion and intracerebral hemorrhage following carotid artery stenting. Catheter Cardiovasc Interv 2007;69:690-6.
36. van Mook WN, Rennenberg RJ, Schurink GW, van Oostenbrugge RJ, Mess WH, Hofman PA, et al. Cerebral hyperperfusion syndrome. Lancet Neurol 2005;4:877-88.
37. Suga Y, Ogasawara K, Saito H, Komoribayashi N, Kobayashi M, et al. Preoperative cerebral hemodynamic impairment and reactive oxygen species produced during carotid endarterectomy correlate with development of postoperative cerebral hyperperfusion. Stroke 2007;38: 2712-7.
38. Tang SC, Huang SJ, Jeng JS, Yip PK. Third ventricle midline shift due to spontaneous supratentorial intracerebral hemorrhage evaluated by transcranial color-coded sonography. J Ultrasound Med 2006;25: 203-9.

Submitted Nov 14, 2007; accepted Feb 1, 2008.