CLINICAL ARTICLE

J Korean Neurosurg Soc 40 : 434-440, 2006

Neurological Improvement after Cranioplasty in Patients with Surgical Bony Defects : The Usefulness of Acetazolamide Activated ^{99m}Tc-HMPAO SPECT

Won-Duck Seo, M.D., Young-Don Kim, M.D., Dae-Young Hong, M.D., Dae-Hyun Kim, M.D., Gi-Hwan Choi, M.D., Hyung-Tae Yeo, M.D.

Department of Neurosurgery, Daegu Catholic University School of Medicine, Daegu, Korea

Objective : The purpose of this study is to examine the influence of cranioplasty on dynamics of cerebral blood flow(CBF) and cerebrovascular reserve capacity(CVRC), and to investigate the usefulness of single photon emission computed tomography (SPECT) as a prognostic factor for neurological improvement after cranioplasty.

Methods : Between March 2003 and December 2005, a prospective study was performed on 24 patients who had undergone total 25 cranioplasty operations. Cerebral blood flow velocities in the middle cerebral artery(MCA) and internal carotid artery (ICA) were obtained by transcranial Doppler ultrasonography(TCD). The CVRC was assessed by SPECT in the natural state and after stimulation with 1g of acetazolamide. Neurological improvement after cranioplasty was compared between patients who showed hyperactivity to acetazolamide-activated SPECT (Group 1, n=7) and hypoactivity to acetazolamide-activated SPECT (Group 2, n=17). These measurements were obtained two weeks prior to and two weeks after cranioplasty.

Results : The blood flow velocities at the opposite site to the cranioplasty as well as at the cranioplasty site were significantly increased ($P<0.05$). Compared with Group 2, there was significant increase in CBF and neurological imrovement after cranioplasty in Group 1.

Conclusion : Among patients with surgical bony defects, the patients who had normal reactivity of the CVRC showed a significant increase in CBF and neurological improvement after cranioplasty. The authors suggest that CVRC measurement prior to surgery may be an important prognostic factor for neurological improvement after cranioplasty.

KEY WORDS : Cranioplasty · Cerebral blood flow(CBF) · Cerebrovascular reserve capacity(CVRC) · Transcranial Doppler ultrasonography(TCD) · Acetazolamide Activated ^{99m}Tc-HMPAO SPECT.

Introduction

Currently accepted indications for cranioplasty are for aesthetic reconstruction or protection of intracranial structures. However, sometimes unexpected improvements of neurological status or activities of daily living after cranioplasty have been reported. Some authors have maintained that these curative effects following cranioplasty might be due to a reduction of local cerebral compression effects by atmospheric pressure[17,21,22]. Removal of the effects of atmospheric pressure might lead to increased CBF, CVRC and glucose metabolism, thus leading to neurological improvement. However, not all patients who have undergone cranioplasty have shown neurological improvements. We hypothesized that patients who had normal reactivity of the cerebrovascular reserve capacity (CVRC) might also have better neurological results after cranioplasty. Therefore, we evaluated the hemodynamic effects of cranioplasty using TCD and cerebrovascular reserve capacity as assessed by SPECT during the natural state and after stimulation with 1g of acetazolamide. We then divided the patients into two groups : Group 1, showed hyperactivity with acetazolamide-activated SPECT; Group 2, showed hypoactivity after acetazolamideactivated SPECT. We had prospectively studied the correlation of neurological improvement after cranioplasty in each group to understand the efficacy of ^{99m}Tc-HMPAO SPECT for prognosis.

• Received : May 17, 2006 • Accepted : September 7, 2006

• Address for reprints : Young-Don Kim, M.D., Department of Neurosurgery, Daegu Catholic University School of Medicine, 3056-6 Daemyeong 4-dong, Nam-gu, Daegu 705-718, Korea Tel : +82-53-650-4257, Fax : +82-53-650-4932, E-mail : shydshyd@cu.ac.kr

Table 1. Clinical data and outcome obtained in 24 patients who underwent cranioplasty

Case	Group	Sex/Age	Reason	OP site	Time lapse (days)	GCS Before	GCS After	Changed Neurologic Symptom
1	1	M/48	Rt. EDH	Rt	41	13	14	improved orientation & ambulation
2	1	M/23	Lt. SDH	Lt	30	12	14	improved orientation
3	1	M/11	Rt. SDH	Rt	35	12	14	improved orientation & ambulation
4	1	M/58	Lt. SDH	Lt	44	12	14	improved ambulation
5	1	M/44	Both SDH	Both	150,174	10	13	improved ambulation
6	1	M/38	Contusion ICH	Rt	21	13	15	improved mentality
7	1	M/38	Contusion ICH	Lt	41	13	14	improved orientation
8	2	M/52	Rt. SDH	Rt	60	8	9	improved mentality
9	2	M/64	Lt. SDH	Lt	53	14	15	improved ambulation
10	2	M/20	Rt. SDH	Rt	84	7	8	no change
11	2	M/41	Contusion ICH	Rt	75	9	10	improved hemiparesis
12	2	M/27	Rt. SDH	Rt	73	7	8	improved hemiparesis
13	2	M/43	Contusion ICH	Rt	53	13	12	increased rigidity
14	2	M/46	AVM	Lt	80	13	14	improved ambulation
15	2	M/47	Lt. SDH	Lt	69	8	9	improved mentality
16	2	M/52	Contusion ICH	Lt	28	12	14	improved mentality
17	2	M/45	Rt. SDH	Rt	46	14	14	improved orientation
18	2	F/43	Rt. PcoA	Rt	54	13	14	improved hemiparesis
19	2	M/69	Rt. SDH	Rt	43	6	7	no change
20	2	M/51	Lt. SDH	Lt	465	14	14	no change
21	2	F/57	Infarction	Lt	29	14	15	improved orientation
22	2	M/37	Lt. SDH	Lt	57	8	8	no change
23	2	M/42	Lt. SDH	Lt	31	12	13	improved orientation
24	2	M/55	Lt. SDH	Lt	64	13	14	improved ambulation

* AVM=arteriovenous malformation; EDH=epidural hematoma; F=Female; GCS=Glasglow coma scale; Group1=hyperactivity to acetazolamide-activated SPECT; Group2=hypoactivity to acetazolamide-activated SPECT; ICH=intracerebral hematoma; M=male; PcoA=Posterior communicating artery; SDH=subdural hematoma; Time lapse=duration from craniectomy to cranioplasty

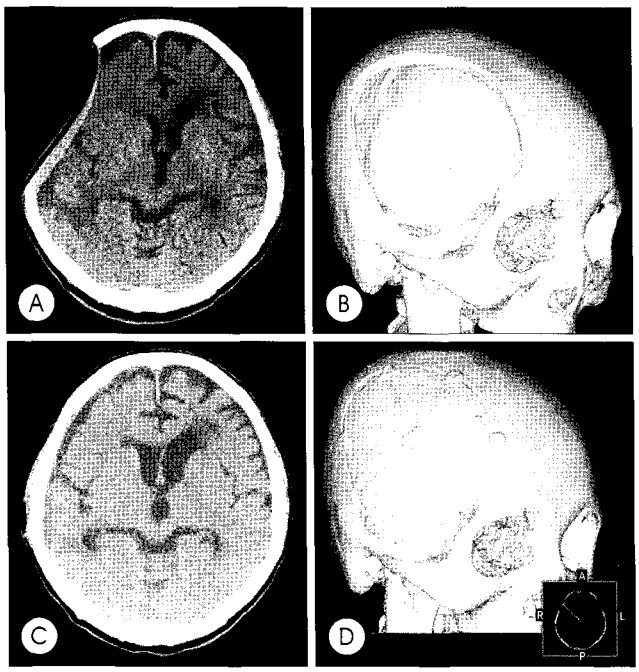

Fig. 1. Brain computed tomography(CT) and three dimensional brain computed tomography scan (3-D CT) obtained before (A, B) and after (C, D) cranioplasty in a patient who had undergone Rt. decompressive craniectomy for acute subdural hematoma (case No. 3).

Materials and Methods

Patient population

Between March 2003 and December 2005, a prospective study was performed on 24 patients who had undergone a total of 25 cranioplasty operations with skull defect size over 100 cm^2. During this period, there were 16 patients who had cranioplasty, but were excluded due to study criteria. The data on the clinical diagnoses, time intervals between craniectomy and cranioplasty, and clinical outcomes are presented in Table 1. The mean age of the patients was 43.79±13.59 years of age and the ratio of male to female patients was 22:2. There were 21 cases in the head injury group and three cases of decompression in the cerebrovascular disease group, respectively.

In 24 (95.8%) of 25 cases, autologous cranioplasty with cranial bone preserved at -70°C was performed, and in one case surgery was performed with methylmethacrylate. The mean interval between craniectomy and cranioplasty was 71.92± 8.78 days. The three dimensional reconstruction brain CT scanning was performed in all patients both pre- and postoperatively on a routine basis for assessment of the skull defect (Fig. 1).

Table 2. The results of SPECT before and after cranioplasty

Case	Group	AI (Asymmetry Index)				Pre OP	Post OP
		Pre OP		Post OP			
		AI1	AI2	AI1	AI2	(AI2−AI1) / AI2*100	
1	1	0.83	0.95	0.97	0.96	12.6	−1.0
2	1	0.68	0.78	0.58	0.62	12.8	6.5
3	1	0.87	0.97	0.73	0.87	10.3	16.1
4	1	0.89	1.05	0.95	1.08	15.2	12.0
5	1	0.89	1	0.81	0.88	11.0	8.0
6	1	1.06	1.24	0.86	0.92	14.5	6.5
7	1	0.76	0.88	0.99	0.98	13.6	−1.0
8	2	1.19	1.12	1.05	1.21	−6.2	13.2
9	2	0.94	0.81	0.81	0.70	−16.0	−15.7
10	2	0.95	0.79	0.87	0.78	−20.3	−11.5
11	2	1.06	0.92	1.04	1.07	−15.2	2.8
12	2	0.78	0.84	1.17	1.11	7.1	−5.4
13	2	1.02	0.85	1.07	1.08	−20.0	0.9
14	2	0.79	0.73	0.59	0.5	−8.2	−18.0
15	2	1.01	0.83	0.93	0.91	−21.7	−2.2
16	2	1.05	1.03	0.95	0.95	−1.9	0.0
17	2	1.07	1.20	0.74	0.81	10.8	8.6
18	2	0.93	0.97	1.07	1.08	4.1	0.9
19	2	1.23	0.98	1.03	0.80	−25.5	−28.8
20	2	0.73	0.71	0.65	0.73	−2.8	11.0
21	2	1.11	1.08	0.97	0.88	−2.8	−10.2
22	2	0.65	0.72	0.75	0.80	9.7	6.3
23	2	0.85	0.89	0.89	0.88	4.5	−1.1
24	2	0.92	1.01	0.86	0.89	8.9	3.4

*AI=a radiation amount of region of interest in skull defect site/a radiation amount of region of interest in opposite site; AI1=ai before acetazolamide injection; AI2=ai after acetazolamide injection; Pre OP=before cranioplasty operation; Post OP=after cranioplasty operation; CVRC=cerebrovascular reserve capacity

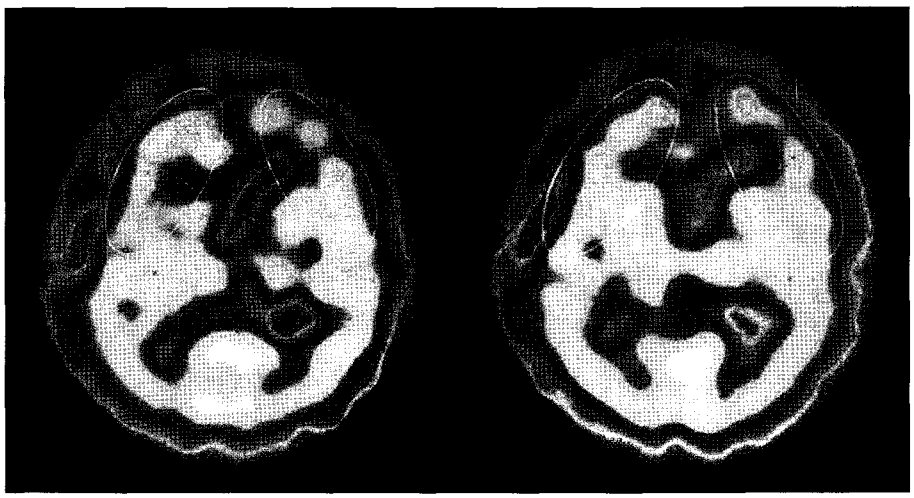

Fig. 2. Brain single photon emission computed tomography(SPECT) obtained in a patient who had undergone Rt. decompressive cranie ctomy for acute subdural hematoma (case No. 3). Lt; Brain SPECT before acetazolamide injection, Rt; Brain SPECT after acetazolamide injection.

Measurements of dynamics of CBF

Cerebral blood flow velocities in the middle cerebral artery (MCA) and internal carotid artery were obtained by transcranial Doppler ultrasonography (TCD; multi-Dop X4; DWL; Germany). These studies were performed at both the decompression site and on the opposite site. These measurements were obtained two weeks prior to and two weeks after cranioplasty.

Measurements of CVRC

The SPECT examination was performed under quiet conditions (lying down with eyes closed). Both a plain SPECT and an acetazolamide-activated SPECT were obtained and analyzed. The plain SPECT images were obtained by reconstruction of data, which formed an axial view, coronal view and sagittal view at 30 minutes after intravenous injection of ^{99m}Tc-HMPAO 20mCi, using a rotatory gamma camera. The acetazolamide -activated SPECT was performed one or two days later. After the first intravenous injection of 1g of acetazolamide, intravenous injection of ^{99m}Tc-HMPAO 20mCi followed 20 minutes later; the images were obtained 30 minutes later, as for the plain SPECT technique.

Each patient's condition and response to the radioisotope is different, therefore it is impossible to measure the quantitative CBF in SPECT. The authors examined the relative CBF, and compared the CBF at the lesion site and at the opposite site. Only one nuclear-medicine specialist interpreted all SPECT images. Regions of interest (ROIs) were placed on both cortical hemispheres and an amount of radiation was calculated for each site (Fig. 2). The authors calculated an asymmetry Index (AI = a radiation amount of ROI in skull defect site/a radiation amount of ROI in opposite site). We then compared the AI with acetazolamide-activated SPECT to the AI with the plain SPECT. We determined that the CVRC was valid for each case that is, above 10% increase in the AI for the acetazolamide-activated SPECT.

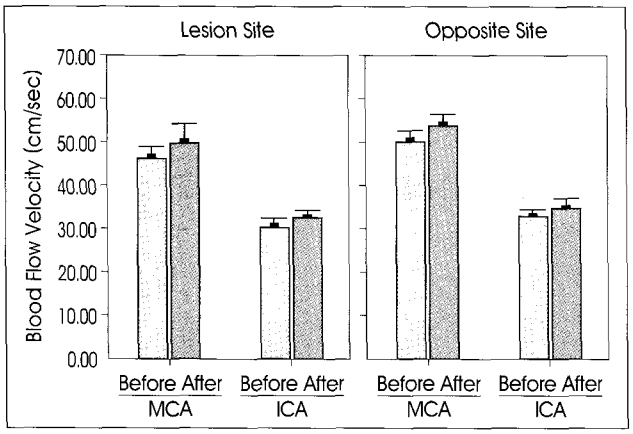

Fig. 3. Bar graphs depict the influence of cranioplasty on the cerebral blood flow velocity obtained in 24 patients (mean±SD). Asterisks show statistically a significant difference compared with 'before cranioplasty' ($P<0.05$).

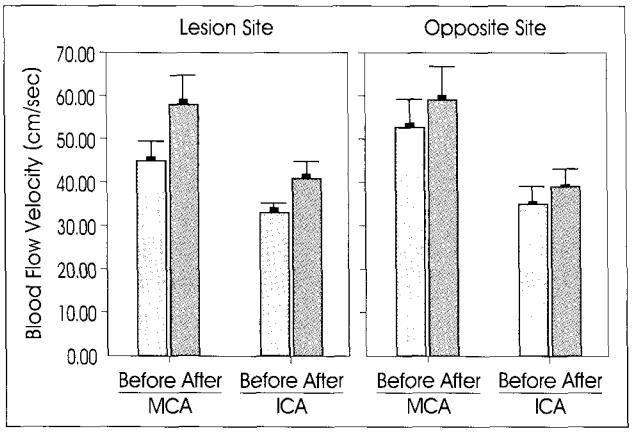

Fig. 4. Bar graphs depict the influence of cranioplasty on the cerebral blood flow velocity obtained in Group 1 patients (mean±SD). Asterisks show statistically a significant difference compared with 'before cranioplasty' ($P<0.05$).

Then, we divided the patients into two groups : Group 1, showed hyperactivity with the acetazolamide-activated SPECT (above 10% increase), Group 2, showed hypoactivity with the acetazolamide-activated SPECT (below 10% increase). The neurological improvements pre- and post-cranioplasty were measured using the Glasgow coma scale(GCS). Special cases were described separately. We studied the correlation of neurological improvement after cranioplasty in each group; in addition, the CRVC changes after cranioplasty were obtained. These measurements were recorded two weeks prior to and two weeks after cranioplasty.

Statistical analysis

The statistical analyses used were the paired t-test and Wilcoxon signed rank test; for pre- and post-cranioplasty variables studied in both groups. And also, two sample t-test and Mann-Whitney U test were used for the comparision of two groups. The correlation between the increments of GCS and intervals were analyzed by Spearman's correlation analysis.

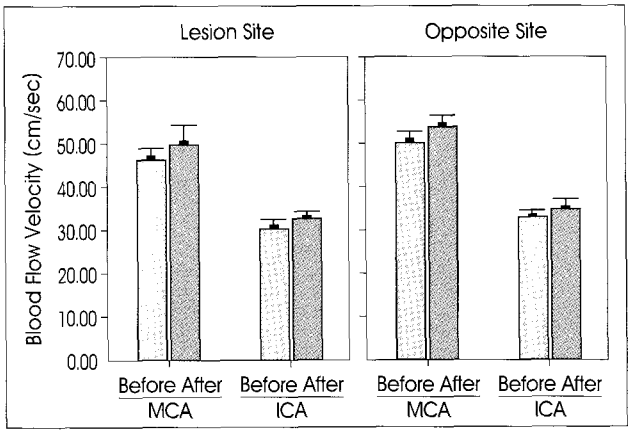

Fig. 5. Bar graph depicts the influence of cranioplasty on the cerebral blood flow velocity obtained in Group 2 patients (mean±SD). Asterisks show statistically a significant difference compared with 'before cranioplasty' ($P<0.05$).

Results

Clinical outcome

The neurological changes before and after cranioplasty are summarized in Table 1. Neurological improvement was found in 20 (83.3%) of 24 cases after cranioplasty. There was significant improvement in GCS as a whole study (11.25 ± 2.61 before cranioplasty vs 12.33 ± 2.68 after cranioplasty, $P<0.05$). The correlation between the intervals elapsed after cranioplasty and neurological changes after cranioplasty were not statistically significant.

Evaluation by TCD

CBF velocity changes before and after cranioplasty are shown in Fig. 3. In the MCA and ICA of the lesion site, the CBF velocity was separately increased from 46.04 ± 11.37cm/sec to 52.79 ± 13.85cm/sec ($p<0.05$) and from 32.08 ± 6.33cm/sec to 35.71 ± 8.17cm/sec ($p<0.05$) after cranioplasty. The CBF velocity in the MCA and ICA of the opposite site was also increased, it was significant. For the comparisons between Group 1 and Group 2, there were significant CBF increases in both groups, however, the increases in Group 1 were more significant ($p<0.05$) (Fig. 4, 5).

Measurement of CVRC

The results of SPECT before and after cranioplasy are summarized in Table 2. Comparisons of the AI after the acetazolamide activation SPECT to the AI of the plain SPECT, Group 1 had a greater than 10% increase in the AI with the acetazolamide activation SPECT in seven (29%) of 24 cases, and for Group 2, hypoactivity with the acetazolamide activated SPECT (below 10% increase) was observed in 17 (71%) of 24 cases. Among cases in Group 1 (n=7) patients who had normal CVRC, neurological improvements were found in se-

Table 3. GCS increase before and after cranioplasty between Group 1 & Group 2

	Group 1 (n_1=7) mean (S.D.)	Group 2 (n_2=17) mean (S.D.)	p-value[a]
GCS	1.86 (0.690)	0.76 (0.664)	0.002[b*]

GCS=Glasgow Coma Scale; Group 1=hyperactivity to acetazolamide activated SPECT; Group 2=hypoactivity to acetazolamide activated SPECT. * : statistically significant ($p<0.05$), a : Independent two sample t-test, 1. b : Mann-Whitney U test if normality is unsatisfied

ven patients (100%). However, 13 (76.5%) patients improved in Group 2 (n=17) with abnormal CVRC. Therefore, neurological improvement after cranioplasty in the two groups studied with GCS was significantly made in Group 1 ($p<0.05$) (Table 3).

Discussion

Cranioplasty is the surgical repair of a cranial defect. Historically, reconstruction of a cranial vault defect has been considered, by some, to be the earliest operation performed in humans, dating back to prehistoric times. Since that time, the reconstructive goals, to protect the underlying brain and restore pre-injury appearance, have remained the major goals of cranioplasty. However, sometimes unexpected improvements of the neurological status or activities of daily living occur after cranioplasty. Therefore, investigators have studied the influence of cranioplasty on the brain by measurements of cerebrospinal fluid(CSF), CBF, and metabolic dynamics[3-6,8,9,11,14,15,17-19,21-23]. The efficacy of cranioplasty is demonstrated by "the syndrome of the sinking skin flap"(SSSF). The SSSF is defined as a series of neurological symptoms associated with skin depression at the site of a cranial defect, which can develop several weeks to months after a large external cerebral decompression[21,22]. In 1977, Yamaura et al.[21] reported that atmospheric pressure was transmitted to the cranial cavity, causing inward rotation of the scalp at the cranial defect, and that 30% of patients with a depressed skin flap after a large craniectomy showed improved neurological symptoms after cranioplasty. In 1997, Dujovny et al.[3] suggested that "the syndrome of the trephined"(ST) was characterized by subjective symptoms such as headache, dizziness, undue fatigue, and vague discomfort. Symptoms associated with SSSF and ST improved rapidly after cranioplasty.

Although the mechanism of improvement remains unclear, the mechanism by which SSSF and ST occur has been speculated to be the result of the combined effects of 1) atmospheric pressure, 2) CSF, 3) CBF, and 4) cerebral metabolism. In regard to atmospheric pressure, Yamaura et al.[21,22] explained that the skin at the a cranial bone defect site sinks as a result of atmospheric pressure, and the cerebral tissue becomes deformed, resulting in local cerebral circulation disorders and cerebral dysfunction. In 1982, Stula[17] suggested that the atmospheric pressure acting on the unprotected brain produces brain compression and cranioplasty can normalize this situation. Consideration of CSF, in 1979 and 1984, Fodstad et al.[5,6] reported on CSF hydrodynamic studies before and after cranioplasty with a constant pressure infusion method. The authors concluded that the variable change in CSF dynamics, with an improved outcome in patients with skull defects, could be explained by the stretching or a distortion of the dura and the underlying cerebral cortex due to the atmospheric pressure with possible shifting of intracranial contents. In 1997, Dujovny et al.[4] described an increase in CSF motion using MRI after cranioplasty. In regard to CBF, in 1985, Richaud et al.[14] reported that CBF, evaluated with Xe-CT, increased 15~30% in the area of the cortex adjacent to cranioplasty as the neurological condition improved. In 1993, Suzuki et al.[18], using dynamic CT, reported that increase in bilateral CBF might play a role in neurological improvements after cranioplasty. In 1996, Yoshida et al.[23], using Xe CT and ^{31}P magnetic resonance spectroscopy(MRS), suggested that cranioplasty should be carried out as soon as the cerebral edema has disappeared, because a bone defect itself may decrease CBF and disturb energy metabolism. In 1999, Maekawa et al.[11], using Xe-CT, reported that cranioplasty might increase CBF in not only the symptomatic hemisphere but also at the other site. In 2003, Huh et al.[8], suggested that cranioplasty could remove the atmospheric pressure on the brain and may decrease the flow velocity and increase the CBF as well as improve cardiac function. The impact on cerebral metabolism, was studied in 2000 by, Winkler et al.[19], using TCD and 18FDG PET; they reported that cranioplasty appeared to affect postural blood flow regulation, CVRC, and cerebral glucose metabolism markedly.

However, not all patients who had undergone cranioplasty showed neurological improvements. The authors focused on this fact and hypothesized that the patients who had normal reactivity of the cerebrovascular reserve capacity(CVRC) might have better results. We evaluated the hemodynamic effects of cranioplasty using TCD and CVRC was assessed by SPECT.

Common measurements of the dynamics of CBF have been transcranial Doppler ultrasonography(TCD), Xe-enhanced Computed Tomography(Xe-CT), CT perfusion imaging, Positron Emission Tomography(PET), and Single Photon Emission Computed Tomography(SPECT)[20].

Xe-CT and CT perfusion imaging have the advantage of obtaining quantitative values of the regional CBF. However, Xe-CT is complex, it requires of special equipment such as a closed rebreathing Xe inhalator and end tidal Xe monitor, and the imaging of Xe-CT requires excellent cooperation from the patient. CT perfusion imaging is not popular and is expensive. PET has not only the advantage of obtaining quantitative values of the regional CBF, but also provides measurement of

cerebral glucose and oxygen metabolism. However, PET requires special equipment such as a cyclotron and is expensive as well. Although TCD does not directly measure CBF, it does measure blood flow velocity in the basal intracranial arteries. Several studies[1,2,16] have shown that CBF velocity, measured by TCD, was correlated with the CBF obtained using ^{33}Xe-enhanced CT. In 1986, Bishop et al.[1] reported that, when at rest, CBF compared to MCA blood flow velocity showed a significant correlation. In 1989, Sorteberg et al.[16] examined the relationship between CBF and blood flow velocity in 17 normal subjects, and observed a statically significant correlation. SPECT does not measure quantitative CBF, but it is cheap, easy, repeatable, and can measure qualitative regional CBF by providing high resolution images. SPECT can be used to evaluate CVRC at the lesion site of the brain using acetzolamide stimulation. Kimura et al.[10] suggested that the acetzolamide activated ^{123}I-SPECT was a good study for predicting cerebral ischemic changes by measuring CVRC in the patients with subarachnoid hemorrhage.

In 1985, the importance of using acetzolamide-stimulated SPECT was widely accepted after the EC-IC bypass study group reported its findings[7]. In 1998, Moon[12], using ^{99m}Tc-HMPAO SPECT, reported that abnormal reactivity of the vascular reserve capacity correlated very well with the prognosis of patients with subarachnoid hemorrhage and suggested that a CVRC study might also help to decide surgical timing for a ruptured aneurysm. In 1999, Rha et al.[13] selected patients for surgery using a CVRC study and reported a good result after bypass surgery in patients with hemodynamic cerebral ischemia.

Therefore, the authors examined CBF changes before and after cranioplasty using TCD, which is simple and easily repeated, and we prospectively studied the correlation of CVRC with the neurological improvement after cranioplasty. In our study, the CBF velocities on the opposite site as well as the lesion site were significantly increased at both MCA and ICA after cranioplasty. In comparisons between Group 1 and Group 2, there were significant CBF increases in both groups, but a more significant increase was observed in Group 1. In evaluation of the correlation of neurological improvement after cranioplasty, for each group, GCS was found to be significantly improved in Group 1.

We confirmed the finding that removal of the effects of atmospheric pressure, after cranioplasty, appears to lead to increased regional CBF, thus leading to neurological improvement. Because the abnormal CVRC, determined after acetazolamide activation SPECT performed preoperatively, suggest a disturbance of cerebrovascular autoregulation, in patients such as those in group 2, the results of cranioplasty were not so good. The reason why this may be that the cerebrovascular autoregulation was destroyed, and an effective and stable blood supply would be impaired. Therefore, CVRC appears to play a major role in the outcome of therapeutic cranioplasty; preoperative CVRC measurement might be an important prognostic factor for neurological improvement after cranioplasty.

Conclusion

In addition to cosmetic and protective effects, cranioplasty might also improve the neurological state of some patients as a result of increased regional CBF in patients with surgical bony defects. Among patients with surgical bony defects, the patients who had normal reactivity of the cerebrovascular reserve capacity(CVRC) showed significant CBF increase and neurological improvement after cranioplasty. The authors therefore suggest that the cerebrovascular reserve capacity(CVRC), as measured preoperatively, may be an important prognostic factor for neurological improvement after cranioplasty.

References

1. Bishop CC, Powell S, Rutt D, Browse NL : Transcranial Doppler measur-ement of middle cerebral artery blood flow velocity : a validation study. **Stroke 17** : 913-915, 1986
2. Dahl A, Russell D, Nyberg-Hansen R, Rootwelt K, Bakke SJ : Cerebral vasoreactivity in unilateral carotid artery disease. A comparison of blood flow velocity and regional cerebral blood flow measurements. **Stroke 25** : 621-626, 1994
3. Dujovny M, Aviles A, Agner C, Fernandez P, Charbel FT : Cranioplasty : cosmetic or therapeutic? **Surg Neurol 47** : 238-241, 1997
4. Dujovny M, Fernandez P, Alperin N, Betz W, Misra M, Mafee M : Post-cranioplasty cerebrospinal fluid hydrodynamic changes : magnetic resonance imaging quantitative analysis. **Neurol Res 19** : 311-316, 1997
5. Fodstad H, Ekstedt J, Friden H : CSF hydrodynamic studies before and after cranioplasty. **Acta Neurochir Suppl (Wien) 28** : 514-518, 1979
6. Fodstad H, Love JA, Ekstedt J, Friden H, Liliequist B : Effect of cranioplasty on cerebrospinal fluid hydrodynamics in patients with the syndrome of the trephined. **Acta Neurochir (Wien) 70** : 21-30, 1984
7. Group TEIBS : Failure of extracranial-intracranial arterial bypass to reduce the risk of ischemic stroke. Results of an international randomized trial. **N Engl J Med 313** : 1191-1200, 1985
8. Huh HY, Yoo DS, Huh PW, Cho KS, Kim DS, Kim MC : Effect of cranioplasty on the cerebral hemodynamics and stroke volume. **J Korean Neurosurg Soc 33** : 13-18, 2003
9. Isago T, Nozaki M, Kikuchi Y, Honda T, Nakazawa H : Sinking skin flap syndrome : a case of improved cerebral blood flow after cranioplasty. **Ann Plast Surg 53** : 288-292, 2004
10. Kimura T, Shinoda J, Funakoshi T : Prediction of cerebral infarction due to vasospasm following aneurysmal subarachnoid haemorrhage using acetazolamide-activated 123I-IMP SPECT. **Acta Neurochir (Wien) 123** : 125-128, 1993
11. Maekawa M, Awaya S, Teramoto A : [Cerebral blood flow(CBF) before and after cranioplasty performed during the chronic stage after decompressive craniectomy evaluated by xenon-enhanced computerized tomography(Xe-CT) CBF scanning]. **No Shinkei Geka 27** : 717-722, 1999
12. Moon JG : A study on the usefulness of acetazolamide-activated ^{99m}Tc-HMPAO SPECT in subarachnoid hemorrhage. **J Korean Neurosurg Soc 27** : 1257-1265, 1998
13. Rha HK, Lee KJ, Cho KK, Park SC, Park HK, Cho JK, et al : Improvement of cerebrovascular reserve capacity by bypass surgery in patients with hemodynamic cerebral ischemia. **J Korean Neurosurg Soc 28** : 35-41, 1999
14. Richaud J, Boetto S, Guell A, Lazorthes Y : Incidence des cranioplasties sur la function neurologique et le debit sangein cerebral. **Neurochirurgia**

(Stuttg) 31 : 183-188, 1985
15. Sakamoto S, Eguchi K, Kiura Y, Arita K, Kurisu K : CT perfusion imaging in the syndrome of the sinking skin flap before and after cranioplasty. **Clin Neurol Neurosurg 108** : 583-585, 2006
16. Sorteberg W, Lindegaard KF, Rootwelt K, Dahl A, Russell D, Nyberg-Hansen R, et al : Blood velocity and regional blood flow in defined cerebral artery systems. **Acta Neurochir (Wien) 97** : 47-52, 1989
17. Stula D : The problem of the "sinking skin-flap syndrome" in cranioplasty. **J Maxillofac Surg 10** : 142-145, 1982
18. Suzuki N, Suzuki S, Iwabuchi T : Neurological improvement after cranioplasty. Analysis by dynamic CT scan. **Acta Neurochir (Wien) 122** : 49-53, 1993
19. Winkler PA, Stummer W, Linke R, Krishnan KG, Tatsch K : Influence of cranioplasty on postural blood flow regulation, cerebrovascular reserve capacity, and cerebral glucose metabolism. **J Neurosurg 93** : 53-61, 2000
20. Wintermark M, Sesay M, Barbier E, Borbelv K, Dillon WP, Eastwood JD, et al : Comparative overview of brain perfusion imaging techniques. **Stroke 36** : 83-99, 2005
21. Yamaura A, Makino H : Neurological deficits in the presence of the sinking skin flap following decompressive craniectomy. **Neurol Med Chir (Tokyo) 17** : 43-53, 1977
22. Yamaura A, Sato M, Meguro K : [Cranioplasty following decompressive craniectomy--analysis of 300 cases (author's transl)]. **No Shinkei Geka 5** : 345-353, 1977
23. Yoshida K, Furuse M, Izawa A, Iizima N, Kuchiwaki H, Inao S : Dynamics of cerebral blood flow and metabolism in patients with cranioplasty as evaluated by ^{133}Xe CT and ^{31}P magnetic resonance spectroscopy. **J Neurol Neurosurg Psychiatry 61** : 166-171, 1996

Commentary

Cranioplasty, as it is noted in this paper, is still controversial on whether this procedure, especially for skull defect, has its positive influence over neurological status. However, the authors demonstrate in their prospective study that the neurological improvement could be expected with the relatively well preserved cerebrovascular reserve capacity based on the acetazolamide activated ^{99m}Tc-HMPAO SPECT. The shortcoming is that the number of patients is not so enough to draw the statistically definite results. In addition, the cerebrovascular reserve capacity appears to be somewhat variable after cranioplasty. I think it would be much better to discuss, if possible, what it means with these postoperative measurements in regard with the above consequence.

There seem to be some factors, involving the dynamics of cerebrospinal fluid, cerebral blood flow and metabolism, to affect the brain after cranioplasty in patients with skull defects. Considering these factors, this study provides a very valuable guide for the neurological problems associated with skull defect. And it would be very helpful to the clinical application with further study.

Young-Seob Chung, M.D.
Department of Neurosurgery
Seoul National University