

Simple Solution for Preventing Cerebrospinal Fluid Loss and Brain Shift During Multitrack Deep Brain Stimulation Surgery in the Semisupine Position: Polyethylene Glycol Hydrogel Dural Sealant Capping

—Rapid Communication—

Ichiro TAKUMI,¹ Masahiro MISHINA,² Kohei HIRONAKA,¹ Kenichi OYAMA,¹
Akira YAMADA,¹ Koji ADACHI,¹ Makoto HAMAMOTO,³
Shin KITAMURA,³ Daizo YOSHIDA,⁴ and Akira TERAMOTO^{4,5}

Departments of ¹Neurosurgery and ³Neurology,
Nippon Medical School Musashi Kosugi Hospital, Kawasaki, Kanagawa;
Departments of ²Neurology and ⁴Neurosurgery, Nippon Medical School, Tokyo
⁵Department of Neurosurgery, Tokyo Rosai Hospital, Tokyo

Abstract

This study evaluated preliminary findings on the efficacy of polyethylene glycol (PEG) hydrogel dural sealant capping for the prevention of cerebrospinal fluid (CSF) leakage and pneumocephalus during deep brain stimulation (DBS) surgery in the semisupine position. Group A consisted of 5 patients who underwent bilateral subthalamic nucleus (STN)-DBS surgery without PEG hydrogel dural sealant capping. Group B consisted of 5 patients who underwent bilateral STN-DBS surgery with PEG hydrogel dural sealant capping. The immediate postoperative intracranial air volume was measured in all patients and compared between the 2 groups using the Welch test. Adverse effects were also examined in both groups. The intracranial air volume in Group A was 32.3 ± 12.3 ml (range 19.1–42.5 ml), whereas that in Group B was 1.3 ± 1.5 ml (range 0.0–3.5 ml), showing a significant difference ($p < 0.005$). No hemorrhage or venous air embolisms were observed in either group. The effect of brain shift was discriminated by STN recordings in Group B. These preliminary findings indicate that PEG hydrogel dural sealant capping may reduce adverse effects related to CSF leakage and brain shift during DBS surgery.

Key words: deep brain stimulation, Parkinson's disease, brain shift, pneumocephalus, polyethylene glycol hydrogel dural sealant

Introduction

Subthalamic nucleus (STN) deep brain stimulation (DBS) has been performed, especially in the last decade, for the treatment of medically refractory Parkinson's disease (PD), as a less destructive technique compared with ablative surgery such as pallidotomy or thalamotomy. Complications and adverse events associated with DBS surgery have been well described and are generally classified as being related to cranial electrode implantation, the implantable pulse generator, or general conditions

such as pneumonia or pulmonary embolism.^{18,20,21} Among the cranial-related complications, cerebrospinal fluid (CSF) leakage during STN-DBS surgery for PD causes pneumocephalus and subsequent brain shift,⁸ resulting in inappropriate planning of recordings and misjudgment of electrode placement.^{7,12,19} Preoperative cerebral atrophy may also be related to the presence of intracranial air.² Several techniques for decreasing CSF loss and pneumocephalus during DBS surgery have been proposed. Placing the patient in a sitting¹² or semi-sitting⁴ position is considered to be one of the key factors for reducing CSF leakage, but this method may increase the risk of venous air embolisms (VAEs). Placing the patient in a completely flat su-

pine position, which is considered to be another method to minimize intracranial air by packing the cranial window from the inside,¹²⁾ for a long duration of time during awake surgery is not always comfortable for the elderly and patients with postural disorders. Minimal dural incision,^{12,14)} avoiding CSF suctioning even for clearer vision of the cortical surface,¹²⁾ and flooding the burr hole with saline irrigation¹⁵⁾ have been advocated. Other techniques for decreasing CSF loss, which has been associated with favorable outcomes,⁵⁾ is the use of fibrin glue sealant and gelfoam, but the half-sitting surgical position is also important in this 2-step technique.

We describe another simple new technique for eliminating CSF leakage during DBS surgery in the semisupine position, called polyethylene glycol (PEG) hydrogel dural sealant capping, and compare outcomes obtained with this technique with previously described methods.

Materials and Methods

Thirteen patients with PD were selected for DBS surgery at the Nippon Medical School Musashi Kosugi Hospital from April 2010 to December 2011. All patients were scheduled for bilateral STN-DBS, performed by a single surgeon (IT), so a total of 26 sides were treated. Ten consecutive patients with PD were included in this study.

Magnetic resonance (MR) images were preoperatively acquired for surgical planning. Target localization was based upon the Schaltenbrand and Wahren atlas and on direct visualization on the MR image using iPlan StereotaxyTM (Brainlab, Munich, Germany). The bottom of the STN target was located 11 mm lateral from the midsagittal plane, 3 mm posterior to the midcommissural point, and 5 mm inferior to the anterior-posterior commissure line, as based on the Schaltenbrand and Wahren atlas. Using red nucleus-based targeting,¹⁾ the target was observed 3 mm lateral to the anterior margin of the lateral border of the red nucleus in the axial plane. iPlan Stereotaxy software was used for target localization, trajectory simulation, and image fusion of computed tomography (CT) scans and MR images. The entry point was determined so that the trajectory avoided the cortical vein, sulcus, abnormal vessels, état criblé, and lateral ventricle.

Surgery was performed, in brief, as follows: The Leksell stereotactic G frame (Elekta AB, Stockholm, Sweden) was applied to all patients under local anesthesia, followed by CT scan acquisition. The preoperatively acquired MR image was then superimposed on the CT scan using iPlan Stereotaxy. After tracking and frame co-ordination were final-

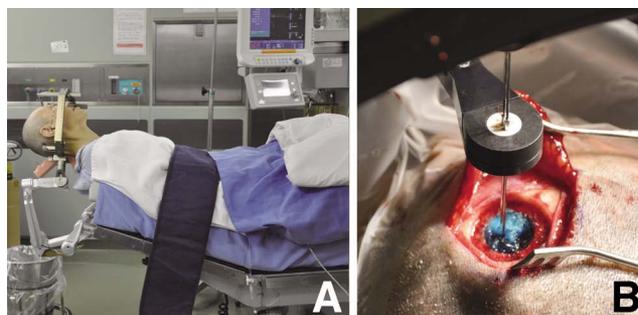


Fig. 1 Photographs showing the typical patient positioning during deep brain stimulation surgery in our institute; the head of the bed is elevated to 15 degrees (A), and the polyethylene glycol hydrogel dural sealant capping procedure, with guiding cannulas (2 cannulas in this case) penetrating the blue layer of the DuraSealTM at the burr hole (B).

ized, the patients were placed in a semisupine position, with the head elevated 10–15 degrees (Fig. 1A) in a head-flat position. The first side to be treated was determined based either on the side of initial parkinsonism presentation or the side with more prominent symptoms, but these were the same in all patients. A burr hole was made after assessing the best tacking route for curved skin incision. STN targeting was performed based on presurgical planning and physiologic multi-tracking micro-recordings using LeadpointTM (Medtronic, Minneapolis, Minnesota, USA; typically of 4–7-mm-long STN activity), followed by test stimulation and electrode placement. Two tracks were always selected for the initial micro-electrode recordings using BenGunTM (Alpha Omega Engineering, Nazareth, Israel), but other tracks were examined if the stimulation test resulted in inappropriate or side effects. The electrode was placed on the track offering the optimum physiological results. The second burr hole was made after surgery on the first side was complete. An implantable pulse generator was placed 3–4 days after electrode placement.

The technique of PEG hydrogel dural sealant capping was as follows. After the burr hole was made and the dura mater was incised in a cross shape (each incision 10 mm in length), the surface of the brain parenchyma was closely and quickly inspected to ensure that the burr hole was placed as designed, with no vessels beneath the burr hole, followed by arachnoid incision and minimal brain parenchyma coagulation. PEG hydrogel dural sealant (DuraSealTM; Covidien, Mansfield, Massachusetts, USA) was applied to cover the entire burr hole. BenGunTM electrode guiding cannulas were then inserted, penetrating the PEG layer to the

parenchyma (Fig. 1B). Excess PEG dural sealant was trimmed after electrode placement. If PEG hydrogel dural sealant was not used, the conventional technique to place a burr hole on top of the gyrus or to minimize CSF suctioning for an even clearer vision of the cerebral cortex was attempted.

Patients were divided into 2 groups: 5 patients who underwent bilateral STN-DBS surgery without PEG hydrogel dural sealant capping (Group A), and 5 patients who underwent bilateral STN-DBS surgery with PEG hydrogel dural sealant capping (Group B). To evaluate the volume of air, a CT scan was taken immediately after the surgery, typically within 1 hour, in all patients. The air volume was measured using the workstation CT scan system (Aquilion; Toshiba Medical Systems Corporation, Otawara, Tochigi). The Welch test was performed for comparison of postoperative intracranial air volumes between the 2 groups, using JMP 9.0.2 (SAS Institute Inc., Cary, North Carolina, USA). Adverse effects were also examined in both groups.

Results

Figure 2 shows the CT scans acquired from representative patients. Group A showed a mean postoperative intracranial air volume of 32.3 ± 12.3 ml (range 19.1–42.5 ml), whereas Group B showed a mean postoperative intracranial air volume of 1.3 ± 1.5 ml (range 0.0–3.5 ml), which were significantly different ($p = 0.0046$). No hemorrhage, VAEs, or related symptoms (coughing, tachypnea, or decrease in O_2 saturation) were observed in either group.

The numbers of tracks or the acquired length of the STN recordings were not significantly different

between Group A and Group B. However, the recording tracks of optimum STN activity were different. In Group A with the conventional maneuver, the first track was planned to consider possible medial brain shift, and the second track was planned to consider both the result of first side recording/test stimulation and the effect of possible posterior brain shift. In contrast, in the Group B treated with the PEG capping method, STN activity recording showed no effects of brain shift. Figure 3 shows the recording results from a representative case in Group B. On the first side surgery, both the center track (STN activity was recorded from -4.5 mm to $+2.0$ mm of the target) and the lateral track (STN activity was recorded from -5.0 mm to $+2.0$ mm of the target) adequately recorded STN activity (Fig. 3A, B). On the second side, the center track adequately recorded STN activity (STN activity from -5.0 mm to $+1.0$ mm of the target), but the posterior track identified no STN activity (Fig. 3C, D), suggesting that the effect of brain shift was discriminated both medially and posteriorly, if the center targets were planned symmetrically based on anterior-posterior commissure coordinates.

Discussion

PEG hydrogel dural sealant was approved by the Food and Drug Administration for cranial use in April 2005 in the United States,¹⁷⁾ but has been available for clinical use in Japan only since April 2010. The sealant is widely, safely, and effectively used in various neurosurgical fields such as general craniotomy,⁶⁾ posterior fossa reconstruction,¹⁷⁾ spinal surgery,¹⁰⁾ pituitary surgery,³⁾ and in combina-

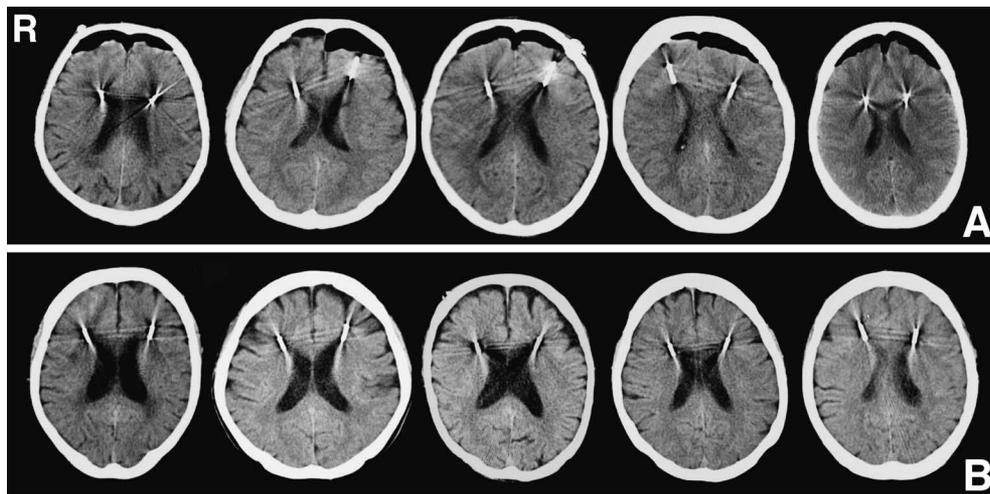


Fig. 2 Computed tomography scans from representative patients in Group A without polyethylene glycol hydrogel dural sealant (A), and Group B with polyethylene glycol hydrogel dural sealant (B).

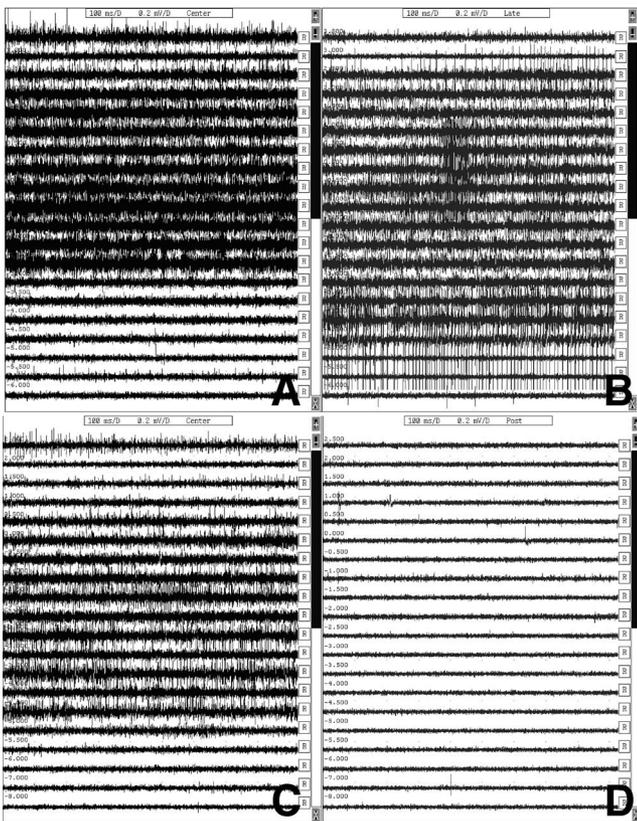


Fig. 3 Microelectrode recordings from a representative patient in Group B. On the first side, both the center track (A, subthalamic nucleus [STN] activity was recorded from -4.5 mm to $+2.0$ mm of the target) and lateral track (B, STN activity was recorded from -5.0 mm to $+2.0$ mm of the target) adequately recorded the STN activity. On the second side, the center track adequately recorded STN activity (C, STN activity from -5.0 mm to $+1.0$ mm of the target), but the posterior track identified no STN activity (D), indicating the effect of brain shift, both medially or posteriorly, was discriminated.

tion with nonautologous dural plasty materials.²²⁾ The clinical efficacy of PEG hydrogel dural sealant has been reported to be 100% for the prevention of intraoperative CSF leakage during surgery with the Valsalva maneuver.⁶⁾ CSF leakage and subsequent pneumocephalus is reported to be the cause of cortical^{8,23)} and subcortical^{7,8,19)} brain shift. The brain shift observed during the surgery is contralateral and posterior to the anterior-posterior commissure line,¹²⁾ and the mechanism is considered to be the pressure gradient between the intracranial and atmospheric pressures. CSF leakage and intracranial pneumocephalus combine to equalize the pressures between these two compartments.

With careful conventional procedures, the mean value of the posterior shift at the anterior commis-

sure point exceeds 2 mm,¹²⁾ but is less than 2 mm at the posterior commissure point,^{12,16)} so is favorable for the accuracy of image-guided targeting. This supports the rationale of the fail-safe system of multi-unit recording with tracks spaced at 2 mm. Multiple cannulas prevent the brain from posterior migration, which is another advantage of the multitrack method to prevent brain shift. Whether the multitrack method increases the chance of CSF leakage and brain shift is controversial, but correct burr hole sealing may decrease the possible brain shift.^{16,24)} Brain shift is also observed long after electrode implantation,¹⁹⁾ but eventually as the intracranial air is disappearing, the brain ‘re-expands’ and ‘shortening’ of the electrode occurs along with the route to cause upward displacement. The larger the postoperative intracranial air volume, the more migration observed. Is there no brain shift if there is no intracranial air or CSF leakage during the surgery? Even with the observation of ‘0 cm³’ intracranial air, electrode migration is observed during a long follow-up period in certain circumstances.¹⁹⁾ For this reason, initial deeper placement of the electrodes for 1 electrode contact¹⁹⁾ is advocated, but this point has to be further investigated. The conventional method in our Group A occasionally recorded STN activity in the posterior track at the second side surgery, but not in Group B as the posterior route was ideally selected without obstacles en route.

To decrease CSF leakage during DBS surgery, minimal dural incision, which may be achieved by limiting the incision to the outer diameter of the guiding cannula (1.5 mm),¹⁴⁾ after placement of the twist drill hole of 4-mm diameter¹²⁾ has been suggested, resulting in the lowest incidence of adverse effects. However, this technique may limit the inspection of the brain parenchyma and brain surface. Our data demonstrate the clinical efficacy of PEG hydrogel sealant, resulting in minute dural deficits sealed in patients treated in the semisupine position, while allowing close inspection of the brain surface without CSF leakage.

DBS surgery involves logical discrepancies regarding head positioning, with pneumocephalus, CSF leakage, and VAE-related adverse effects associated with higher head positioning, whereas elevation of hemorrhagic risk appears to be associated with lower head positioning.¹⁴⁾ VAEs are known to occur more frequently during neurosurgical procedures in the sitting position⁹⁾ than the supine position with a moderate level of head elevation.^{6,9,11,13)} DBS patients placed in a ‘strict’ supine position with elimination of intracranial air using a small dural incision based-technique resulted in favorable outcomes in terms of reduction in adverse effects

such as brain shift and VAEs.¹⁴⁾ Our findings also demonstrated the potential clinical efficacy of PEG dural sealant to avoid brain shift by eliminating CSF loss and intracranial air during DBS surgery in the semisupine position.

Our simple method of employing PEG hydrogel dural sealant enables DBS surgery to be performed in the semisupine position, and easily and safely prevents intracranial air accumulation and CSF loss. Our preliminary results suggest that this method may reduce adverse effects related to CSF leakage and brain shift in patients undergoing DBS surgery.

Acknowledgment

This work was supported by a Grant-in-Aid for Scientific Research (B 21390414) from the Japan Society for the Promotion of Science.

Conflicts of Interest Disclosure

None. All authors who are members of The Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forms through the website for JNS members.

References

- 1) Andrade-Souza YM, Schwalb JM, Hamani C, Eltahawy H, Hoque T, Saint-Cyr J, Lozano AM: Comparison of three methods of targeting the subthalamic nucleus for chronic stimulation in Parkinson's disease. *Neurosurgery* 56(2 Suppl): 360-368, 2005
- 2) Azmi H, Machado A, Deogaonkar M, Rezai A: Intracranial air correlates with preoperative cerebral atrophy and stereotactic error during bilateral STN DBS surgery for Parkinson's disease. *Stereotact Funct Neurosurg* 89: 246-252, 2011
- 3) Burkett CJ, Patel S, Tabor MH, Padhya T, Vale FL: Polyethylene glycol (PEG) hydrogel dural sealant and collagen dural graft matrix in transsphenoidal pituitary surgery for prevention of postoperative cerebrospinal fluid leaks. *J Clin Neurosci* 18: 1513-1517, 2011
- 4) Chang EF, Cheng JS, Richardson RM, Lee C, Starr PA, Larson PS: Incidence and management of venous air embolisms during awake deep brain stimulation surgery in a large clinical series. *Stereotact Funct Neurosurg* 89: 76-82, 2011
- 5) Coenen VA, Abdel-Rahman A, McMaster J, Bogod N, Honey CR: Minimizing brain shift during functional neurosurgical procedures—a simple burr hole technique that can decrease CSF loss and intracranial air. *Cent Eur Neurosurg* 72: 181-185, 2011
- 6) Cosgrove GR, Delashaw JB, Grotenhuis JA, Tew JM, Van Loveren H, Spetzler RF, Payner T, Rosseau G, Shaffrey ME, Hopkins LN, Byrne R, Norbash A: Safe-

- ty and efficacy of a novel polyethylene glycol hydrogel sealant for watertight dural repair. *J Neurosurg* 106: 52-58, 2007
- 7) Derrey S, Lefaucheur R, Proust F, Chastan N, Leveque S, Gerardin E, Freger P, Maltete D: The unsuccessful placement of a deep brain stimulation electrode due to a brain shift induced by air invasion: case report. *Parkinsonism Relat Disord* 17: 393-394, 2011
- 8) Elias WJ, Fu KM, Frysinger RC: Cortical and subcortical brain shift during stereotactic procedures. *J Neurosurg* 107: 983-988, 2007
- 9) Hooper AK, Okun MS, Foote KD, Haq IU, Fernandez HH, Hegland D, Robicsek SA: Venous air embolism in deep brain stimulation. *Stereotact Funct Neurosurg* 87: 25-30, 2009
- 10) Kim KD, Wright NM: Polyethylene glycol hydrogel spinal sealant (DuraSeal Spinal Sealant) as an adjunct to sutured dural repair in the spine: results of a prospective, multicenter, randomized controlled study. *Spine (Phila Pa 1976)* 36: 1906-1912, 2011
- 11) Kumar R, Goyal V, Chauhan RS: Venous air embolism during microelectrode recording in deep brain stimulation surgery in an awake supine patient. *Br J Neurosurg* 23: 446-448, 2009
- 12) Miyagi Y, Shima F, Sasaki T: Brain shift: an error factor during implantation of deep brain stimulation electrodes. *J Neurosurg* 107: 989-997, 2007
- 13) Moitra V, Permut TA, Penn RM, Roth S: Venous air embolism in an awake patient undergoing placement of deep brain stimulators. *J Neurosurg Anesthesiol* 16: 321-322, 2004
- 14) Nazzaro JM, Lyons KE, Honea RA, Mayo MS, Cook-Wiens G, Harsha A, Burns JM, Pahwa R: Head positioning and risk of pneumocephalus, air embolism, and hemorrhage during subthalamic deep brain stimulation surgery. *Acta Neurochir (Wien)* 152: 2047-2052, 2010
- 15) Patel NK, Heywood P, O'Sullivan K, Love S, Gill SS: MRI-directed subthalamic nucleus surgery for Parkinson's disease. *Stereotact Funct Neurosurg* 78: 132-145, 2002
- 16) Petersen EA, Holl EM, Martinez-Torres I, Foltynie T, Limousin P, Hariz MI, Zrinzo L: Minimizing brain shift in stereotactic functional neurosurgery. *Neurosurgery* 67(3 Suppl Operative): ons213-ons221, 2010
- 17) Than KD, Baird CJ, Olivi A: Polyethylene glycol hydrogel dural sealant may reduce incisional cerebrospinal fluid leak after posterior fossa surgery. *Neurosurgery* 63(1 Suppl 1): ONS182-ONS187, 2008
- 18) Umemura A, Oka Y, Yamamoto K, Okita K, Matsukawa N, Yamada K: Complications of subthalamic nucleus stimulation in Parkinson's disease. *Neurol Med Chir (Tokyo)* 51: 749-755, 2011
- 19) van den Munckhof P, Contarino MF, Bour LJ, Speelman JD, de Bie RM, Schuurman PR: Postoperative curving and upward displacement of deep brain stimulation electrodes caused by brain shift. Neu-

- rosurgery 67: 49–54, 2010
- 20) Videnovic A, Metman LV: Deep brain stimulation for Parkinson's disease: prevalence of adverse events and need for standardized reporting. *Mov Disord* 23: 343–349, 2008
- 21) Voges J, Hilker R, Bötzel K, Kiening KL, Kloss M, Kupsch A, Schnitzler A, Schneider GH, Steude U, Deuschl G, Pinski MO: Thirty days complication rate following surgery performed for deep-brain-stimulation. *Mov Disord* 22: 1486–1489, 2007
- 22) Weinstein JS, Liu KC, Delashaw JB Jr, Burchiel KJ, van Loveren HR, Vale FL, Agazzi S, Greenberg MS, Smith DA, Tew J Jr: The safety and effectiveness of a dural sealant system for use with nonautologous duraplasty materials. *J Neurosurg* 112: 428–433, 2010
- 23) Winkler D, Tittgemeyer M, Schwarz J, Preul C, Strecker K, Meixensberger J: The first evaluation of brain shift during functional neurosurgery by deformation field analysis. *J Neurol Neurosurg Psychiatry* 76: 1161–1163, 2005
- 24) Zonenshayn M, Sterio D, Kelly PJ, Rezai AR, Beric A: Location of the active contact within the subthalamic nucleus (STN) in the treatment of idiopathic Parkinson's disease. *Surg Neurol* 62: 216–226, 2004

Address reprint requests to: Ichiro Takumi, MD, PhD, Department of Neurosurgery, Nippon Medical School Musashi Kosugi Hospital, 1-396 Kosugi-cho, Nakahara-ku, Kawasaki, Kanagawa 211-8533, Japan. e-mail: takumi@nms.ac.jp