Dural sinus arteriovenous fistulas are rare vascular lesions, and their symptoms vary depending on their location and venous drainage route.1,3,5 Cavernous sinus DAVFs are a type of DAVF in which the branches of the ECA and/or ICA communicate with the CS.

Clinically, CSDAVFs are known to cause several ocular symptoms such as bruit, blurred vision, exophthalmos, chemosis, and diplopia. Although these symptoms are spontaneously resolved in most cases in which the CSDAVF is a low-flow shunt, a more rapid therapeutic intervention may be required in some cases to prevent loss of vision from increased IOP or reduced ocular perfusion pressure.22,26,30

Management of CSDAVFs includes observation, manual compression, microsurgery, endovascular embolization, and radiosurgery. Among these treatment modalities, endovascular embolization has been a popular choice because of its prompt effect and high cure rates.30,15,32 However, recanalization from an embolized fistula, failure of access to the lesion, and other complications associated with endovascular embolization may necessitate additional therapy.

We present our experiences with GKS for the treatment of low-flow CSDAVFs with no cortical venous drainage.

**Methods**

**Patient Population**

Between May 1992 and March 2009, 4123 GKS pro-
cures were performed at our institution (4045 at Severance Hospital and 78 at Wonju Christian Hospital), and 890 vascular lesions (870 at Severance Hospital and 20 at Wonju Christian Hospital) were treated. There were 24 cases of DAVFs, 6 of which involved the cavernous sinus. One of these 6 cases was lost to follow-up, and thus only 5 cases (consisting of 4 women and 1 man) were included in this study. In all patients, the CSDAVF was confirmed by conventional angiography. All of the lesions were Type D, according to the classification of Barrow et al., with no cortical venous drainage. The ages of the patients at the time of GKS ranged from 50 to 73 years (mean age 62.4 years). All patients had 1 or more ocular symptoms. None of them had head trauma or a pertinent medical history before the development of these symptoms. Gamma Knife surgery was performed 5 days to 10 months after onset of the ocular symptoms. The patients’ clinical characteristics and the treatment data are presented in Table 1.

**Treatment Modalities Other Than GKS**

All patients underwent manual carotid compression for a certain period of time, but their ocular symptoms were not improved.

Three of the patients were selected to be treated with GKS alone, because a tortuous arterial route and inaccessible venous route precluded endovascular embolization. The other 2 patients underwent transarterial embolization, which produced partial obliteration of the CSDAVF prior to GKS. In 1 case, GKS was performed as a separate additional treatment of the residual CSDAVF due to a delay caused by referral from another department. In the other case, embolization was performed on the same day as GKS, after the Leksell stereotactic head frame had been mounted, so that preembolization angiograms could be used for GKS targeting.

**Targeting and Parameters**

Stereotactic MR imaging and stereotactic angiography were used for GKS targeting. The cavernous sinus wall, including the lateral and inferior walls supplied by multiple feeders from the ECA, was delineated for targeting, and adjacent radiosensitive structures, such as the optic apparatus and brainstem, were sufficiently distant from the 50% isodose line and thus were exposed to less than 8.5 Gy. The median volume of the lesions treated was 1.7 cm³ (range 0.24–4.7 cm³). The treatment was performed using multiple isocenters (mean 11.8, range 1–22 isocenters) with 4- and 8-mm collimators to improve conformity. The prescribed median dose to the target margin was 20 Gy (range 16–20 Gy) at the 50% isodose line.

**Follow-Up Monitoring**

All 5 patients were observed over time at out-patient clinic visits. Magnetic resonance imaging or MR angiography, CT angiography, and/or conventional angiography were performed when the patient noted improvement of ocular symptoms or when an adverse radiation effect was suspected. The median clinical follow-up period was 30 months after GKS (range 9–59 months).

**Results**

The median follow-up period in this group of patients was 30 months. In some cases, the patients’ ocular symptoms began to improve as early as 4 weeks after GKS, and it took an average of 20 weeks (range 12–24 weeks) for the ocular symptoms to fully disappear. Two patients received embolization before GKS but did not exhibit improvement in ocular symptoms. The intervals between embolization and GKS in Cases 3 and 5 were 8 and 1 days, respectively. In Cases 1 and 2, conventional angiography was used for follow-up after GKS, and the findings documented total obliteration of the CSDAVF. There were no complications during the follow-up period related to either GKS or embolization.

**Illustrative Cases**

**Case 4**

**Examination.** This 73-year-old woman, with no history of head trauma or surgical operation, presented with abrupt onset of ptosis, chemosis, exophthalmos, and EOM palsy in her left eye, which lasted approximately 7 days. When she was examined by an ophthalmologist, her IOP was 39 mm Hg on the left side. She was referred to our neurosurgical department. The bruit on the left orbit could be auscultated by a stethoscope. Computed tomography angiography showed widening of the cavernous sinus on

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**TABLE 1: Characteristics of 5 cases of CSDAVF***

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Barrow Type</th>
<th>Symptoms Associated w/ CSDAVF</th>
<th>Margin/Maximal Dose (Gy)</th>
<th>Total Vol (mm³) of CSDAVF</th>
<th>FU (mos)</th>
<th>FU Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50, F</td>
<td>D</td>
<td>tinnitus, chemosis</td>
<td>16/32</td>
<td>170.0</td>
<td>59</td>
<td>MRI, MRA, DSA</td>
</tr>
<tr>
<td>2</td>
<td>69, F</td>
<td>D</td>
<td>headache, chemosis</td>
<td>20/40</td>
<td>52.0</td>
<td>47</td>
<td>MRI, MRA, DSA</td>
</tr>
<tr>
<td>3†</td>
<td>53, F</td>
<td>D</td>
<td>chemosis, exophthalmos, EOM palsy</td>
<td>18/36</td>
<td>240.0</td>
<td>30</td>
<td>MRI, MRA</td>
</tr>
<tr>
<td>4</td>
<td>73, F</td>
<td>D</td>
<td>chemosis, exophthalmos, EOM palsy</td>
<td>20/40</td>
<td>4700.0</td>
<td>14</td>
<td>MRI, CTA</td>
</tr>
<tr>
<td>5†</td>
<td>67, M</td>
<td>D</td>
<td>chemosis, exophthalmos, EOM palsy</td>
<td>20/40</td>
<td>2700.0</td>
<td>9</td>
<td>MRI, CTA</td>
</tr>
</tbody>
</table>

* CTA = computed tomography angiography; DSA = digital subtraction angiography; FU = follow-up; MRA = magnetic resonance angiography.
† Endovascular embolization preceded GKS.
Gamma Knife surgery for CSDAVFs

the patient’s left side with an engorged SOV. Convention- 
al angiography was performed to explore the possibility 
of embolization. Because of the patient’s tortuous carotid 
artery, ICA, and ECA, however, endovascular emboliza- 
tion via an arterial route was not an option.

**Gamma Knife Surgery.** Gamma Knife surgery was 
chosen as the primary treatment modality in this case. 
The delineated volume of the target was 4.7 cm³, and the 
prescribed dose to the margin was 20 Gy at the 50% iso-
dose line (Fig. 1).

**Posttreatment Course.** After GKS, the patient’s IOP 
was measured weekly. Four weeks after the procedure, 
her IOP decreased to less than 20 mm Hg and stayed 
within the normal range thereafter. The patient’s ex- 
ophthalmos improved accordingly (Fig. 2). The rest of 
her ocular symptoms were resolved approximately 12 
weeks after GKS. When the patient’s clinical symptoms became 
stable, a CT scan showed normalization of the prominent 
SOV (Fig. 3). There was no evidence of CSDAVF recurrence 
or other instance of morbidity after GKS during the 
follow-up period.

**Case 5**

**Examination.** This 67-year-old man, with no his-
tory of head trauma or surgical operation, was referred 
from the Department of Ophthalmology because of EOM 
palsy, chemosis, and exophthalmos. The patient’s right-
sided diplopia on lateral gaze had developed 2 weeks 
previously, and he reported having experienced vertical 
diplopia approximately 6 months earlier, which resolved 
spontaneously. Computed tomography angiography re-
vealed a slightly engorged SOV, and thus conventional 
angiography was performed. A Barrow Type D CSDAVF 
was confirmed, and embolization was planned. However, 
the neuroendovascular radiologist stated that an aggres-
sive endovascular embolization could result in blindness 
during the procedure because the feeder vessels were too 
small. We therefore planned a combined treatment of em-
bolization and GKS.

**Embolization and GKS.** A Leksell stereotactic frame 
was mounted on the head of the patient, and conventional 
angiography was performed after T1- and T2-weighted 
MR images had been obtained. After the preembolization 
angiograms had been sent to the GKS planning worksta-
tion to delineate the target, embolization was partially 
performed but did not improve the patient’s ocular symp-
toms. Gamma Knife surgery was then performed. The 
delineated volume of the target was 2.7 cm³, and the pre-
scribed dose to the margin was 20 Gy at the 50% isodose 
line.

**Posttreatment Course.** The patient’s ocular symptoms, 
especially the diplopia on lateral gaze, gradually became 
normalized over approximately 24 weeks after GKS. 
There was no CSDAF recurrence or other incidence of 
morbidity during the follow-up period (Fig. 4).

**Discussion**

Cavernous sinus DAVFs are abnormal communica-
tions between the branches of the ECA and/or ICA and 
the CS. Barrow et al. classified these malformations into 
4 types based on angiographic findings: Type A fistulas 
are direct shunts between the ICA and the CS; Type B are 
dural shunts between the meningeal branches of the ICA 
and the CS; Type C are dural shunts between the menin-
and these symptoms include chemosis, bruit, exophthalmos, and cranial nerve palsies (affecting cranial nerves III, IV, V, and VI). Also, loss of vision may occur and be caused by increased IOP or reduced ocular perfusion pressure.

There are various treatment modalities for CSDAVF, including observation, intermittent manual compression, microsurgery, transarterial or transvenous embolization, stereotactic radiosurgery, and combined therapies. Among these options, transvenous embolization is the most popular treatment modality when the CSDAVF causes visual deterioration or intolerable ocular symptoms, cosmetic disfigurement, or angiography-documented cortical venous drainage, which could cause intracranial hemorrhage or infarction.

Gamma Knife surgery has been chosen as a combined or additional therapy to embolization and, only in a few cases, as a first-line therapy when there is a failure of access to embolize fistulas. In our 5 cases, all of the CSDAVFs were Type D fistulas with no cortical venous drainage, and the patients displayed various ocular symptoms. In 3 cases, GKS was selected as the first-line therapy as an alternative to embolization. In the other 2 cases, GKS was selected as an additional or combined therapy. When GKS was used in combination with embolization, as in Case 5, the target was delineated based on findings of preembolization angiography, which was performed after fixation of the Leksell frame. The rationale for using preembolization angiography is to avoid delivering radiation to only part of the target, which could occur if, after embolization, the temporarily occluded region was omitted from the GKS target plan, which could lead to subsequent recanalization of the CSDAVF. By using preembolization angiograms in the radiosurgical treatment plan, the entire target was covered.

All 5 patients improved clinically, and the success
of their treatment was supported by findings on MR imaging or MR angiography, CT angiography, and/or conventional angiography. It is well known that CSDAVFs display a much faster response to GKS than DAVFs that drain to sinuses other than the CS. Clinical improvements after GKS are known to occur as early as 2 months after the procedure.2,18,20,29 The report of the largest study of intracranial DAVFs treated by GKS, published by Wu et al.,31 demonstrated that symptom improvement occurred as early as 6 weeks after GKS. In our Case 4, a change in IOP was noted after GKS; at 4 weeks after the procedure, the patient’s IOP had decreased to normal range, where it remained throughout the follow-up period. Ocular symptoms in our patients were relieved after a mean of 17.6 weeks. This prompt response of CSDAVFs to GKS may be because they are smaller than other AVMs of the brain and 3 types of CSDAVFs are low-flow shunts.

The angiography-documented obliteration rate after GKS as a first-line treatment was 75% in the study conducted by Wu et al.,31 and 91% in the study by Barcia-Salorio et al.2 In 20 cases of CSDAVFs, Pollock et al.23 reported a clinical improvement rate of 95% (19 of 20 patients) and an angiography-documented complete obliteration rate of 87% (13 of 15 patients); in 1 patient, near-total obliteration of a CSDAVF produced clinical silence for 33 months. Although there is a disparity between angiographic evidence of obliteration and an improvement in clinical symptoms, not all CSDAVFs should be observed using conventional angiography after GKS. Because there has been no report of recanalization of a DAVF or other AVM shown to be obliterated on angiography after GKS alone,28 and because the ocular symptoms caused by CSDAVF are easily recognized by the patient, follow-up after GKS can be done using noninvasive studies such as CT angiography or MR angiography, unless the CSDAVF has cortical venous drainage.

In their 4-patient series, Onizuka et al.30 reported that their lowest effective dose (a margin dose of 13–15 Gy) resulted in symptom and angiographic improvements in all cases during a mean follow-up of 24 months (range 14–32 months). In our cases, we prescribed a margin dose that was higher than 18 Gy except in 1 case (range 16–20 Gy). According to other published papers about GKS for treating CSDAVFs, a high dose (margin dose > 18 Gy) resulted in more than a 72% rate of occlusion throughout variable follow-up periods.2,4,7,9,14,21,23,31 Such a high radiation dose is very similar to that used elsewhere in GKS to treat AVMs.6 The use of a high dose in the treatment of CSDAVFs is to ensure delivery of an adequate radiation dose to the target. The adverse radiation effect is not a concern in such cases, because the target is usually sufficiently distant from radiosensitive structures. The CS region (in and around the CS and parasellar region) contains cranial nerves III, IV, V (branches V1 and V2), and VI, and it is close to the optic nerves and chiasm. Among these cranial nerves, the optic apparatus is known to be sensitive to radiation. Although less than 10 Gy is recommended, there is no clear dose limit to these structures; the volume of exposed nerve should also be considered.11,13,17 In our study, when a high radiation dose was delivered to the delineated target, with or without plugging, the optic apparatus was exposed to less than 8.5 Gy. No radiation injuries were identified during our patients’ follow-up periods.

Although there have been no reports of trigeminal dysfunction or arterial occlusion or stenosis after high-dose GKS for CSDAVFs, worsening or new trigeminal dysfunction and ICA occlusion or stenosis have been described after GKS for cavernous sinus meningiomas, as a late complication that should not be ignored.7,24,25 Therefore, patients should be monitored for such late adverse symptoms over long periods to establish the effect of a high radiation dose for CSDAVF despite good early results.

Generally, GKS is selected for the treatment of CSDAVF as an additional method to treat residual fistulas after embolization or as a combined therapy with embolization.2,4,7,9,14,20,21,23,31 Gamma Knife surgery alone is chosen in selected cases, such as those in which the shunts are low flow (Barrow Types B, C, and D) without cortical venous drainage. Wu et al.31 treated 146 cases of CSDAVF with GKS alone, and the cases they treated included Cognard Types I, IIa, IIb, and IIa+b with retrograde drainage of the sinus into a cortical vein. Those
authors presented 2 cases of intracerebral hemorrhages and 9 cases of SOV thrombosis. Although a thrombotic SOV can be recanalized and transiently worsened ocular symptoms can improve, the presence of central retinal vein occlusion in addition to SOV thrombosis is a critical finding that could result in permanent visual impairment.\textsuperscript{12,27} Unlike embolization, GKS for CSDAVF is accompanied by a variable latency period until symptoms improve. During this post-GKS latency period, the critical complications mentioned earlier could occur before the symptoms improve. Although endovascular embolization has immediate results, with success rates around 90\%, multiple embolization procedures can be required and can be accompanied by a high rate of complications (up to 25\% in difficult cases), which can be either transient or permanent.\textsuperscript{10,19,32} Therefore, in cases of low-flow CSDAVFs, combined therapy, consisting of vigorous embolization with the stereotactic frame mounted and GKS, could be ideal for immediate improvement in symptoms and for lessening the risk of recurrence from recanalization after embolization.

**Conclusions**

Gamma Knife surgery should be considered as a primary, combined, or additional treatment option for CSDAVF in selected cases, such as those in which the lesion is a low-flow shunt and there is no cortical venous drainage. For those selected cases, GKS alone may suffice as the primary treatment method when combined with close monitoring of ocular symptoms and IOP.

**Disclosure**

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