A comparison of the gamma knife model C and the Automatic Positioning System with Leksell model B

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Object. The authors sought to compare the quality of treatment planning, radiation protection, and the time taken for treatment in the Leksell gamma knife model B with that using the model C Automatic Positioning System (APS).

Methods. Data were obtained in 463 patients treated with the B model and 518 patients treated with the C model. Data were analyzed in patients in whom the following diagnoses had been made: vestibular schwannoma, pituitary adenoma, meningioma, solitary metastasis, and other benign and malignant solitary tumors. Patients with arteriovenous malformations, ocular lesions, and functional diagnoses were excluded from this study.

Conclusions. With the C model there was a better conformity for most treated targets, such as vestibular schwannomas (p = 0.005) and meningiomas (p = 0.015). The level of radiation exposures to personnel was significantly decreased when using the model C (p < 0.001). There was no significant difference in radiation exposure of extracranial structures for the same number of shots in patients treated by both models. The mean time saved using the C model with the APS was 41 minutes per treatment. It would seem that the gamma knife model C permits better dose conformity, shorter treatment times, and less radiation exposure to personnel.

Key Words • stereotactic radiosurgery • conformity index • staff exposure • extracranial exposure

Stereotactic radiosurgery is based on the precise delivery of a high radiation dose to a small well-defined and well-localized intracranial target volume. Prior to the development of the latest Leksell gamma knife, the C model, positioning the patient in the machine during treatment has been carried out manually. The C model is equipped with an APS. The APS is a robot that moves the patient’s head by using motors from the position of one isocenter to the next without the intervention of the treating personnel in the treatment room. With previous models the treatment staff had to enter the treatment room between each isocenter and set the next isocenter manually. This is a time-consuming procedure.

The aim of this study was to compare the model C and APS unit with the previous model B, particularly to compare advantages and disadvantages of both models.

Quality of Treatment Planning

The aim of stereotactic radiosurgery is to design and implement a treatment plan in which the prescription isodose line covers the target with a minimal excess volume and a sharp dose fall off outside the target volume. Gamma knife surgery involves the use of four collimator helmets with beams of different diameters. The use of smaller beams and many isocenters improves the conformity between the radiation dose and the target volume.

Conformity indices are often used to compare treatment plans, evaluate treatment techniques, and assess clinical complication. The conformity index should be an objective measure of how well the distribution of radiation conforms to the shape of the radiosurgical target.

Radiation Protection and Safety

In any system in which patients are treated using ionizing radiation, it is important to minimize the radiation dose outside the target to be treated in the patient. It is also important to minimize the dose to the personnel performing the treatment. Part of this study was designed to measure radiation exposures to the staff as well as extracranial doses to the patient. In theory the use of more isocenters could increase the total treatment time and thus burden patient and staff with extra doses outside the target. Despite this, because the APS minimizes the time spent by the staff in the treatment room, the effect of increasing the number of isocenters should be more than offset by the use of the APS, which minimizes the time spent by the personnel in the treatment room.

Treatment Duration

It is known that the APS reduces the time required to set stereotactic coordinates for each isocenter. An attempt was made to quantify just how much time is saved for each treatment procedure by performing GKS with the model C and APS unit.
Clinical Material and Methods

Data were obtained in 463 patients undergoing GKS with the model B and 518 patients undergoing GKS with the model C between 1999 and 2003.

Data obtained in patients with the following diagnoses were analyzed: vestibular schwannomas, pituitary adenomas, meningiomas, solitary metastases, and other benign and malignant solitary tumors. Because it is difficult to define the volume of an arteriovenous malformation with precision this diagnosis was excluded. Patients with ocular lesions are treated in the prone position (and thus in trun- nion mode) and functional treatments usually involve the use of a single shot, so these diagnoses were excluded from this study.

The following factors were studied to compare treatment conformity: target volume (TV), prescription isodose volume (PIV), target volume covered by prescription isodose (TVPIV), brain integral dose, tumor integral dose, and number of isocenters. Conformity index (CIx) was defined according to Paddick as $\text{CIx} = \frac{\text{TV}_{\text{PIV}}}{\text{TV} \times \text{PIV}}$. To achieve a perfect conformity according this definition the plan would have CIx = 1.0.

Radiation exposure to personnel has been monitored with film badge dosimeters over a period of 1 month, according to national radiation safety regulations. Average monthly exposures were calculated for four members of the staff who were performing the majority of GKS treatments and compared for both models.

Data related to exposure of extracranial structures in patients included measurements of absorbed doses in eyes, thyroid, breast, abdomen, gonads, knee, and ankle. Extracranial radiation was measured in 51 and 200 patients by thermoluminescent dosimeters for the aforementioned structures for both the model B and model C. All measurements were performed in adult patients. Measurements for model B were made in another study in which detailed information about thermoluminescent measurements can be found.

The total time for setting the isocenter position for each isocenter was evaluated in both models. The data on which calculations were based are shown in Table 1. The clearance test mentioned in that table refers to a special test performed in the APS. The system checks that no collision occurs between the stereotactic frame or the patient’s head and the helmet containing the collimators. If the treatment planning system calculates that any component of the frame or head is 12 mm or less from the helmet, that isocenter is marked as at risk for collision. Before a treatment is started, the system checks that each of these positions is in fact achievable. This check is called the clearance test. When necessary it is performed just once at the beginning of any given treatment. The time necessary for changing collimator helmets is not included and is supposed to be approximately the same in both models. The irradiation time was also excluded from these calculations because it is the same for both models. Thus, these calculations are independent of the total activity of the cobalt-60 sources. Only the time required for setting the isocenter coordinates was compared.

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**TABLE 1**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration (mins)</th>
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<tr>
<td>Import file</td>
<td>Model B</td>
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<tr>
<td></td>
<td>1.9</td>
</tr>
<tr>
<td>Position test/clearance test</td>
<td>2.9</td>
</tr>
<tr>
<td>Setting coordinates</td>
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</tr>
<tr>
<td>Fixation of patient</td>
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</tr>
<tr>
<td>Couch in</td>
<td>1</td>
</tr>
<tr>
<td>Couch out</td>
<td>1</td>
</tr>
</tbody>
</table>

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**Fig. 1.** Graphs showing conformity indices for different diagnoses evaluated in this study. The difference was significant for vestibular schwannomas ($p = 0.005$) and meningiomas ($p = 0.015$).

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Results

Quality of Treatment Planning

The conformity was better with the use of the model C unit. For vestibular schwannomas the significance of this difference was $p = 0.005$ and for meningiomas it was $p = 0.015$. Results of the statistical analyses are given in Fig. 1.

Radiation Protection and Safety

Despite the use of more isocenters with smaller collimators (frequently 4 and 8 mm), no significantly higher extracranial exposure could be recorded in patients being treated with the model C and APS unit. Comparisons of doses received by the eyes, thyroid, breast, and gonads are shown in Fig. 2. The higher number of shots did increase the total integral brain dose. Comparisons of the number of shots and brain integral doses between models B and C are given in Figs. 3 and 4. The frequency of the collimators used in the two models is compared in Fig. 5. Radiation exposure in staff were significantly ($p < 0.001$) decreased when using the model C (Table 2).

Time Required for the Treatment

The mean savings in treatment time in this study was 41 minutes when using the C model compared with the B model.

Discussion

In this study we noted an improvement in conformity indices, which indicates how well the prescription isodose is fitted to the target volume. These indices were significantly better for vestibular schwannomas and meningiomas; however, the improved conformity was not significant for either pituitary adenomas or solitary metastases. In the case of pituitary adenomas, conformity below the lesion is often sacrificed to ensure that the tumor is adequately covered by the prescription dose while no damage is done to the optic pathways or brainstem, respectively, above and behind the lesion. Only bone and air in the sphenoid sinus lie below the tumor, and conformity in this location is considered less important. In the case of metastases conformity is deliberately allowed to be less because there can be tumor cells lying outside the target that are not clearly visible on MR images. Thus a small rim of surrounding brain is included in the dose plan.

Despite the frequent need for a larger number of 4- and 8-mm collimators in treatment plans involving the use of the APS it has been shown that there is not significantly higher radiation burden to extracranial structures. The extracranial doses increase in relation to the number of shots according to a linear relationship; thus, increasing the number of shots unnecessarily should be avoided, especially in...
cases in which long-term survival is expected. An excessive number of shots can induce depilation of the patient’s hair, as has been shown after a patient has undergone GKS in which a very large number of shots has been used. To optimize treatment time, it is suggested that larger collimators for large simple targets are preferred as this will minimize the total number of shots and therefore the total treatment time.

The APS in this study would certainly seem to convey a benefit to the staff in terms of radiation exposure. Finally, the significant savings of time during a GKS procedure brings benefits to the patients and the staff.

Conclusions

It would appear that the model C with APS provides a better quality of treatment with better dose conformity, shorter treatment time, and less exposure of the staff to radiation.

TABLE 2

<table>
<thead>
<tr>
<th>No. of Patients (yr of treatment)</th>
<th>Collective Effective Dose</th>
<th>model B</th>
<th>model C</th>
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<tbody>
<tr>
<td>770 (2002)</td>
<td></td>
<td>—</td>
<td>0.83 mSv</td>
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<tr>
<td>735 (2001)</td>
<td>3.67 mSv</td>
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References


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