Stereotactic Radiosurgery Using a Linear Accelerator

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Abstract

A basic and clinical study of radiosurgery using the linear accelerator (Linac) system for unremovable deep-seated brain tumors is reported. A Komai stereotactic ring was used to locate the target coordinates. The patient was laid on the Linac treatment table and held in the head fixation system. Irradiation was given in five positions. The dose profile by film dosimetry and Rando phantom was satisfactory. Seventeen tumors in 14 patients were treated. Clinical or histological diagnoses were nine metastases, one benign and two malignant gliomas, one meningioma, and one craniopharyngioma. Tumor sizes were between 8 and 30 mm. Doses were between 12 and 30 Gy. Computed tomographic evaluation after 3 months of 12 tumors in 11 survivors showed one complete remission, three partial remission, six no change, and two partial deterioration. For progressive tumors, Linac radiosurgery results are excellent.

Key words: stereotactic radiosurgery, linear accelerator, metastasis

Introduction

Deep-seated gliomas or metastatic tumors impossible to remove surgically are normally treated by biopsy and external irradiation with or without chemotherapy. However, 50 or 60 Gy irradiation sometimes does not control tumor growth. Even if tumorostasis is achieved, regrowth starts after a short interval. Further irradiation carries a high risk of radiation necrosis in the surrounding brain tissue. The external and interstitial methods of stereotactic irradiation were therefore developed to deliver concentrated doses to deep-seated tumors. These methods allow greater doses to be delivered to the tumor without adversely affecting the surrounding normal structure. Current reliable external methods include Kjerberg's Bragg peak proton beam irradiation, the Leksell technique with multiple narrow 60Co beams, and convergent beam irradiation with a Linac. The last is more easily performed if a Linac is already available. Conventional irradiation can of course also be given.

Here, we report the use of Linac stereotactic irradiation to treat 17 tumors in our facility since July, 1990.

Materials and Methods

A Komai stereotactic head ring was attached to the patient’s head using four metal pins under local anesthesia. The patient was then laid supine or prone on the table with the head ring attached to a head ring mount. The edges of the head ring were aligned parallel to the scanning plane. Gauge plates were attached to both sides of the head ring. The coordinates of the isocenter of stereotactic irradiation were then calculated. The upper edge of the head ring could not be positioned caudally over 2.5 cm rostral to the orbitomeatal line. Coordinates of tumors below this position were calculated with the gauge plates reversed and the patient in the prone position. After the coordinates were calculated, the patient was transferred to the Linac room.

Stereotactic irradiation requires the target to coincide accurately with the isocenter of the rotating Linac arc. We used a head fixation system (Marui Medical Instrument Co., Tokyo) positioned at the rostral end of the treatment table (Fig. 1). The patient is positioned so that the stereotactic head ring can be fixed to this system by an aluminum plate 50 x 36 cm and an adaptor to the head ring. The
adaptor has three degrees of freedom using three manipulators, caudally, right, and left, and tilting in the caudal-rostral direction. This allows the target point to coincide with the Linac isocenter.

Before patient fixation, another Komai stereotactic ring was mounted on the adaptor to act as a phantom. The stereotactic arc and probe were set as in operation. The treatment table and the head adaptor were adjusted to position the probe tip at the Linac isocenter. The patient was then laid on the table with the head fixed. Distortion of the table by the patient required readjustment of the head position using the manipulators. The gauge plate used for calculating the target coordinates had no surface marker, so we used three cylindrical rods with gauges instead (Fig. 1). Rods were mounted on both sides of the head ring to act as the X-coordinate and one rod on the top of the head ring as the Y-coordinate. The rods were then extended as the Z-coordinate. Three laser beams were then projected onto the rods.

The patient was irradiated in five positions 40° apart around a vertical axis passing through the target (Fig. 2). The Linac (10 MeV; LMR-18A, Toshiba, Tokyo) was rotated around the patient's head in each position (Fig. 3). The Linac path between the head surface and the target was calculated every 15° of arc. These data were used to calculate the radiation dose. The 80% isodose curve coincided with the approximate border of the tumor. For supratentorial tumors, the Linac arc was 105° or 120°. The Linac arc for posterior fossa tumors was narrower than for rostral lesions.

Results

Calibrations were performed before clinical application. The accuracy of target coincidence with the Linac isocenter was checked in the five patient positions. The crossing point of the three laser beams was observed, but complete coincidence could not be obtained in the five positions. Therefore, the coincidence had to be checked in each patient position. The dose distribution was checked by the film dosimetry method. The dose distribution in the axial, coronal, and sagittal planes when coincidence
was achieved in the five positions shows a steep dose gradient toward the isocenter (Fig. 4). For example, when the field diameter was 2 cm, the 80% isodose curve diameter was 1.7 cm, and the 30% isodose curve diameter was 2.7 cm with spherical distribution. The dose distribution was also measured distally using a Rando phantom. This plastic head model has parallel slices, each carrying thermoluminescent dosimeters (TLDs) 3.5 cm apart. The phantom was attached to a stereotactic head ring and irradiated. The resultant dose distribution shows very low or negligible dose scattering (Fig. 5). The isodose gradient became flatter for tumors bigger than 3 cm, so our method is suitable for tumors up to 3 cm.

Seventeen tumors in 14 patients were treated between July, 1990 and June, 1991 (Table 1). Histological diagnoses were nine metastases, one benign and two malignant gliomas, one cranio-pharyngioma, and one meningioma. The tumor diameters were between 8 and 30 mm. Initially, 20 Gy was delivered at the tumor borders. However, after we experienced one recurrence, the dose was gradually increased to 30 Gy. An early radiation side effect was nausea within 1 week, which was controlled by steroids and hyperosmotic fluid infusion. Three patients who received irradiation to two metastatic

Fig. 3 A patient in the stereotactic head ring on the treatment couch. The Linac gantry is shown at the starting (upper) and final (lower) positions for the stereotactic irradiation.

Fig. 4 Dose profiles in the axial (left), coronal (center), and sagittal (right) planes measured by the film dosimetry method. Field size was $2 \times 2$ cm at the isocenter. A: anterior, F: foot, H: head, L: left, P: posterior, R: right.

Fig. 5 Dose distribution in remote areas measured by Rando phantom. A shaded TLD on the left of the slice was stereotactically irradiated. Dose scattering in remote areas was low.

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tumors of 1–2 cm diameter on the same day suffered reduced consciousness levels. Soon after irradiation, the original tumor regrew rapidly. Follow-up after 3 months found that three cases had died of the original tumors. In the 11 other cases, no delayed neurological deficit was observed. Computed tomography (CT) showed that complete remission occurred in one tumor, partial remission in three, partial deterioration in two, and no change in six which remained clinically stable. One metastatic tumor in the upper clivus evaluated as no change changed from radiolucent to radio-opaque after irradiation.

### Discussion

One purpose of stereotactic irradiation is to prevent radiation necrosis. Brain atrophy on CT scans or neurological deterioration often develops after irradiation. Postoperative irradiation of surface tumors requires only submaximal doses. However, deep-seated tumors not removed surgically require the maximal or greater radiation doses, and the risk of radiation necrosis becomes higher. Stereotactic irradiation can deliver a high dose to focal intracranial lesions such as tumors or arteriovenous malformations without affecting the surrounding normal structures. A greater dose can be delivered than by conventional methods.

Stereotactic irradiation includes both external and internal methods. Previously, we used interstitial irradiation with iridium-192 for 3 years. Catheters were placed stereotactically through the scalp in the operating room and the radioactive material afterloaded in a radiation treatment room. This method requires invasive procedures and may cause brain trauma along the intracranial catheter path. CT assessment of two low-grade gliomas, seven malignant gliomas, two metastatic tumors, and one malignant lymphoma showed complete remission in one case and partial remission in eight. However, postoperative transient neurological deficit appeared in five cases, and persisted in one for a long period. In our experience, the interstitial method is not as safe as previously considered. In contrast, the external method needs only scalp stab wounds for the stereotactic fixation pins.

We were attracted to stereotactic Linac irradiation because it is a non-traumatic procedure. We found that metastatic tumors responded to the localized irradiation well, and therefore started stereotactic Linac irradiation for relatively localized tumors such as metastatic or other small tumors. Our radiosurgical results for progressive tumors have been excellent. The method requires no remodeling of the conventional Linac system, only a head fixa-
tion apparatus. The gamma knife has a longer history as an external method and achieves a steeper isodose gradient. However, only a few hospitals can afford the extremely high cost. Also, the limited range of collimators (4, 8, 14, and 18 mm) make irradiating larger lesions difficult. The Linac method can use any size of collimator. Future development of computer technology and software will make the Linac method more effective.

The Linac method has been given various terminologies. Colombo et al.\textsuperscript{4,5} called it external stereotactic irradiation by Linac, Betti and Derechinsky\textsuperscript{6} used hyperselective encephalic irradiation with Linac, and Pastry et al.\textsuperscript{7} stereotactically guided convergent beam irradiation with a Linac. Recently, the term "stereotactic Linac radiosurgery"\textsuperscript{8} or "Linac radiosurgery"\textsuperscript{9} has become popular. The Leksell method is called "gamma knife radiosurgery."\textsuperscript{10}

Most hospitals performing Linac radiosurgery use the Brown-Roberts-Wells (BRW) stereotactic apparatus. Calculation of the target coordinates with BRW is more precise than with the Komai ring. We could not use BRW because the treatment table was not completely stable. The coincidence of the target with the Linac isocenter adjusted the phantom might be disturbed when the patient was laid on the treatment table or the table placed in a different position. The BRW apparatus does not allow adjustment of the target after the patient is loaded. The Komai apparatus also has advantages in locating lesions in the deep posterior fossa.

The patient may be placed on the treatment table in the sitting position, or, as we use, in the lying position. The former allows the patient to be rotated through 360° and the dose concentration steeper. However, patients with physical and neurological deterioration may not tolerate the sitting position, and the lying position is thought to be safer and applicable to more patients.

Various tumors including acoustic neurinoma, craniopharyngioma, and metastatic tumors have been treated radiosurgically. In our series, metastatic tumors were the most common. The treatment of metastases is controversial. Our policy is surgical removal and intraoperative irradiation for tumors near the surface even if multiple. Unremovable tumors are treated by fractionated Linac irradiation and are candidates for radiosurgery. Solitary deep-seated tumor and multiple (two or three) tumors can be treated. The use of radiosurgery for disseminated gliomas may also increase. These patients have limited survival, so radiosurgery over a short period is most suitable. Reported response rates are excellent.\textsuperscript{11,12}

The optimum dose for radiosurgery has not been established as in conventional fractionated irradiation. One reason is that the biological effect of radiosurgery is not so well understood. Radiation doses currently used adopt an 80% isodose line for metastatic tumor margins with total doses varying in the ranges 20-30,\textsuperscript{13} 15-20,\textsuperscript{14} 25,\textsuperscript{15} 12-46,\textsuperscript{16} and 15-30 Gy. In most cases, tumor growth ceased clinically and radiologically. Rich et al.\textsuperscript{16} found three cases of regrowth with 15 Gy which were reirradiated. Subsequently, they increased the mean radiation dose to 25 Gy. Initially, we prescribed 20 Gy, but recurrence occurred in one case. Since then, the radiation dose has been increased to 30 Gy. No major side effect has appeared up to now.

To increase the accuracy of focusing and dose concentration, we are planning to revise the treatment table and the head fixation apparatus to widen the Linac arc range. Several methods have been used previously. One minimizes the separation of the target point and Linac isocenter while rotating the table. The patient's head is attached to an independent stand fixed on the floor.\textsuperscript{17} In Florida, the Linac gantry is tightly connected with a collimator arm, achieving a beam accuracy of +0.2/−0.1 mm, equaling the accuracy of the gamma knife. An additional collimator at the Linac source is commonly used. Another method is to turn the treatment table continuously while rotating the Linac.\textsuperscript{18} In some hospitals, once the isocenter of the Linac and the target point coincide, the whole stereotactic irradiation procedure can be programmed automatically. The improvement of computer software now allows irradiation of various shaped tumors. We will continue efforts to improve our system.

References

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