Stereotactic Radiotherapy by 6MV Linear Accelerator

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Eight patients with intracranial tumors or arteriovenous malformation (AVM)s which were less than 3 cm in diameter were treated by a technique of stereotactic radiotherapy during the 4 months period from July 1988 through October 1988 at the Division of Radiation Therapy, Kang-Nam St. Mary's Hospital, Catholic University Medical College. The patients were diagnosed as AVMs in 3 cases, acoustic neurinoma, craniopharyngioma (recurrent), hemangioblastoma, pineocytoma, and pituitary microadenoma in each case. There are several important factors in this procedure, such as localization system, portal, field size, radiation dose, and perioperative supportive care. It is suggested that stereotactic radiotherapy may be performed safely with a radiation dose of 12-30 Gy. So this nonivasive procedure can be used to treat unresectable intracranial tumors or AVMs. Of these, clinical symptoms had been regressed in AVMs in 2 cases at 3 months and 2 months after Stereotactic radiotherapy, one of whom was confirmed slightly regressed on the follow-up angiogram. And also craniopharyngioma and pineocytoma was minimally regressed on 3 month follow-up CT.

Key Words: Intracranial tumors, Arteriovenous malformation, Linear accelerator, Stereotactic radiotherapy

INTRODUCTION

Stereotactic radiotherapy (radiosurgery) was defined by Leksell as a technique for the destruction of intracranial targets without opening the skull using high doses of ionizing radiation in stereotactically directed narrow beams in 1951[1]. The current definition is the use of a "single high dose of radiation to destroy an intracranial target or to induce in the target a certain biologic effect.

Radiosurgery is a one-session procedure, and the dose given in a single sitting is biologically equivalent to a three-fold higher fractionated dose. Radiosurgery has three advantages: (a) It is a completely bloodless procedure[2,3]. (b) The entire therapeutic radiation dose is delivered in a short time. (c) It is possible to target a lesion accurately and to prevent damage to nearby radiosensitive structures because of the steep dose gradient.

There are various techniques used for radiosurgery; intersecting beam irradiation with photons as well as protons, Bragg-peak irradiation, and $^{60}C_0$ gamma unit.

Considering there are few proton and gamma units in the world, whereas conventional X ray irradiation from a linear accelerator is widely available, the employment of X rays and modern moving field irradiation technique for radiosurgery appear very attractive and was described by Colombo in 1985[4].

The purpose of this paper is to report our experiences of stereotactic radiotherapy in 8 patients of intracranial tumors or AVMs using the linear accelerator.

MATERIALS AND METHODS

1. Patient Selection and Characteristics

The authors has performed stereotac c radiotherapy for patients with unresectable 5 intracranial tumors and 3 AVMs from July 1988 through October 1988 at the Division of Radiation Therapy, Kang-Nam St. Mary's Hospital, Catholic University Medical College.

The characteristics of these 8 patients are displayed as Table 1. The age ranged from 5 to 46 years of age (median age was 33 years). The male to female ratio was 5 to 3. AVM was the most

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frequent diagnosis. The diameter of lesions ranged from 0.2 to 3.0 cm (mean diameter was 1.7 cm).

2. The Principle

The technique is essentially based on the composition of multiple isocentric arc irradiations with small fields centered in the stereotactic target. A single arc is performed during the rotation of the radiation source around the target. Arcs are repeated while the patient is set in various angular positions around a vertical axis passing through the stereotactic target(Fig. 1).

Table 1. Patient Characteristics

Total number of patients 8		
Sex :	Male 5	
	Female 3	
Age range : 5–46 years (median ; 33 years)		
Diagnosis		
AVM		3
Acoustic neurinoma (bilateral)		1
Craniopharyngioma (recurrent)		1
Hemangioblastoma		1
Pineocytoma		1
Pituitary microadenoma		1
Diameter of lesion : 0.2–3.0 cm (mean : 1.7cm)		

3. The Physical and Dosimetric Considerations

The first step was to determine the radiation dose emitted by the linear accelerator. The measurements were carried out using a 0.5 cc PR-05 P ion chamber in conjuction with Capintec dosimeter for a reference field of 10x 10 cm in polyethylene phantoms

With our set-up, because of the mechanical restraints imposed by the head frame, the treatment couch, and beam-stopper. only arc irradiations with angles up to 50-180° in given plane were feasible.

4. Technique

1) The procedure was started by fixing the patient to the stereotactic apparatus.

2) Target localization was accomplished by stereotactic computed tomographic (CT) scans. Stereotactic coordinates were calculated from CT scans according to a computerized procedure, and then the profile of the head along the preset planes of irradiation was reconstructed from CT data(Fig. 2).

3) The profile of the head was used for calcula-

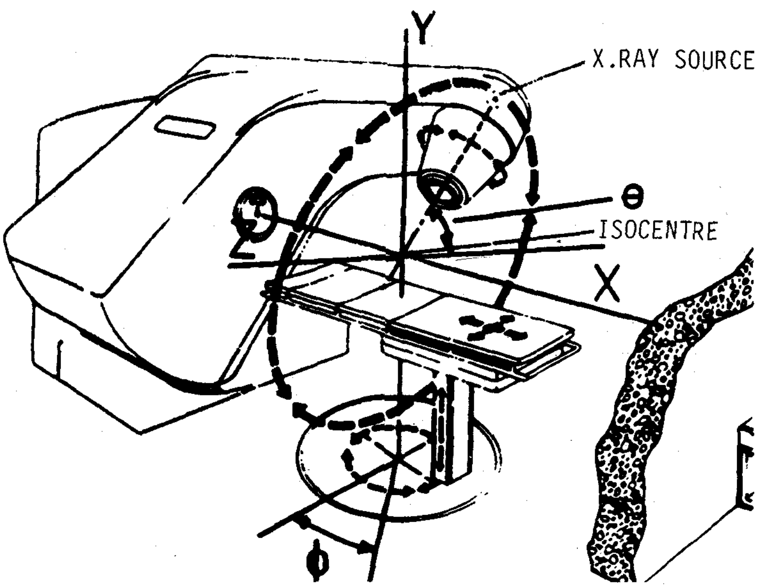

Fig. 1. Schematic illustration of the three dimensional cross fire irradiation. (From Leksell D.G., Special stereotactic techniques : stereotactic radiosurgery. In Stereotactic Neurosurgery edited by M. Peter Heilbrun, Williams & Wilkins. 1988).

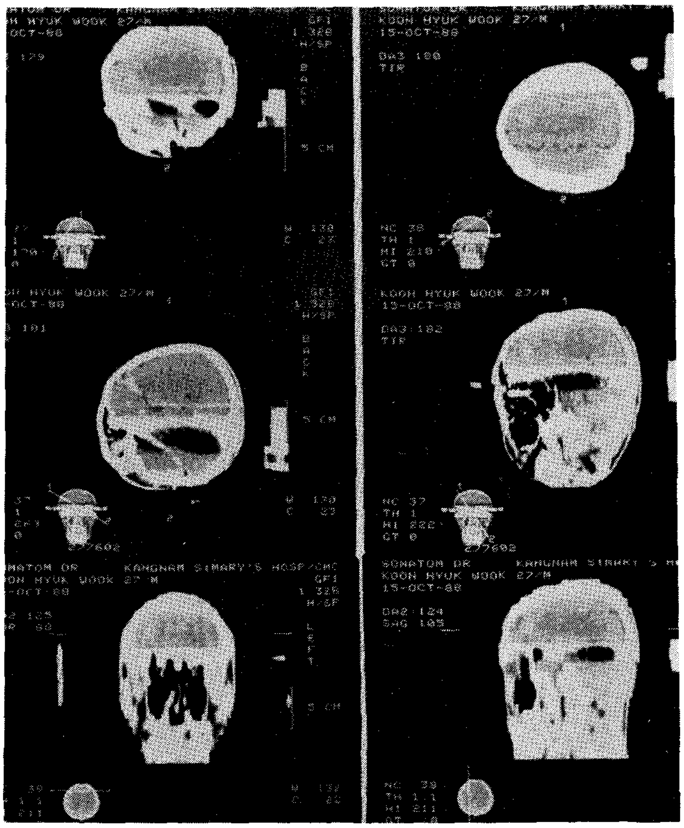

Fig. 2. The profile of the head along the preset planes of irradiation reconstructed from CT data.

tion of isodose distribution by computer. The total amount of dose emitted by the linear accelerator was determined to obtain the prescribed absorbed dose in the tumor volume. Field size was selected on the basis of the target volume determined during the stereotactic phase of the procedure. When the lesion was shown by reconstruction of the CT data to be roughly spherical or sheroidal, a single field size was selected to ensure that the 80% isodose curve will coincide with the approximate borders of the tumor. If the lesion was more irregularly shaped in stereoreconstruction, we varied the field size (fixed values for each arc). These field sizes were selected so that the 80% isodose curve would cover the variable cross section of the lesion, as determined from reconstruction of the tumor volume.

4) The patient was moved to the linear accelerator room. A head frame holder was mounted on the treatment couch of a 6 MV linear accelerator (NEC). The target was made to coincide with the isocenter of the linear accelerator.

5) The irradiation was performed by cross-fire to the target with narrow beams of photons. For cross-fire of beam to the target region the couch of linear accelerator was rotated a preselected number of degrees around a vertical axis passing through the target, and the arc irradiation was repeated on 6 to 7 planes distributed on a angle of 50° to 180°.

CLINICAL RESULTS

From July 1988 to October 1988, the technique was used on a series of 8 patients. Follow-up periods longer than 3 months were available only for the first 3 patients(Table 2). So the paper deals with the preliminary results.

Typically a whole procedure took 5 hours, and the irradiation only took 90 minutes including the

Table 2. Clinical Results in 8 Patients

Case	Age/ Sex	Symptom	Lesion	Diameter (cm)	Irradiation	Follow up	
1	10 M	Cbll Sx IICP	Cbll stem. AVM	2.3	30 Gy 7 arc 2 cm field	3mo.	Shrinkage Reression of Sx
2	5 F	Visual Sx. IICP	Craniopharyngioma	1.8	30 Gy 7 arc 2 cm field	3mo.	Min. Shrinkage Regression of Sx
3	32 M	IICP Parinaud's	Pineocytoms	2.0	25 Gy 7 arc 1 cm field	3mo.	Min. Shrinkage Regression of Sx
4	46 M	Headache Parinaud's	Venous Malformation	1.0	12 Gy. 7 arc 0.8 cm field	2mo.	Unchanged Regression of Sx
5	46 M	Headache	Hemangioblastoma	3.0	40 Gy. 7 arc 2 cm field	2wk.	Raised ICP Operated on
6	42 F	VIII n. sign	Bilateral Acoustic Tu	2.0	30 Gy. 6 arc 2x1.5 cm field	1mo.	Yot checked Improved hearing
7	27 M	Headache Epilepsy	Frontal Vascular Malformation	1.5	30 Gy. 7 arc 1.5x1 cm field	1mo.	Not checked Unchanged
8	34 F	Cushing's synd.	Pituitary Microadenoma	0.2	15 Gy. 7 arc 0.5 cm field	1mo.	Not checked Unchanegd

Cbll ; Cerebellum. Sx ; Symptom. IICP ; Increased intracranial presure. Min. ; Minimal. n. ; nerve. Tu ; Tumor. Synd. ; syndrome.

time for rotating the couch and rechecking the isocenter. All patients well tolerated the procedures of stereotactic radiotherapy. No untoward effects were noticed except one after this procedure. One patient (Case 5), was operated on 2 weeks after radiosurgery for increasing intracranial pressure.

1. AVMs and Vascular Tumor

Three patients affected by AVMs were treated with 12-30 Gy. The clinical symptom was regressed in two patients at 3 months. Follow-up angiography was checked in two patients, and showed slight regression of AVM in one patient(Fig. 3), and no change in the other.

One patient affected by hemangioblastoma who strongly refused operation was treated with 40 Gy. At two weeks after radiosurgery he complained of severe headache and was operated for increasing intracranial pressure.

2. Craniopharyngioma

One child was treated with 30 Gy for recurrent craniopharyngioma on eleven months after surgical removal. She showed improvement of the clinical picture and minimal shrinkage of the mass by follow-up CT scan at 3 months.

3. Pineocytoma

One patient was affected by tumor in the pineal region. A total dose of 2160 cGy was irradiated on the whole brain at other hospital. After whole brain irradiation, the follow-up CT scan was checked, and did not appear any regression of mass. At our hospital stereotactic biopsy was performed, and the pathologic disgnosis was pineocytoma. He was treated with 25 Gy by stereotactic radiotherapy. He showed improvement of the clinical picture, and minimal shrinkage of mass by follow-up CT scan at 3 months.

4. Acoustic Neurinoma

One patient with bilateral acoustic neurinoma was referred for radiosurgery. Left-sided tumor was treated because of its rapidly progressive nature and severe tinnitus. She was treated with 30 Gy, and showed improvement of hearing impairment at 1 moth after radiosurgery.

5. Pituitary Microadenoma

One patient with pituitary dependent Cushing's

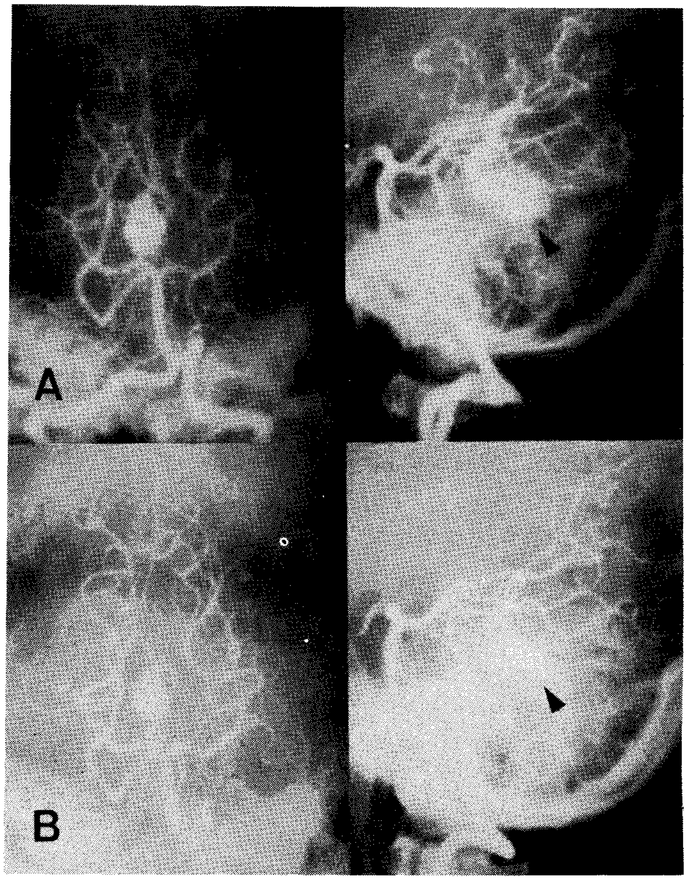

Fig. 3. Slight regression of arteriovenous malformation (A) at 3 months after stereotactic radiotherapy (B) ih Case 1.

disease was treated with 15 Gy(Fig. 4).

DISCUSSION

In 1951, the term radiation surgery (radiosurgery) was introduced by Leksell to describe a technique in which narrow beams are stereotactically focused onto a target within the brain in order to achieve a high dose of localized irradiation[1]. If the dose gradient is very steep at the edge of the volume chosen for irradiation, a single dose that is suffient to cause necrosis of the tissue volume selected can be administered. Therefore, the most important factor in radiation surgery is the physically determined concentration of the radiation on the target, in contrast to fractionated radiotherapy, which is based on difference in radiosensitivity between tumor cells and cells of the adjacent healthy tissue.

Since their introduction in clincal practice, radiosurgical procedure have been used for functional neurosurgery (chronic pain, psychiatric disorders, Parkinson's disease)[5], vascular neurosurgery (aneurysms, AVMs, carotid-cavernous fistulas)[2,3], and oncological surgery (acoustic neuromas, craniopharyngiomas, pituitary adenomas)[6,7].

To date two types of of radiation units have been specially designed for radiosurgery. These units use multiple external $^{60}C_0$ gamma sources or the advantageous beam characteristics of high energy protons[8].

In orginal Leksell methods, the patients is fixed to the stereotactic head frame and the target is localized by standard stereotactic technique. The head frame is then moved to the "gamma unit". The target is adjusted to the focal point and is cross

Fig. 4. Pituitary microadenoma (Case 8).

fired by 179 beams of gamma radiation generated by $^{60}C_0$ sources arranged on a spherical sector 70°×160° wide.

External irradiation with the "gamma unit" is extremely precise and sure, but requires complicated and dedicated equipment that is also very expensive. On the other hand, external stereotactic irradiation using a linear accelerator gives equivalent radiation and could be carried out whenever an isocentric linear accelerator is availabe. It would require only the construction of the head frame holder for the standard treamtment couch[4].

A single rotational irradiation does not fresult in a dose distribution with suffient steep dose gradients required for radiosurgery. Therefore, an improved irradiation method must be employed. Based on early investigations of moving field techniques, made up of a series of combinations of conventional moving field irradiations with differently rotated treatment table positions, while the radiation at each of these combinations is directed at the same isocenter point[9].

A localization system is an essential prerequisite for radiosurgery, because side effects of the single high dose irradiation can only be avoided or minimized if the area of tissue chosen for irradiation is precisely anatomically defined and adjusted during irradiation. The localization technique includes the stereotactic localization of the target in the brain by using a head frame, determination of the coordinates of the target point with reference to this head frame and adjustment of the target point to the isocenter[10].

In 1985, Colombo et al have utilized computer techniques to aid in their three dimensional targeting of the brain tumors and have built a new stereotactic head frame by which the intracranial target is fixed to the rotational isocenter of a 4 MV linear accelerator[4]. This procedure was noninvasive and was possible to obtain very high radiation doses centered into the target with a stepped dose gradient.

This principle was simple, so the authors made the stereotactic head frame holder by which the target is fixed to the rotational isocenter of a 6 MV linear accelerator equipped at our hospital.

There are several important factors in stereotactic radiotherapy. They are localization system, portal, field size, radiation dose, and perioperative supportive care.

The first, stereotactic head frame including grid marked with vertical and horizontal scale in mm was used for localization in our cases and permits good localization and easy control.

The second, determination of the field size is based on the target volume in head profile reconstructed from CT data along preset planes of irradiation. Field sizes are selected so that the 80% isodose curve will coincide with the borders of the target volume[11]. If the lesion is spherical or spheroidal a single field size is selected, and if the lesion is more irregularly shaped in stereoreconstruction varied field sizes are selected in variable cross section. We used varied field sizes in 3 out of 8 patients.

The third, determination of the radiation dose is a difficult problem. The total dose to be applied is determined taking into account the volume of the lesion, the age of the patient, and the spatial relationship with nearby radiosensitive structures. In intracranial tumors, it is considered that the dose given in single sitting is biologically equivalent to a three fold higher frationated dose. In experience of Colombo a dose of 2000~2500 cGy delivered in two sessions, 8 days apart, is both safe and well tolerated for lesions up to 30 mm in diameter[11]. In cases of AVM, Colombo reported that the volume of the obliterated part was encompassed by isodose surfaces marking absorbed dose from 24 to 27 Gy, so the lowest efficient dose for obtaining vessel obliteration in one year should be at least 27 Gy[12]. The choice of the dose still remains a difficult one.

Finally, perioperative supportive care is important. We used steroid one day before radiosurgery for prevention of brain edema. Steroid was continuously given with high dose during radiosurgery and until a few days after radiosurgery according to a condition of patient and then tapered. After the removal of metal frame, the small wounds caused by the screws are cleansed and dressed. They usually heal quickly, and no patient has so far developed an infection. The patiet may take food immediately after the procedure and may leave the hospital the next day. Our patients usually leaved the hospital, two or three days after stereotactic radiotherapy.

After stereotactic radiotherapy, we used CT scans in tumors and angiography in AVMs for follow-up reviews. In AVMs, follow-up angiography is repeated at 3, 6, 9, 12, 24 and 60 months after radiosurgery. CT scan or digital venous imaging also may be used for follow-up evaluations.

In summary, stereotactic radiotherapy was performed by 6MV linear accelerator in 8 cases of intracranial tumors and AVMs. It is suggested that stereotactic radiosurgery may be performed very safely with a radiation dose of 12-30 Gy. So this noninvasive procedure can be used to treat unresectable intracranial tumors or AVMs.

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= 국문초록 =

6MV 선형가속기를 이용한 정위다방향 단일 고선량 조사

가톨릭의과대학 방사선과학교실

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정위다방향 단일 고선량 조사는 비침습적으로 두개골에 중추신경계 정위수술기구(Stereotactic frame)를 고정시켜 병소부위를 정확히 조준한 후 작은 조사야들을 통하여 단일고선량을 병소부위에 집중시킴으로써 이를 파괴시키거나 생물학적 효과를 유도하는 것으로 정의되고 있다.

이 방법은 비침습적이며 병소부위를 중심으로 여러 방향으로부터 방사선을 조사하므로서 병소부위에는 고선량을 집중시키고 주위정상 뇌조직에 가는 선량을 최소한으로 줄일 수 있다. 또한 1회에 주는 방사선량은 보편적인 다분할 조사방법에 의한것 보다 동일한 선량을 비교해 볼때 그 생물학적 효과가 3-4배로 높다.

이 방법은 크기가 작고 수술이 불가능한 두개내 심부종양 즉, 뇌하수체 종양, 두개인두관종양, 송과체종양, 수막종, 청신경초종 및 혈관기형등에 주로 시도하여 왔다.

저자들은 1988년 7월부터 10월 까지 6MV 선형가속기를 이용하여 병소가 3 cm이하로 작고 수술이 불가능한 두개내 심부뇌종양 5예(청신경초종, 재발성 두개인두관종양, 혈관아세포종, 송과체세포종 및 뇌하수체 소선종, 각각 1예)와 동정맥성 기형 3예에 대해서 정위다방향 단일고선량조사를 시행하였기에 그 방법과 중간성적을 보고하는 바이다.