Selective Beam Shielding Method of Gamma-Knife Unit Using Various Plugging Patterns

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The B-type gamma knife unit was installed at Kyung-Hee University Hospital in March 1992. The selective beam plugging method can be used to reduce the low percentage isodose profiles of normal sensitive organ and to modify the isodose curves of treatment volume for better shaping of the target volume. For representing the changes of the low percentage isodose profiles, the variations of dose distribution for several cases were discussed in this paper. The film dosimetry was performed for the evaluation of calculated isodose profiles predicted by KULA dose planning system. The results were verified by RFA-3 automatic densitometry. The clinical application of selective beam shielding method was performed in 17 patients in 100 patients who have undergone gamma knife radiosurgery for a year.

The calculated and the measured isodose profiles for the high percentage regions were well consistent with each other. When the target of pituitary tumor is macro-size, the selective beam shielding method is the most applicable method. When the target size, however, is small, the correct selection of the proper helmet size is very important. All patients were exposed almost about 3～12 Gy for brain stem, and 3～11.2 Gy for optic apparatus. It is recommended that the same or other plugging patterns with multiple isocenters should be used for protection of the radiosensitive normal structures with precise treatment of CNS lesions.

Key Words: Stereotactic radiosurgery, Selective beam shielding method, Plugging pattern, Multiple isocenters

INTRODUCTION

Since Lars Leksell proposed the concept of stereotatic radiosurgery in 1951, techniques have been developed and used for single high dose irradiation of small target volume in the brain[1~3]. The first (1968) and the second (1975) gamma knife used 179 ^{60}Co sources and the third gamma knife (1980) used 201 sources[1,4,5]. The B-type gamma knife unit using 201 sources was installed at Kyung-Hee University Hospital in March 1992. The 100 patients with CNS lesions were treated by gamma-knife radiosurgery for a year.

The Leksell gamma unit is equipped with four interchangeable helmets having collimators measuring 4, 8, 14, and 18 mm in diameter. All 201 beam channels are focused to a single point at the center of the radiation unit. This results in a spherical shaped radiation field which delivers a high radiation dose at the isocenter which decreases as a function of the inverse square of the distance from the isocenter but has a steep dose gradient[1,6,7]. Depending on the techniques used and the position of the target volume within the skull, the treatment volume may have an elongated diameter in one particular direction and can be modified by selective beam shielding[8].

Three-dimensional dose distributions are calculated with a Micro-Vax II computer using micro VMS version 4.5 based software developed at the University of Uppsala which sums the dose distribution from individually measured beam profiles to each point in the dose matrix[9]. The plugs need to optimize the relationship between the shape of the cerebral target and the isodose configuration.

The selective beam blocking for A-type Leksell gamma unit was presented in reference 8. But B-type Leksell gamma unit in soure arranges is distinguishly different to A-type. Also, the selective beam shielding for B-type is not discussed anyone. The object of present paper is to evaluate the techniques for reducing the low percentage isodose profiles of normal sensitive organs and for producing modification of the treatment volume with a selective beam method and is to present these results of clinical applications.

MATERIALS AND METHODS

Because physical descriptions of the B-type gamma unit were presented in reference 10, therefore, those parts skipped in this paper. Any number of sources can be blocked or plugged to prevent the entry of beams through the orbit and to modify the shape of the dose distribution[3,9]. The isodose configuration depends primarily on the collimator helmet. In this paper a KULA software package was used to determine the isodose configuration from a given plugging patterns of active beams and from the final collimator aperture size. Two-dimensional xy, yz, or xz isodose plots at shot point in the dose distribution were printed at (100, 100, 100) for x-, y-, and z-point, respectively and isodose curves for the 10, 20, 30, 50, 80, 95%. We used Kodak Xomat-V films for dosimetric instrument in order to compare with the calculated isodose profiles in the KULA program. Those films were evaluated and verified by RFA-3 automatic densitometer having an aperture, 2 mm in diameter. The measurements of the film dosimetry were performed in spherical polystyrene phantom, 160 mm in diameter and about 100 mm × 120 mm film in size. The phantom is aligned in the helmet so that its center coincides with the point where all beam axes intersect at x=100, y=100, z=100 in trunnion center position (Fig. 1). It is assumed that gamma angle is 90 degrees. The gamma angle is the angle in degrees between the central ray of the Gamma Unit and the positive Y-axis of the stereotactic frame when the patient is fixed on the treatment table. The planes of film orientation are the Z-X, Y-X, Z-Y planes and exposure time with 14 mm helmet is 18 sec. Fig. 1 displays the dosimetric coordinate systems of the B-type for the evaluation of the calculated isodose profiles in each plugging types.

The displayed magnification size, that is, Grid size, has 2.00 in order to display the low percent isodose profiles. For the plugged position, eight cases were studies, that is, full plugging (1 case) and seven portion pulgging type in collimator position for the X-, Y-direction in order to study the change for the low percentage isodose profiles. For the Z-direction plugging the low percent isodose variation was studied by several plugging cases shown in figure 2. For two cases of the patients the clinical application was displayed and discussed in the X-, Y-, Z-direction (Fig. 1), respectively.

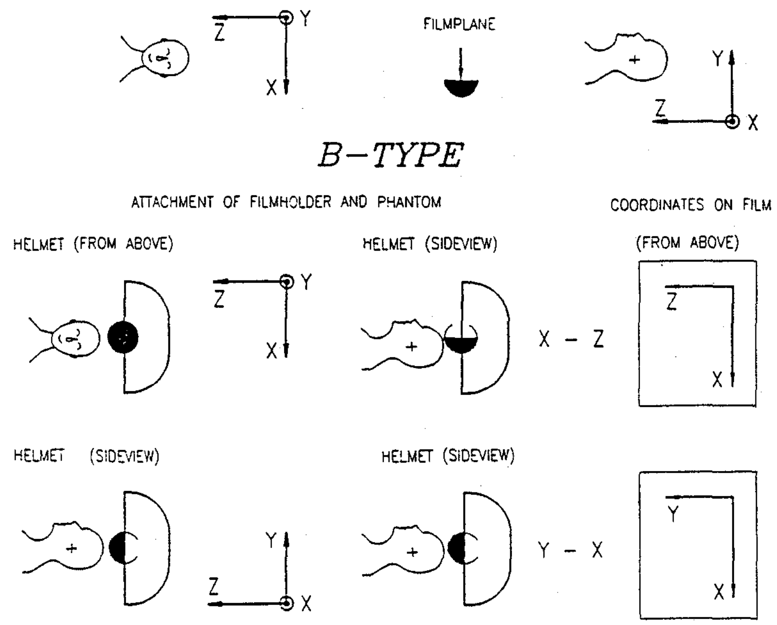

Fig. 1. Gamma Knife coordinate systems used to define the film dosimetry in the spherical polystyrene phantom 160 mm in diameter and about 100 mm × 120 mm film size.

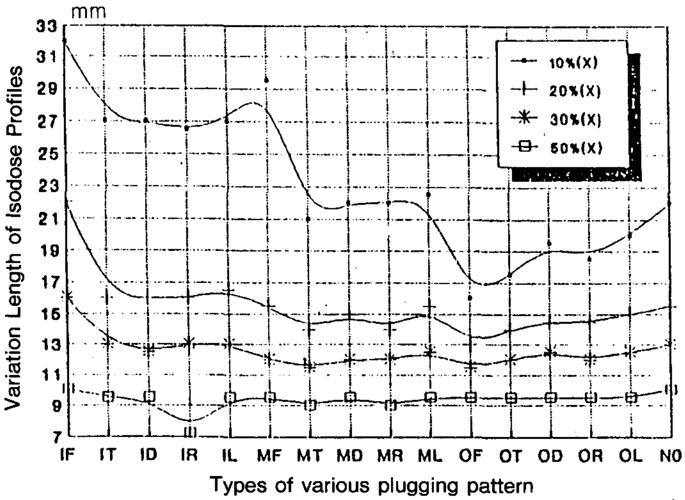

Fig. 2. The X-, Y-distance variation of isodose profiles for the several Z-direction plugging for 10%, 20%, 30%, 50% isodose profiles.

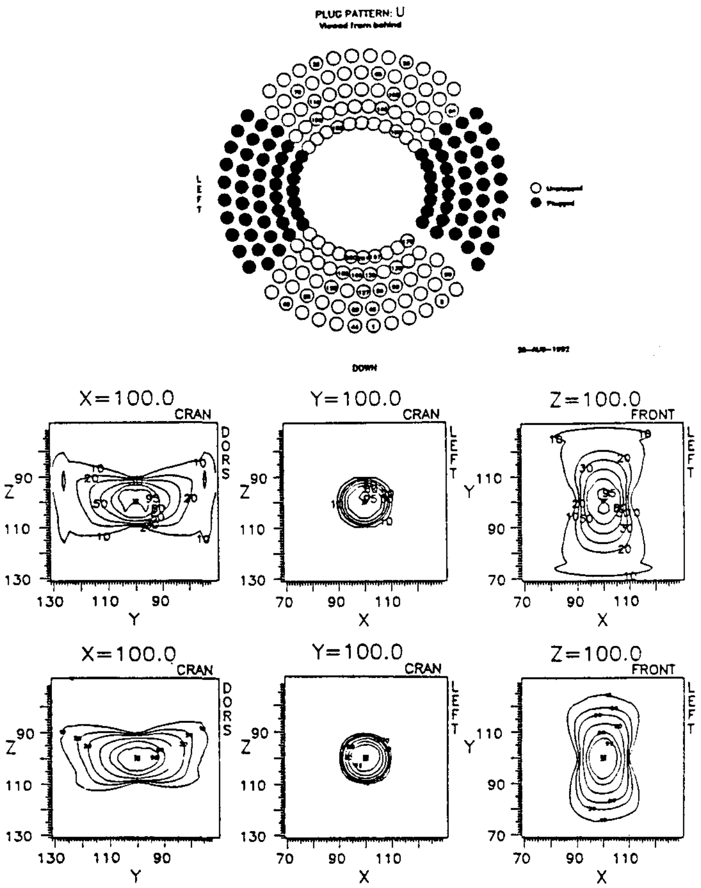

Fig. 3. Comparision of calculated isodose profiles (b) and measured isodose profiles (c) with a plugging pattern U (a) in order to shield the X-direction of the treatment volume.

RESULT

1. The Characteristics of Selective Beam Shielding

It is possible to shield any number of sources with plugging pattern option. This option gives us the large possibilities to shape non-standard dose distributions and can be used to protect vital organs, such as the lens of the eyes, brain stem, optic chiasm, potic nerves etc., by plugged channels for which the beams would pass through the parts to be protected. A plugging pattern is defined by specifying of which the sources of the gamma unit that should be plugged. Each pattern is labeled with one of the characters "A to Z". This technique is commonly used in treating pituitary tumors in order to flatten the isodose contour in the superior inferior direction and to limit radiation exposure to the optic apparatus[6]. In order to apply the real treatment case in the gamma knife, the number of useful plugging in this research was limited to less than 100.

Fig. 3, 4, and 5 display the plugging pattern U (a), T (a), W (a) of the selective beam for shielding of the x-, y-, and z-direction of the radiosurgical treatment volume. The computer calculation (b) and film dosimetry (c) of this type are shown for treatment with 14 mm diameter collimator for the 10, 20, 30, 50, 80, and 95% isodose profiles in the yz, xz and xy planes, respectively. For full-x plugging, the characteristics represent that the high percentage isodose profiles in the zy plane result in enlargement y-direction. The low percentage

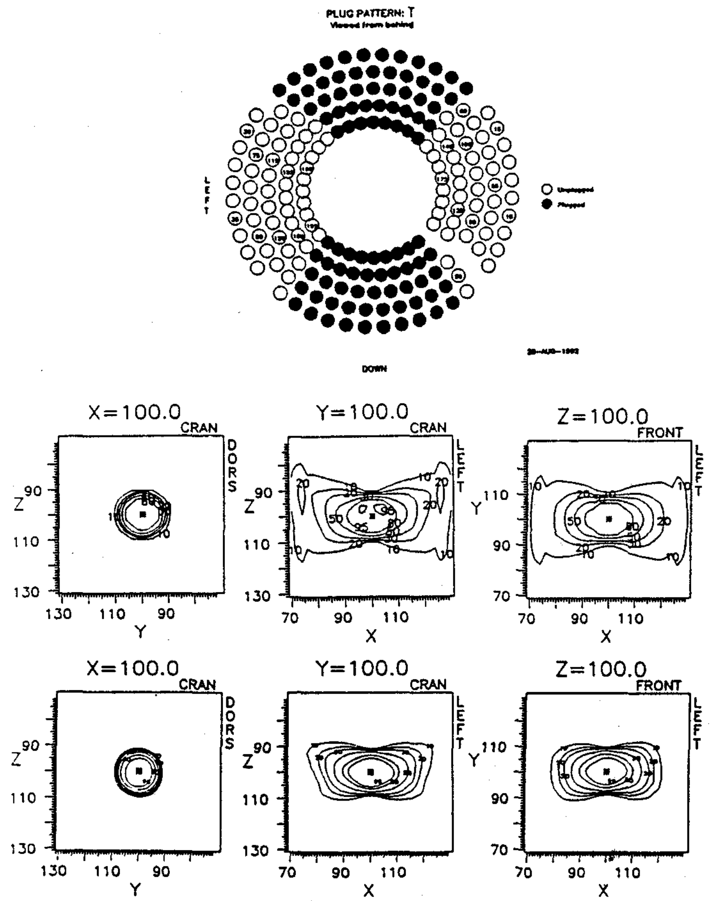

Fig. 4. Comparision of calculated isodose profiles (b) and measured isodose profiles (c) with a plugging pattern T (a) in order to shield the Y-direction of the treatment volume.

isodose profiles in the yx-plane is resembled the double-headed drum shape and the high percentage isodose profiles appear track shaped enlarged y-direction, If the left-side for full-x-direction is plugged, the zx-plane isodose profiles will be elongated left-diagonal shape. When the right-side, however, is plugged, then the zx-plane isodose profiles are enlarged to the right-diagonal shape. In the case of the inside parts plugging, the zy plane isodose profiles are enlarged X-direction. Further protection of the x-direction could be achieved by increasing the number of source blocked or treating with multiple isocenters.

For y-direction shielding, the characteristic of full-Y plugging is shown that the zy isodose profiles are almost circular shape, whereas the x-diameter is enlarged. The isodose profile in the yx-plane appeared as track shapes in the high percentage profile. In the inside-plugging cases, the low percentage isodose profile is to elongate for y-direction. Therefore, this isodose profiles are badly affected the brainstem in treatment of the pituitary region, but are well affected the optic chiasm in the pituitary adenoma. In the outside-plugging cases, the low percentage isodose shapes are good for treatment in the brainstem of the pituitary adenoma. For the top-side plugging, the isodose profiles in the zy plane showed the enlarged right-diagonal shape, but for the down-side plug that in the zy plane appeared the elongated left-diagonal shape.

To avoid direct irradiation through the brain-

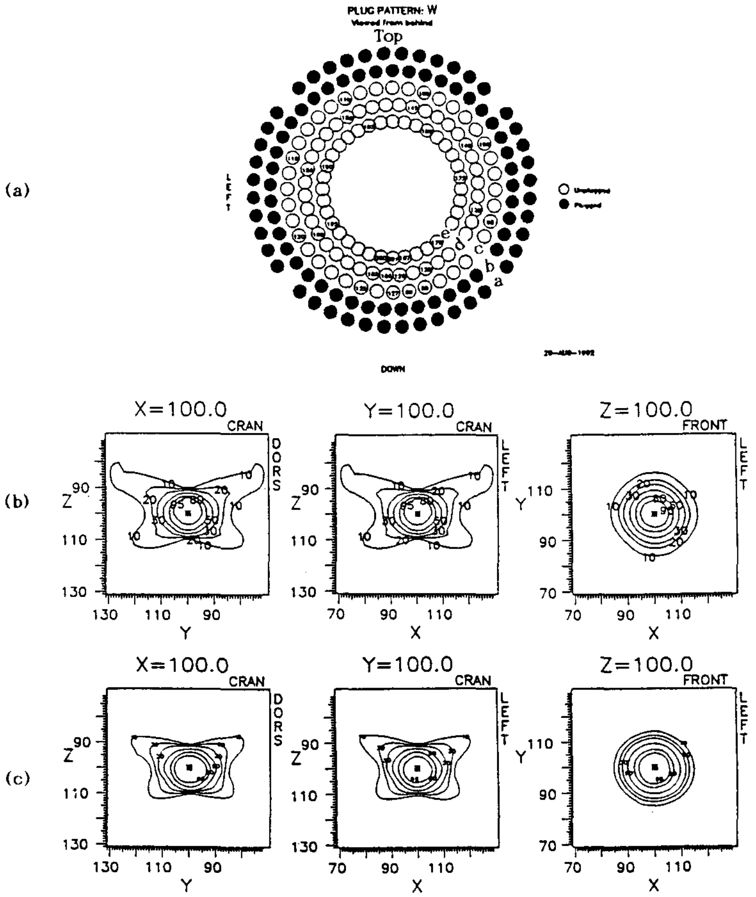

Fig. 5. Comparision of calculated isodose profiles (b) and measured isodose profiles (c) with a plugging pattern W (a) in order to shield the Z-direction of the treatment volume where a, b cycle line is Outside, b, c, d cycle line is Middle side and d, e cycle line is Inside Portion.

stem, total head and total body, the B-type of the Leksell gamma unit is designed in including few number of sources in the direction of the z-axis more than the other axes[11~14]. Because of this, it is more difficult to reduce the treatment volume diameter in the direction of the z-axis. For full-inside plugging case, the zx-plane and zy-plane isodose curves are the enlarged-shape in the x-, y-direction, respectively. But for z-direction the isodose profiles have the steep dose gradient. For full-middle part plugging, all isodose curve elongated distribution relative to inside part plugging in the zy, zx planes. For full-outside plugging, the low percentage isodose curves shaped the enlarged diagonal for the left, right side in the zy, zx planes. This case is very good for shielding brainstem of the pituitary adenoma treatment in the yx plane by comparison with the above two cases because the isodose profile diameter in the yx plane is well reduced. Figure 2 displays the x-distance variation of isodose profiles for the several z-direction plugging. The y-distance variation of isodose profiles has similar to that for the z-direction plugging. In the figure 2, the isodose profiles of the outside full plugging had appeared the very small size in comparison with no plugging. Where I is inside, M is middle, O is outside, and F=full, T=top, D=down, R=right, L=left, No=no plugging.

2. Clinical Application

The selective beam shielding or blocking were applied to seventeen of 100 patients, that is, 4 cases of pituitary adenoma, 5 cases of acoustic neurinoma and CPA region tumor, 4 cases of supraseller region, 4 cases of others (Table 1). The isodose profiles for clinical application displays in figure 6 for pituitary adenoma and in Fig. 7 for acoustic neurinoma in treatment planning either used plugging pattern (c) or not (b). Also, the sample case of the plugging method applied for patient of pituitary

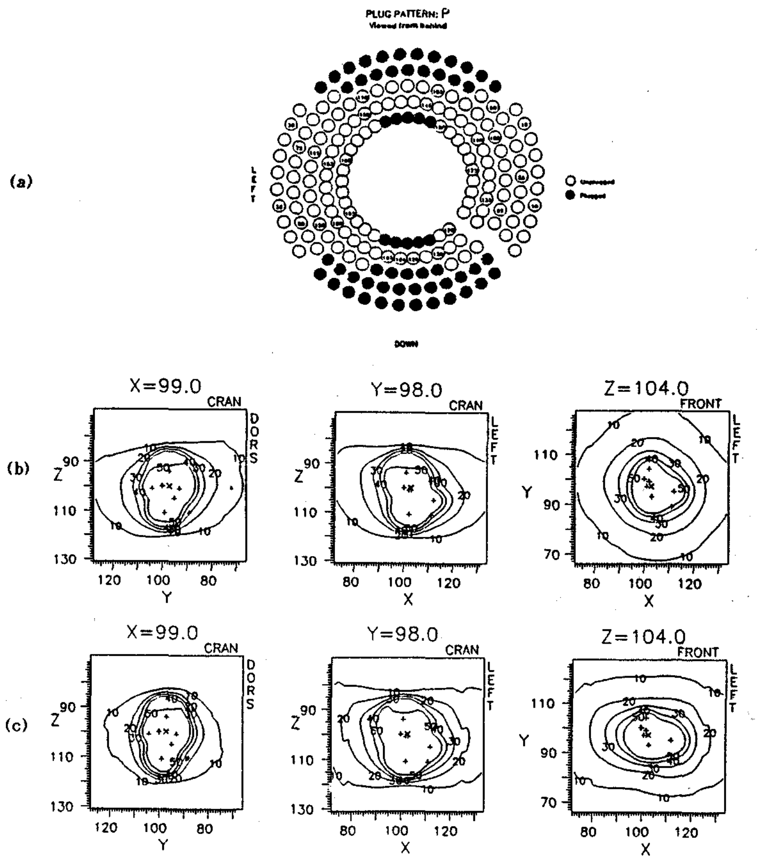

Fig. 6. The isodose profiles for clinical application of pituitary adenoma.

adenoma shows in Fig. 8.

3. Case

1) Pituitary Adenoma

The selective beam shielding were used to four cases of those patients (14). The plugging pattern "P" in figure 6 was applied to a patient in this paper and was plugged 60 sources. Six shots were used

Table 1. Patient Characteristics

	Pituitary Adenoma	Acoustic Neurinoma & CPA Region Tumor	Suprasellar Region Tumor	Others
No. of Patients	14	8	6	72
No. of Plugging Cases	4	5	4	4
No. of shots per collimator	4 mm: 4, 8 mm: 38 14 mm: 19, 18 mm: 8	4 mm: 0, 8 mm: 16 14 mm: 26, 18 mm: 14	4 mm: 0, 8 mm: 13 14 mm: 13, 18 mm: 4	
Target Volume (mm³)	299~12,300 (6300)	2,800~29,610 (16200)	2,907~8,237 (5600)	
No. of shots	1~10 (5)	4~10 (7)	2~8 (5)	
No. of plug per plug cases	37~100	33~63	35~85	35~65

(*): Median values.

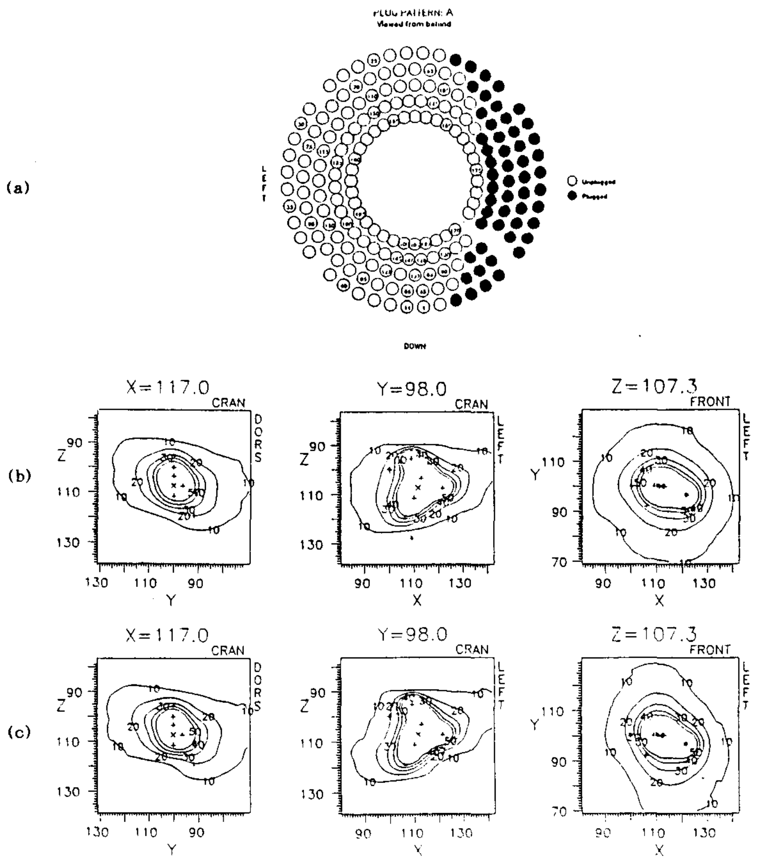

Fig. 7. The isodose profiles for clinical application of acoustic neurinoma.

Fig. 8. The sample case of the plugging method applied for patient of pituitary adenoma.

in real treatment. Target volume is about 6600 mm^3. Table 1 shows the kind of collimator, target volume, the number of shot in average and from minimum to maximum, and the number of plugging.

In the calculated isodose profiles of this patient, without plug shielding dose 27% isodose curve line interfaces with the brainstem, but this value could be reduced to 18% with plug shielding technique applied. However the isodose curves for optic chiasm were almost not changed before and after using the plugging pattern.

2) Acoustic Neurinoma

The plugging method was applied to 3 cases of these patients (6). The used model of patient in this paper is the plugging pattern "A" in Fig. 7. Fig. 7 shows not used (b) and used (c) isodose profiles. The number of total shots were 5 (14×2, 8×3). Target volume is about 5,400 mm^3.

In the caculated isodose profiles, without plug shielding larger than 33% isodose line passes the brain stem region, but this value could be reduced to 26% with plug shielding technique applied.

DISCUSSION

The configuration of dose distribution can be further varied by plugging of individual beam channels. Within small and well defined volume the tissue is affected by a single dose of ionizing radiation with minimal effects on the normal structures and tissues outside the target[2,11~14]. When using photon beams, the dose gradients at the border of the target strongly depend on the size of the target, and on the beam distribution in space around the target but less on the photon energy[1,2].

There are two rules that should always be kept in mind when dose treatment planning are performed with the gamma unit; (1) the concept of the radiation surgical method implies steep dose gradients at the border of the target. (2) even though the theoretical dose distribution is favorable in the more complicated alternative, the less complicated technique is chosen[3,7,9]. The possibilities of optimum treatment planning are dependent on (1) the accuracy in localization and positioning of the target volume in relation to the beam focus, (2) the dose to be administered to the target volume, (3) the adaptation of the geometrical irradiation parameters and the beam channel to the target volume, and (4) radiation protection of other organs. Risks of inadvertent injury to healthy structures in the brain are hereby also minimized[3,15,16].

Table 2. Radiation Doses of Normal Structures

Tumors	Normal Structures	
	Brain Stem	Optic Apparatus
Pituitary Adenoma	5.6 Gy~12 Gy (7.6 Gy)	1.5 Gy~11.2 Gy (5.9 Gy)
Supraseller Region Tumor	3 Gy~10 Gy (7.7 Gy)	3 Gy~10 Gy (7.0 Gy)
Acoustic Neurinoma & CPA region Tumor	9 Gy~13.6 Gy (10.0 Gy)	

(*): Median doses in normal structures.

From above study, we reconginized that it is helpful to change the shape of the treatment volume for limiting the amount of the high dose irradiation to surrounding normal brain. Because of the steep dose volume relationship expected for radiation tolerance at the doses and volumes used for radiosurgery, making even small changes in treatment volumes to match more closely the target should be very important[15,16]. The use of plugging patterns to sharpen the dose fall off superiorly also appears to be a useful technique, especially when treating a target volume situated directly underneath an important and/or radiosensitive structure. The proper beam shielding can reduce the dose to the sensitive structure relative to the target volume. All patients were exposed almost about 3~12 Gy for brain stem, and 3~11.2 Gy for optic apparatus (Table 2).

The use of the selective beam shielding method is helpful (1) to reduce the aborbed dose (10~30%) of normal sensitive organ, (2) to modify the high ones in the treatment volume to match better shape of the target volume, (3) to save the treatment time because of already setting eyes plugging and reducing of the number of shots by using larger collimator but using the selective beam shielding before the patient's treatment in treatment planning, (4) administering the beam in the subcortically located treatment.

The techniques of selective beam shielding were described in this paper to change the low percentage isodose profiles. The results show that the calculated in used resently patient's treatment and the measured isodose profiles for the high percentage region are well consistent with each other. The significant difference between the calculated and film dosimetry isodoses for the 10% is appeared in each figure of plugging pattern. This difference may be due to measurement error and to using the large aperture (2 mm) in diameter of the film densitometer. But, this difference is smaller than one of U-type Leksell gamma knife for plugging shown in reference 6. The Z-direction plugging types for the reduction of the z-diameter are that all cases are very small reduction. For treatment of pituitary region tumor, this type of modification can substantially very small decrease the dose to the optic chiams (Fig. 8). Therefore, the shot position change for the reduced z-diameter is more effective than plugging in the same collimator helmet size in the small size target volume. When the taget size in pituitary tumor is large (≧10 mm), the selective beam shielding method is the most applicable. But if it is small (≦10 mm), the correct selection of the proper helmet size is very important. It is recommanded that the same or other plugging patterns of multiple shots should be used for protection of the radiosensitive normal structure. The potential for error would be greatly increased in a computer plan for treatment with multiple isocenters using any extensive plugging pattern. Techniques for using the selective beam shielding method and the calculating computer planning algorithm need to be further improved and developed for precise treatment of CNS lesions.

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= 국문초록 =

다양한 Plugging 형태를 이용한 감마나이프의 선택적 빔 차폐 방법

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Leksell 감마나이프(B-형)가 1992년 3월 경희대학교 의과대학 병원에 설치되었다. 선택적 빔 Plugging 방법을 이용하여 정상 민감 조직에 대한 저선량 분포를 현저히 줄일 수 있으며, 또한 치료 부위에 더 좋은 선량 분포를 얻을 수 있다. 저선량에 대한 여러가지 선량 분포의 변화에 대한 연구를 하였으며, 사용중인 KULA 프로그램의 선량 분포 곡선을 평가하기 위해 필름을 이용한 방사선량 계측을 실시하였고, RFA-3 자동 밀도 측정기를 이용하여 평가하였다. 1992년 3월부터 1993년 2월까지 1년동안 100명의 환자중 17명의 환자에 선택적 빔 차폐 방법이 적용되었다.

고선량 영역에서는 측정값과 프로그램에서 제공된 선량 분포가 잘 일치하였다. 뇌하수체 선종의 치료시 치료 부위가 클 경우에는 본 연구 방법의 적용이 매우 중요시 되었으며, 반면에 치료 영역이 작을 경우에는 적절한 헬맷의 선택이 중요함을 알 수 있었다. 치료 환자의 중요 민감 장기의 방사선 선량 평가에서는 뇌간에 3~12 Gy, 시신경 교차에 3~11.2 Gy이었다. 중추신경계 영역의 최적화된 치료를 위하여 다양한 Plugging 형태를 임상에 적용하는 것이 방사선에 민감한 정상 조직을 보호하기 위해 매우 중요한 인자가 됨을 알았다.