J. Korean Soc Ther Radiol Vol. 11, No. 1, June, 1993

Dosimetry and Three Dimensional Planning for Stereotactic Radiosurgery with SIEMENS 6-MV LINAC

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Radiosurgery requires integral procedure where special devices and computer systems are needed for localization, dose planning and treatment. The aim of this work is to verify the overall mechanical accuracy of our LINAC and develop dose calculation algorithm for LINAC radiosurgery.

The alignment of treatment machine and the performance testing of the entire system were extensively carried out and the basic data such as percent depth dose, off-axis ratio and output factor were measured. A three dimensional treatment planning system for stereotactic radiosurgery has been developed. We used an IBM personal computer with C programming language (IBM personal system/2, Model 80386, IBM Co., USA) for calculating the dose distribution.

As a result, deviations at isocenter on gantry and table rotation for our treatment machine were acceptable since they were less than 2 mm. According to the phantom experiments, the focusing isocenter were successful by the error of less than 2 mm. Finally, the mechanical accuracy of our three dimensional planning system was confirmed by film dosimetry in sphere phantom.

Key Words: Radiosuregery, Three dimensional planning, Small field dosimetry.

INTRODUCTION

Stereotactic radiosurgery has been extensively studied by many investigators since the Swedish neurosurgeon Lars Leksell introduced it in 1951[1,2]. In recent, radiosurgery treatment techniques by using LINCA were proposed by various institutions and were carried out at lots of hospitals[3~5]. Stereotactic radiosurgery delivered a high dose of single fraction radiation to a defined volume of intracranial region that it requires high precision localization and elaborate treatment system[6,7].

In this present work, we are to verify the overall mechanical accuracy of our LINAC and to measure the basic data such as percent depth dose, off-axis ratio and output factor and to develop three dimensional treatment planning system for LINAC radiosurgery.

MATERIALS AND METHODS

Successful stereotactic radiosurgery requires 1) mechanical accuracy for treatment, 2) fixed stereotactic frame for a patient and CT localization, 3) reasonable small field dosimetry, and 4) three dimensional treatment planning system[3,8].

1. Verification Procedure

The gantry axis, collimator axis, and turntable axis should be focused at the isocenter and remain stable during rotation. There are many methods for measuring the accuracy of isocentric axis[9]. In this present work, we determine the accuracy of isocenter on the treatment table and then expose it to x-ray for about 20 seconds (dose rate: 200 cGy/min). In this case, we set up the collimator size by 0.2 cm×20 cm. And then we repeat this procedure only changing the collimator (or gantry or turntable) angle by 30 degrees. From this measurement, we can estimate the deviation of isocentric axis by collimator (or gantry or turntable) rotation.

The conventional movable collimator of linac is used for stereotactic radiosurgery. Although it has some disadvantages for stereotactic radiosurgery[3], it can be applied for simple conformal radiosurgery. The accuracy of collimator alignment can be verified using the radiation beam, a lead ball (2.5 mm diameter, which positioned at the isocenter, and a test film. The collimator is properly aligned when a series of radiographs for various square field sizes (1.5 cm to 4.0 cm), demonstrates the image of the lead ball to be within 0.5 mm of the center of the field.

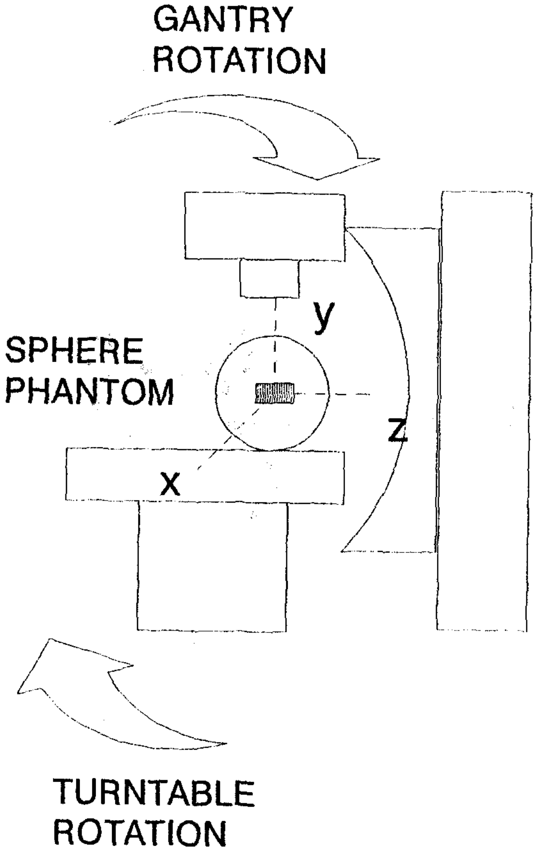

Fig. 1. *Overview of phantom experiment. Gantry and turntable rotations are carried out at LINAC's isocenter.*

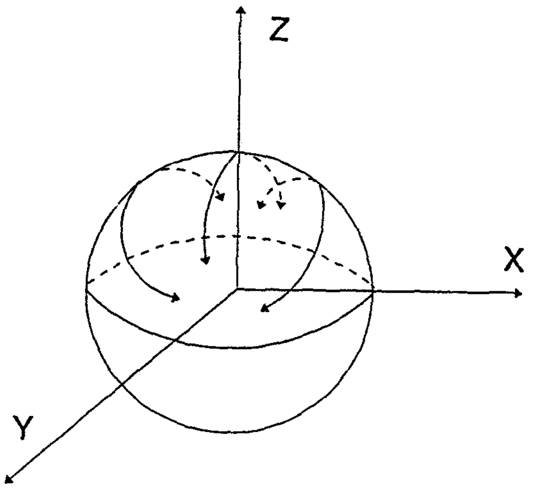

Fig. 2. Orthogonal coordinate axes and the four arcs of the typical treatment.

Although the accuracy of x-ray's focusing at a point is good enough for radiosurgery, it is more important for x-ray to be focused at the defined position. We use sphere phantom with lead mark (3 mm×3 mm×0.5 mm), where the diameter of the phantom is 16 cm and film can be inserted in. One point within the lesion is selected as the focus by using coordinates obtained from stereotactic localization, and positioned at isocenter of a linear accelerator. We put the sphere phantom on the treatment table and perform the arc rotations at this isocenter at a different turntable position respectively (Fig. 1). For a treatment, the path of the beam's *entry will consist of four arcs (Fig. 2). In our* present work, a transverse arc of approximately 260° would be followed by several vertex arcs of 100° each.

2. Measurement of Basic Data

%DD (percent depth dose), output, and OAR (off-axis ratio) in water phantom irradiated by 6 MV photon beam are measured by using MULTIDATA dosimetry system for treatment planning of radiosurgery[10,11]. MULTIDATA dosimetry system consists of ionization chamber, water phantom, electrometer, dual processor based 3 dimensional drive control, and IBM personal computer. In this case, field sizes are 1.5 cm to 4.0 cm square fields. For small field dosimetry[12], we used small size ion chamber (CAPINTEC 0.07 cc PR-05P minichamber) in water phantom.

3. 3-dimensional Planning System

We developed a three dimensional treatment planning system for stereotactic radiosurgery using a IBM compatible personal computer. We used an personal computer with C programming language for calculating the dose distribution in tumors. To calculate the three dimensional dose distribution, we used a single isocentric dose model[13] and a newly developed algorithm. The dose calculation matrix is defined by user selection of calculation limits, which also determines thereby the resolution of the calculation grid. The calculation time of a 31×31 matrix in a selected plane is about 1 min for the four arcs treatment plan, using a 20-MHz Intel™ 80386-based computer (IBM PS-2, USA), equipped with an Intel™ 80387 math coprocessor. The dose-computation program permits the display of a two-dimensional dose distribution of user selected isodose lines in any plane and a three-dimensional dose distribution of user

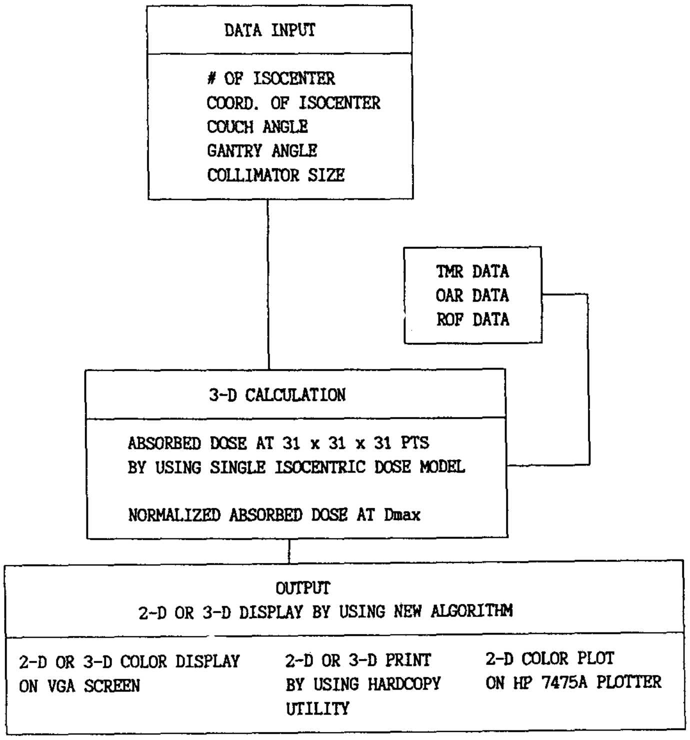

Fig. 3. Block diagram of the 3-D treatment planning program for stereotactic radiosurgery.

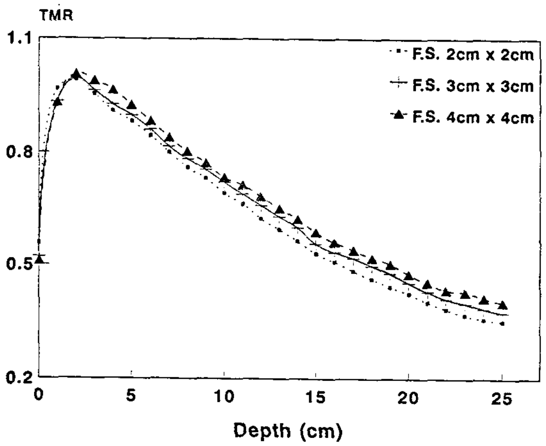

Fig. 4. TMR curves of small fields for 6 MV X-ray in LINAC (SIEMENS MEVATRON-MD).

selected isodose surfaces in any direction. Two-or three-dimensional Isodose distributions are printed on a laser printer (Hewlett-Packard Laser Jet). Especially, two-dimensional Isodose distributions can be plotted on a color plotter (Hewlett-Packard 7475A Plotter). The schematic diagram for 3-dimensional planning system is shown in Fig. 3.

RESULT

The deviation of isocenter for gantry, collimator, and treatment table rotation was estimated by using film dosimeter. The distance error resulted from turntable rotation was less than 1.0 mm and collimator rotation less than 0.5 mm. And the distance error with gantry rotation was about 1.5 mm because of LINAC's massive weight.

Our LINAC's beam alignment was verified by using a film exposure. A lead ball was placed at isocenter localized by laser beams. The distance error for the position of the lead ball relative to the various radiation fields was within 0.5 mm.

As shown in Fig. 1, the performance test measuring the overall accuracy for typical treatment was carried out by using sphere phantom. The CT localization error was estimated by less than 1.0 mm and, including this error, the total isocentric deviation is within 2.0 mm.

The measured basic data, such as TMR (tissue maximum ratio) derived from %DD, FSF (field size factor), and OAR, is represented by Fig. 4, Fig. 5, and Fig. 6. As shown in Fig. 4, the TMRs in variation of field sizes are plotted as a function of depths in cm. As field sizes change 2 cm×2 cm to 4 cm×4 cm, Dmax (maximum dose) varies 1.2 cm to 1.5 cm for 6MV X-ray. The TMRs at a depth of 10 cm are measured by about 0.69 to 0.73. Fig. 5 represent FSF as a funtion of field sizes in cm. From these, we know that FSF for field sizes 2 cm×2 cm to 3 cm×3 cm is as much as 14% to 10% lower than that for a conventional 10 cm×10 cm field. This fact is good agreement with Lutz etal.'s data[3]. Dose profiles for various field sizes are measured by ion chamber and films. Fig. 6 represent the dose profiles for 2.0 cm, 3.0 cm, and 4.0 cm square fields at a depth of 8.0 cm. The measured penumbral distances (90% to 20%) for the 2.0 cm to 4.0 cm square fields are 4.7 mm to 5.6 mm.

These measured basic data are used in our computer program to simulate the dose distribu-

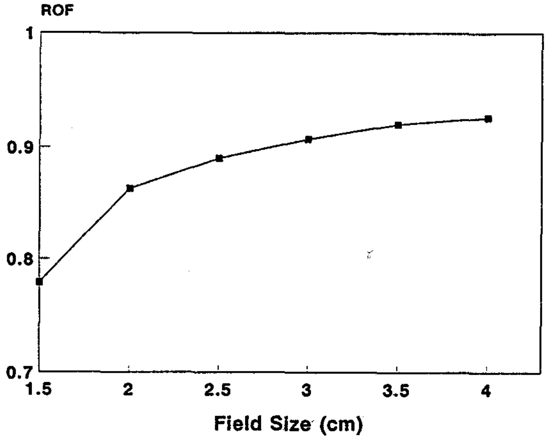

Fig. 5. ROF curve of small fields for 6 MV X-ray in LINAC (SIEMEMS MEVATRON-MD).

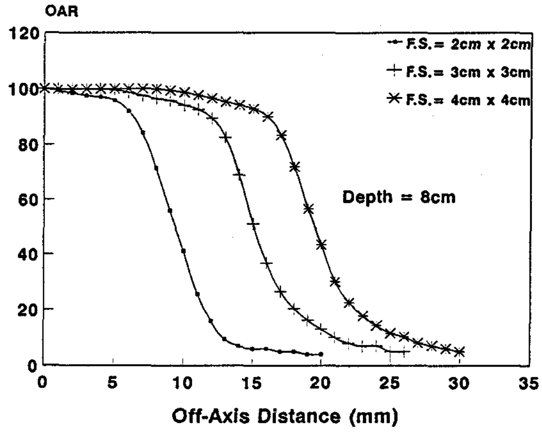

Fig. 6. OAR curves of small fields 6 MV X-ray in LINAC (SIEMENS MEVATRON-MD).

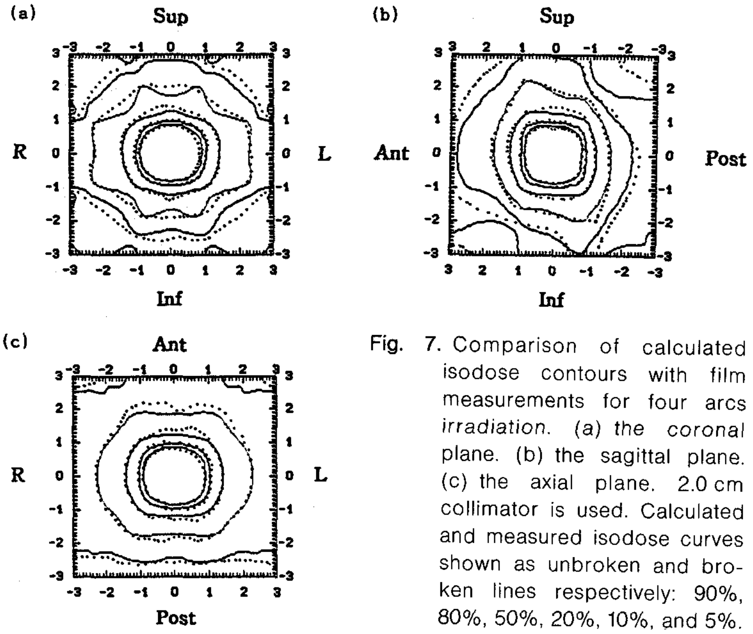

Fig. 7. Comparison of calculated isodose contours with film measurements for four arcs irradiation. (a) the coronal plane. (b) the sagittal plane. (c) the axial plane. 2.0 cm collimator is used. Calculated and measured isodose curves shown as unbroken and broken lines respectively: 90%, 80%, 50%, 20%, 10%, and 5%.

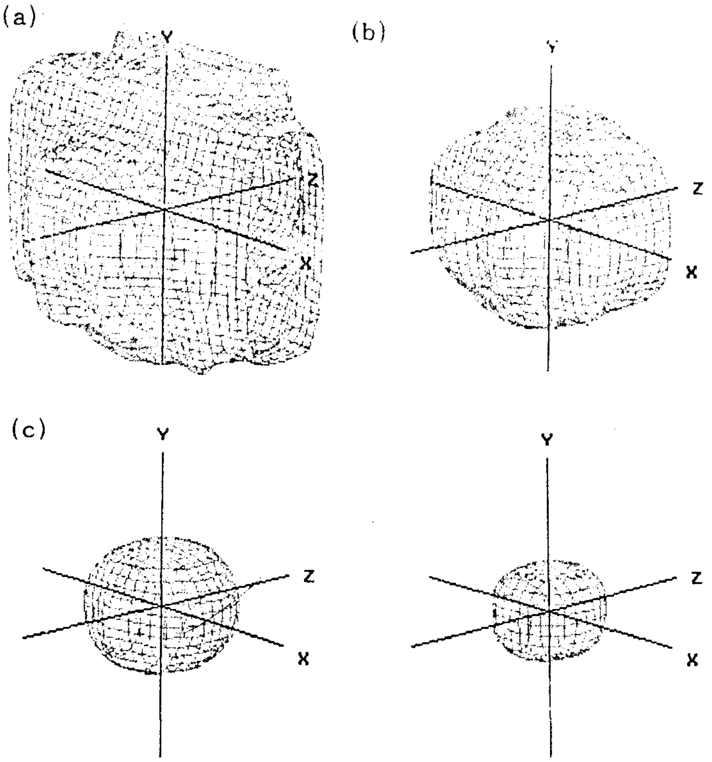

Fig. 8. 3-D isodose contours of single isocenter for four arcs irradiation. (a) 10% isodose contour. (b) 20% isodose contour. (c) 50% isodose contour. (d) 80% isodose contour.

tions obtainable from non-coplanar arcs.

For four arcs, two-dimensional isodose lines of the 20 mm collimator for the sagittal, coronal and axial planes are displayed in Fig. 7. Isodose lines, as derived from the film measurements are shown as dotted curves superimposed over the calculated ones by using our tretment planning system, represented by the unbroken isodose lines. Comparison between calculation and measurements shows excellent agreement for each planes. From these results, we can confirm our algorithm for each planes. From these results, we can confirm our algorithm for three dimensional treatment planning. Finally, three-dimensional isodose surface of single or multiple isocentric treatment for four arcs are displayed in Fig. 8 and Fig. 9.

DISCUSSION

The overall mechanical accuracy of our linear accelerator was within 2 mm. This accuracy was comparable to Lutz etal's[3].

The basic data such as percent depth dose, off-axis ratio and output factor were measured in order to get some information about an absorbed dose distribution in intracranial regions. The penumbral distances for our LINAC were greater than other published ones. This results were mainly due to not using circular collimator cones. For example, the measured penumbral distances for the 2 cm circular collimator reported by Lutz etal was 3.8 mm and those for the 2 cm×2 cm conventional rectangular collimator reported by us was 4. 7 mm. But using a conventional collimator system may have some advantages of circular collimator system in controlling irregular shaped tumors- especially cylindrical shaped tumors- by the conformal therapy based on beam's eye view. In this case, although the penumbral distances of single beams using the conventional collimator system are larger than those using circular collimator system, the dose gradients after 3 dimensional beam exposure was carried out proved to be steeper in case of using the conventional rectangu-

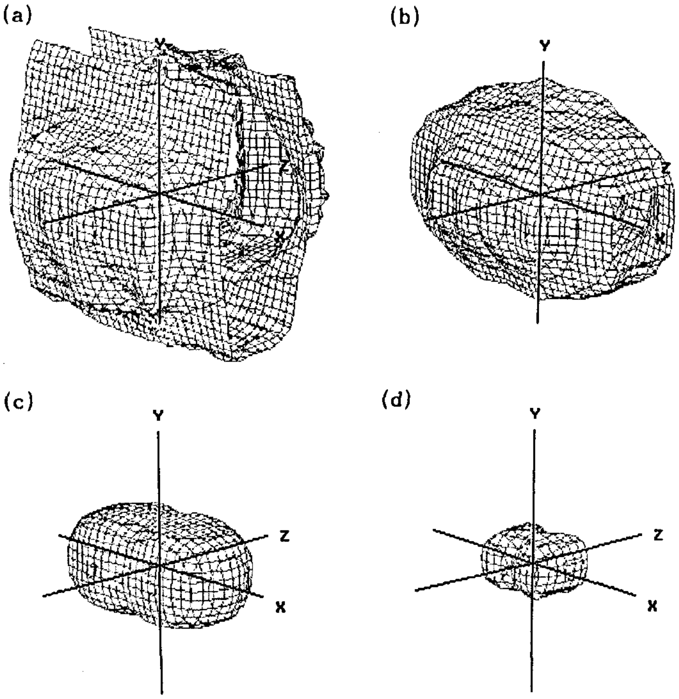

Fig. 9. 3-D isodose contours of double isocenter for four arcs irradiation. *(a) 10% isodose contour. (b) 20% isodose contour. (c)* 50% isodose contour. (d) 80% isodose contour.

lar collimator system14).

Based on these raw data, we could calculate and display three dimensional dose distributions by using our treatment planning system for LINAC radiosurgery. To calculate the three dimensional dose distribution, we used a single isocentric dose model and a newly developed algorithm. An IBM personal computer with C programming language (IBM personal system/2, Model 80386, 24 MHz, IBM Co., USA) was used to calculate the dose distribution in tumors. Isodose curve of one plane per beam is displayed by the calculation algorithm in 1.2 seconds after a dose calculation in 31×31×31 dose matrix. For example, the calculation time for the four arc beams including axial, frontal and sagittal planes, was about 3-4 minutes. With the use of more complex hardware, the computing time of our program can be reduced to an extent similar to the computing time of a commercially available system. Above all, the 3 dimensional display capability of our computer program may certainly improve a user's appreciation of absorbed dose distribution in intracranial region.

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= 국문초록 =

6-MV 선형가속기를 이용한 입체방사선수술의 선량측정 및 3차원적 치료계획

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방사선수술을 시행하기 위해서는 종양의 위치결정, 흡수선량 계산, 그리고 치료를 위한 특수제작된 기구와 컴퓨터 프로그램이 요구된다. 본 연구의 목적은 선형가속기의 전반적인 기계적 정밀도를 확인하고 선형가속기를 이용한 방사선수술에 있어서의 선량계산 알고리즘을 개발하는 것이다.

치료기계의 정렬과 전반적인 치료체계의 성과에 대한 점검을 행하였고 백분율 심부선량, 중심축외 선량비, 그리고 출력인자와 같은 기본 계산자료를 측정하였다. 또한, 입체방사선수술을 위한 3차원적 치료계획 체계를 개발하였다. 선량분포를 계산하기 위하여 C-언어를 이용한 컴퓨터 프로그램을 작성하였고 하드웨어로는 IBM PS/2(Intel 80386 SX, 24 MHz)를 사용하였다.

그 결과, 본 병원이 보유한 선형가속기의 겐트리와 테이블 회전에 따른 중심점에 대한 오차는 2 mm 이내로 방사선수술을 시행하기에 충분하였다. 팬톰실험에 따르면, 컴퓨터 단층촬영을 이용한 위치결정을 포함한 표적에의 빔의 일치도는 역시 2 mm 이내였다. 끝으로, 본원에서 개발한 3차원적 치료계획의 정확도는 필름을 이용한 선량측정을 통하여 입증되었다.