Dosimetric Characteristics of Multileaf Collimator-based Intensity-modulated Arc Therapy for Stereotactic Radiosurgery

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This study was designed to evaluate radiosurgery technique using multiple noncoplanar arc therapy with intensity modulated fine MLC shaped photon beam. The stereotactic radiosurgery was performed with 6-MV X-ray beams from a Clinac 21EX LINAC (Varian, Palo Alto, CA, USA) with a MLC-120, which features a full 40×40 cm field and is the first MLC for general use that offers 0.5 cm resolution for high precision treatment of small and irregular fields. We used a single isocenter and five gantry-couch combinations with a set of intensity modulated arc therapy. We investigated dosimetric characteristics of 2 cm sized spherical target volume with film (X-OMAT V2 film, Kodak Inc, Rochester NY, USA) dosimetry within 25×25 cm acrylic phantom. A simulated single isocentric treatment using inversely planned 3D radiotherapy planning system demonstrated the ability to conform the dose distribution to an spherical target volume. The 80% dose level was adequate to encompass the target volume in frontal, sagittal, and transverse planes, and the region between the 40% and 80% isodose lines was 4.0~4.5 mm and comparable to the dose distribution of the Boston Arcs. We expect that our radiosurgery technique could be a treatment option for irregular-shaped large intracranial target.

Key Words: Radiosurgery, Multileaf collimator, Intensity-modulated arc therapy, Dosimetry

INTRODUCTION

Stereotactic radiosurgery (SRS) is a specific type of external irradiation technique that has become an important method of treatment of small intracranial lesions such as benign or malignant brain tumors, isolated metastases and arteriovenous malformations. Nowadays, the most commonly used tool for radiosurgery is a 6~10 MV photon beam from a linear accelerator (LINAC), and the basic treatment technique is to apply multiple noncoplanar rotational arcs around the one or more intracranial targets using cylindrical cones.[1-5] As LINACs with fine leaf widths are now available, it may be possible to achieve clinically acceptable treatment plans for stereotactic radiosurgery. Recently, intensity-modulated radiation therapy (IMRT) is receiving increasing interest and may allow for an increase in the therapeutic ratio for treating stereotactically defined large, irregularly shaped intracranial targets. IMRT combines two advanced concepts to deliver 3D conformal radiation therapy using inverse treatment planning with optimization by computer and computer-controlled intensity modulation of the radiation beam during treatment. This study was designed to evaluate a radiosurgery technique, intensity-modulated arc therapy (IMAT), by using multiple noncoplanar arc therapy with intensity modulated fine MLC shaped photon beam. We evaluated the dosimetry of this treatment technique in comparison with conventional cylindrical collimation for the treatment of a spherical target volume in the brain.

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MATERIALS AND METHODS

The stereotactic radiosurgery was performed with 6-MV X-ray beams from a Clinac 21EX LINAC (Varian, Palo Alto, CA, USA) with a MLC-120, which features a full 40×40 cm field and is the first MLC for general use that offers 0.5 cm

resolution for high precision treatment of small and irregular fields. We used a single isocenter and five gantry-couch combinations with a set of IMAT (Table 1). Our system was five different couch angles separated by 30° each from longitudinal direction and one axial arc with lengths of 120° as Fig. 1. We used a 3-dimensional treatment planning system (Eclipse, Varian, Palo Alto, CA, USA), which was developed for IMRT. Each beam was weighted and intensity modulated to deliver a homogeneous dose to the surface of the target volume.

We investigated dose distribution characteristics using film (X-OMAT V2 film, Kodak Inc, Rochester NY, USA) dosimetry. The radiotherapy verification film was positioned at isocenter level within 25×25 cm acrylic phantom. We compared dosimetric characteristics for 2 cm sized spherical target with 2 cm sized cylindrical collimator of a LINAC based multiple arc system. The prescribed dose was assumed to be the minimum target dose, and all of the dose calculations were based on relative dose to a single isocenter. We used OmniPro IMRT software (Scanditronix Wellhofer, Sweden) to verify 2D dosimetry of film data.

Table 1. Physical characteristics of arcs.

Arcs	I	II	III	IV	V
Couch angle	+60°	+30°	0°	-30°	-60°
Rotation angle	330~210°	330~210°	300~60°	30~150°	30~150°

+: clockwise rotation of the couch. −: counterclockwise rotation of the couch.

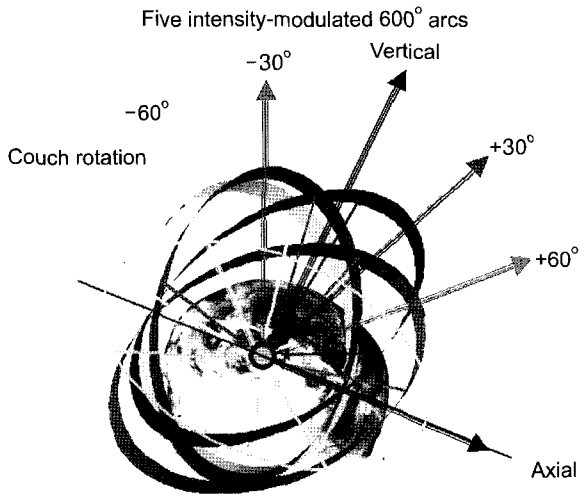

Fig. 1. A graphical illustration of arcs.

RESULTS

The first procedure for LINAC-based radiosurgery was to measure the isocentric accuracy of the gantry and treatment couch rotation. The mechanical and radiation isocentric accuracy of the treatment machine was 0.1 cm or less.

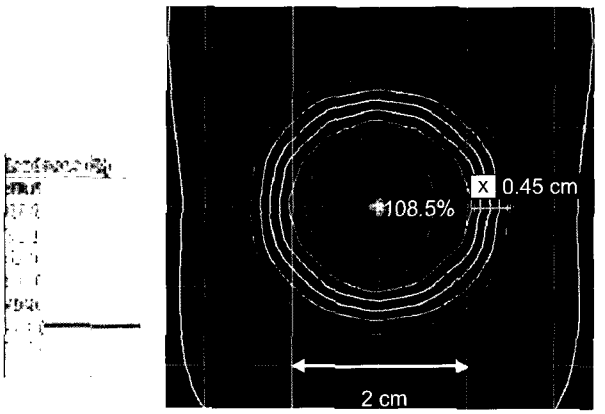

Fig. 2. Planned isodose contour for a 20-mm target volume in transverse plane.

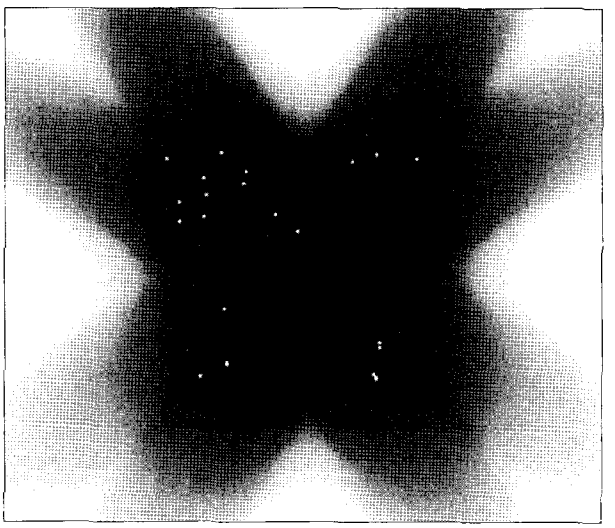

Fig. 3. Film verification of dose distribution in central transverse plane.

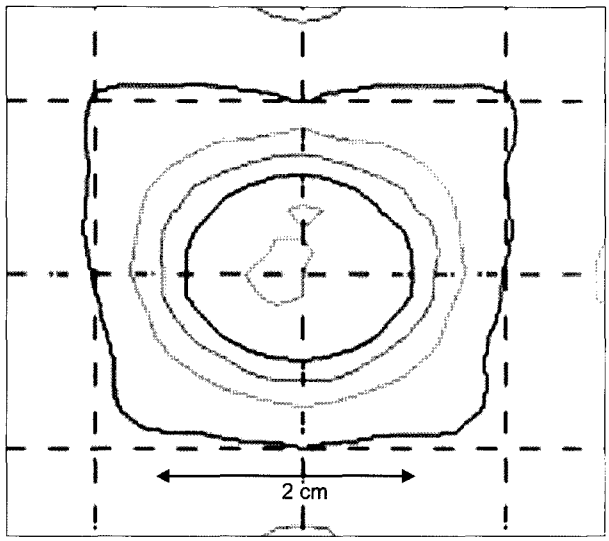

Fig. 4. Measured isodose contour in central transverse plane.

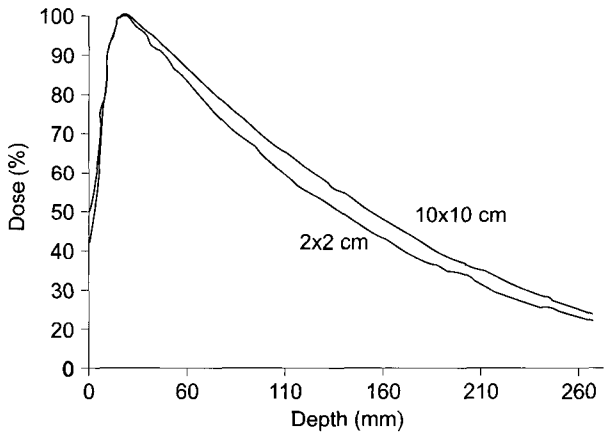

Fig. 5. PDD (Percentage Depth Dose) of 2×2 cm and 10×10 cm.

Fig. 2 showed dose distribution of planned isodose line. The isodose values ranged from 20 to 100% in increments of 10%. The 80% dose level was adequate to encompass the target volume, 2 cm diameter, in frontal, sagittal, and transverse planes, and the subdivision were spaced at 1 cm. Our radiosurgery technique showed that the region between the 40% and 80% isodose lines was 4.0~4.5 mm and verification film was as shown on Fig. 3. Two dimensional dose distribution was as shown on Fig. 4. Fig. 5 and 6 showed PDD (Percentage Depth Dose) and beam profile.

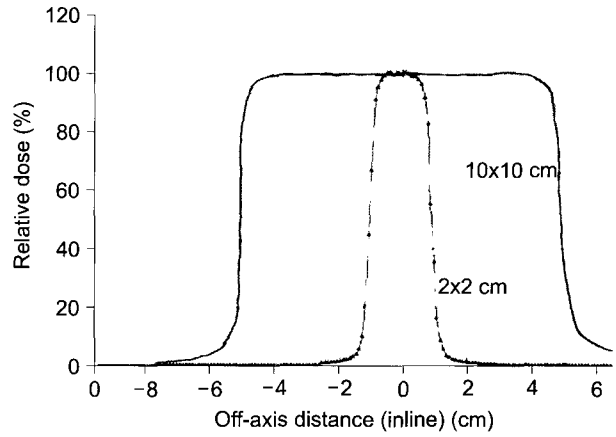

Fig. 6. Beam Profile of 2×2 cm and 10×10 cm.

DISCUSSION AND CONCLUSION

We started a LINAC-based radiosurgery system with cylindrical cone in 1991 using multiple arcs by a combination of rotational gantry and couch movements.[6] Linear accelerators with a computer controlled multileaf collimator are now available in most radiation oncology centers. Recent technological developments make implementation of intensity-modulated radiotherapy planning and high precision radiation delivery with fine multileaf collimators.[7]

Present study, we used a single isocenter and five gantry-couch combinations. Graham et al[1] and Schell et al[2] indicated that a 5-arc treatment technique appeared to be optimal for LINAC-based radiosurgery. We also implemented the intensity-modulated arc therapy (IMAT) to deliver highly conformal dose distributions by combining gantry rotation and dynamic multileaf collimation.

We demonstrated the clinical feasibility of a technique for LINAC-based SRS using existing LINAC equipped with 0.5 cm resolution fine MLC. For IMAT treatments, the leaves travel continuously, resulting in tighter conformity at the target boundaries, and providing a dosimetric advantage over 3D conformal radiotherapy. IMAT is an IMRT technique delivering intensity-modulated beams at all the beam angles around the patient with overlapping arcs.[8-10] Duthoy et al[11] used this technique in Whole abdominopelvic radiation therapy. We made use of advantage of dynamic MLC combined with

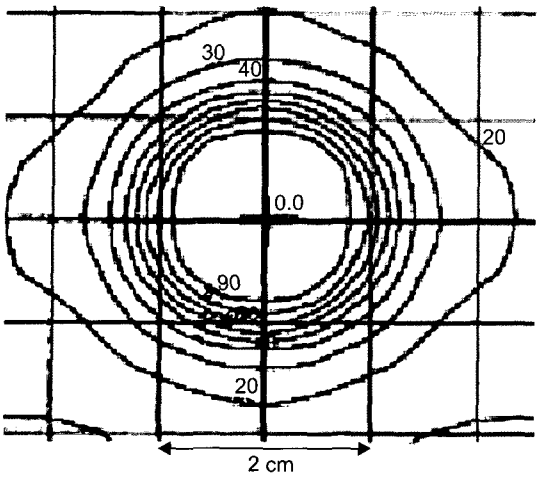

Fig. 7. Isodose contour for a 20-mm collimator in transverse plane.

noncoplanar arc rotation, and radiation delivery time would be decreased. Dosimetric characteristics of this technique was comparable to the dose distribution of the noncoplanar multiple convergent arc therapy in Boston Arcs (Fig. 7).[12]

Kubo et al[13] reported that micro-multileaf collimator (minimum leaf width of 0.3 cm) could improve conformity. But, Monk et al[14] demonstrated that improvements were quantitatively small.

We expect that the single isocentric, 0.5 cm resolution fine MLC-based SRS technique with intensity-modulation could be a treatment option for a irregular shaped target volume, and the time to deliver will be reduced in comparision with conventional cylindrical collimator technique. Although preliminary dose distribution was satisfactory, plans should be generated to test the dosimetric accuracy of the entire process from radiotherapy planning and radiation delivery prior to clinical application of this technique for variable sized, irregular shaped targets.

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방사선수술 시 다엽 콜리메이터를 기초로 한 IMAT의 선량분포

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본 연구는 세기 변조된 multiple noncoplanar arc를 이용한 방사선수술 기법을 평가하기 위해 고안되었다. 정위적 방사선수술은 0.5 cm resolution의 MLC가 장착된 6-MV X-ray beam을 사용하였다. 본 연구에서는 단일 중심점(single isocenter)으로 5 gantry-couch 조합을 이용한 intensity modulated arc therapy (IMAT)를 응용하였다. 저자들은 2 cm의 구형 표적용적에 대하여 25×25 cm 아크릴 팬톰으로 선량분포 특성을 조사하였다. 단일 중심점을 이용한 방사선조사에서 구형의 표적에 대하여 비교적 적절한 선량분포를 얻을 수 있음을 확인할 수 있었다. 80%의 선량 곡선이 frontal, sagittal, transverse planes에서 표적 용적을 적절히 포함하였으며, 40%와 80% 선량곡선 사이는 4.0~4.5 mm이었다. 이것은 cylindrical cone을 이용한 다른 연구자들의 선량분포와 유사한 결과였다. 따라서, 본 연구에서 사용한 방사선수술 기법을 비정형적 모양의 뇌내 표적에 대한 방사선수술시에 이용이 가능할 것으로 사료된다.

중심단어: 방사선수술, 다엽 콜리메이터, Intensity-modulated arc therapy, 선량분포