Extracranial Doses during Stereotactic Radiosurgery and Fractionated Stereotactic Radiotherapy Measured with Thermoluminescent Dosimeter in vivo

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INTRODUCTION

Stereotactic radiotherapy has been majorly applied to the intracranial targets as primary or metastatic brain tumors, benign tumors, vascular malformations as arteriovenous malformations(AVM) or angiographically occult vascular malformations(AoVM), and functional neurologic diseases as neuralgias since 1951, when Dr. Leksell, a Swedish neurosurgeon, used radiation making intentional lesions or destruction of the certain focus in the brain for the relief of pain instead of neurosurgery. The idea was contrary to the idea of advantage of fractionated radiotherapy in protracted time periods and almost forgotten until its clinical effectiveness and physical accuracy was accepted in 1980's. Leksell's Gamma Unit using 179 or 201 fine sources of Co-60, Synchrocyclotron, or linear accelerator(Linac) have been used for the clinical application of the technique. The Gamma Unit was the only apparatus in 1960's but Linac systems prevail the these days with the rapid development and imaging techniques as computerized axial tomography(CT) or magnetic resonance imaging(MRI) and of medical engineering (1, 2).

This technique can be applied just once or many times. Stereotactic radiosurgery(SRS) is an alternative to neurosurgery and single high-dose delivery of large dose of radiation from many non-coplanar directions toward well define targets of small volume usually less than 4 cm in diameter. But when the above technique is combined with fractionation, to get two birds at once with a stone, we can achieve physical and biological advantages. We can have a new way of taking advantages in beam delivery within 2 mm by precision immobilization for stereotaxy and also in reducing of normal tissue toxicity by fractionated beam delivery. That is the fractionated stereotactic radiotherapy(FSRT). Recently the usage of 3-dimensional non-coplanar radiotherapy technique is increasing toward intracranial and extracranial targets mainly for intrahepatic, pulmonary, or retroperitoneal/abdominal targets. (3)

We developed our own hardware and software system(Green Knife) for intracranial stereotactic radiotherapy using invasive stereotaxy in 1994 and system using for non-invasive fractionated stereotaxy in 1997. But the high dose can reach the extracranial normal tissue or organs after transmitting intracranial targets and thus unwanted damages can be elicited, because extracranial organs are usually not considered in planning of beam delivery. Thus it is very necessary to confirm the quantity and factors affecting that and make every efforts to reduce its affection if it is substantial. We have used the both systems for the clinical application. We measured the extracranial dose and its distribution during the above medical procedures to estimate effect of exit doses of stereotactic radiosurgery(SRS) and fractionated stereotactic radiotherapy (FSRT) of the intracranial target lesions using a linac system. We'd like to integrate and compare the doses by further extending of previous works (4,5,6)

MATERIALS & METHODS

Stereotactic radiotherapy procedure consists of stereotaxy for the reference of 3-dimensional coordinates of brain, acquisition of CT images with reference frame, dose planning for optimal beam delivery, and finally beam delivery and verification of accuracy.

For Green Knife SRS, a round reference frame(Fisher, Germany) was fixed to patient skull using 4 pins under local anesthesia of lidocaine in operation room. Axial CT was taken by 2-3 mm slice and then reconstructed in sagittal, coronal, and oblique plane at isocenter with intervals of 15 degree. For vascular lesions, transfemoral carotid angiography was also performed. Our routine plan consisted of 5-6 non-coplanar arcs at axial, sagittal, 3-4 oblique(-60, -30, +30, and +60) planes. Both procedures used 6 MV X-ray generated from a linear accelerator of Clinac-18(Varian, USA) without a beam stopper. The patients were monitored with 2 CCTVs during whole procedure and position accuracy was checked

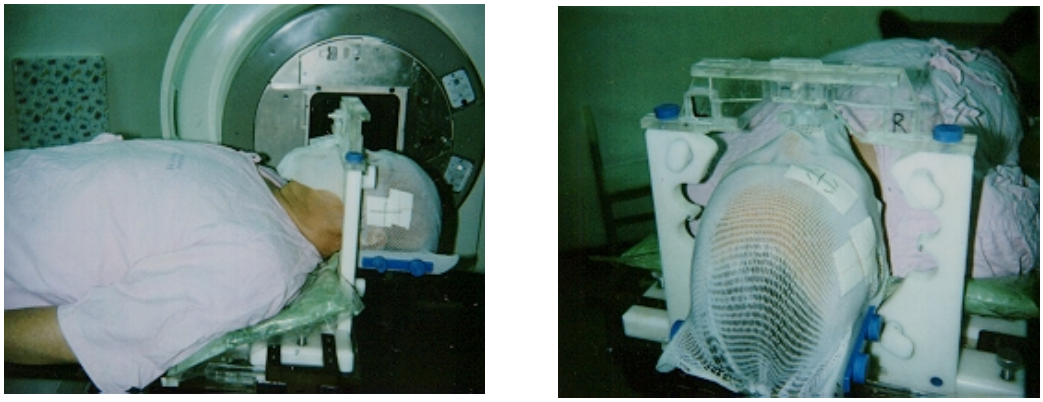

Figure 1. Set-up position of stereotactic radiotherapy using Green Knife system , which consisted of basic frame, aquaplaster immobilizer. TLD chips were attached on aquaplaster or skin at the pre-setermined extracranial points during stereotactic radiotherapy. .

before, during, and immediately after the stereotactic procedures. [Fig. 1 (A, B) & 2(A, B)]

For Green Knife FSRT, the same frame was attached to our own immobilizer and patient was fit tightly using Aqua-Plaster(Jun Sung, Korea), a thermoplastic and an integral bite block. Our routine plan consisted of 4 non-coplanar arcs at axial, sagittal, 2 oblique(-45 and +45) planes. Others were same as SRS procedures. Fractionation numbers depended upon indication of FSRT or performances status of patient.

Among over hundred patients who were treated with SRS or FSRT from 1995 to 1998, radiation dosimetry data of 15 cases with SRS and 20 cases with FSRT were analyzed. All patients were adults. Of SRS cases, 11 were male and 4 were female. Vascular malformation cases were 9, benign tumors were 3, and malignant tumors were 3. Of FSRT cases, males were 12 and females were 8. Primary malignant brain tumors were 5, benign tumors were 6, and metastatic brain tumors were 10.

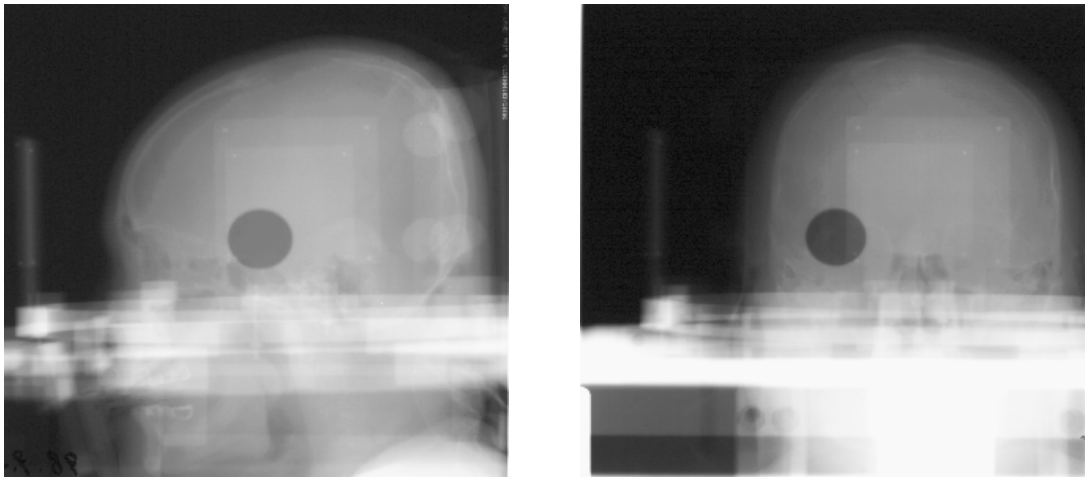

Figure 2. Verification films taken immediately after stereotactic radiotherapy procedure from lateral (left-side film) and anterior-posterior (right-side film) with basic frame attached with two pairs of rectangular coordinate makers imbedded with 4 lead balls that can be easily identified in ECL films(Kodak) in ECL cassette.

Doses were measured with lithium fluoride TLD chips(7.5% Li-6 and 92.5% Li-7; TLD-100, Harshaw/Filtrol, USA). The chips wrapped in were attached patient's skin at the various extracranial locations during SRS or FSRT. For SRS, 14-25 Gy were delivered with 1-2 isocenters using 12-38mm circular tertiary collimators with reference to 50-80% isodose line conforming at the periphery of the target lesions. For FSRT, 5-

28 fractions were used to deliver 9-56 Gy to periphery with dose maximum of 10-66 Gy.

RESULTS

Extracranial doses (relative doses) during SRS procedures were 8.07±4.27 Gy (0.31±0.16% Mean±S.D.) at the upper eyelids, 6.13±4.32 Gy (0.24±0.16%) at the submental jaw, 7.80±5.44 Gy (0.33±0.26%) at thyroid, 1.78±0.64 Gy (0.07±0.02%) at breast, 0.75±0.38 Gy (0.03±0.02%) at umbilicus, 0.40±0.07 Gy (0.02±0.01%) at perineum, and 0.46±0.39 Gy (0.02±0.01%) at scrotum. Thus the farther the distance from the brain, the less the dose to the location. In overall the doses were less than 0.3% and thus less detrimental.

Extracranial doses during FSRT procedures ranged 1.7 to 4.0 Gy in the head and neck region, 0.07 to 1.35 Gy for the other extracranial locations. Absolute doses were 2.11±2.84 Gy (0.73±0.84%) at the upper eyelids, 3.10±4.12 Gy (1.03±1.33%) at submental area, 3.60±4.48 Gy (1.44±2.18%) at submandibular region, 1.99±2.84 Gy (0.71±1.05%) at thyroid, 1.35±1.89 Gy (0.45±0.64%) at breast, 0.20±0.20 Gy (0.07±0.07%) at umbilicus, 0.07±0.05 Gy (0.03±0.02%) at perineum. From the relative doses below 1.6% in average, detriment from the mainly exit doses were less likely problematic.

DISCUSSION

Our data were obtained from serial measurement in single institute by the same x-ray, measurement method, and manpower. We confirmed that the dose to the extracranial organ inversely related with the distance from the brain during both SRS and FSRT procedures, which was rational and also fully anticipated.

But it is very interesting that there were some differences in patterns of doses according to the methods of stereotactic irradiation. Let's make some dosimetric comparisons. The dose to head and neck region ranged from 6 to 8 Gy (0.24 to 0.31% of maximum intracranial dose) during SRS procedures, in the mean while, the dose to head and neck region ranged from 2 to 3.6 Gy (0.71 to 1.44% of maximum intracranial dose) during FSRT procedures

In head and neck region, the absolute dose was 2 to 3-fold higher during SRS procedures compared to FSRT procedures but relative dose was different, it was 3 to 11-fold higher during FSRT procedures in comparison with SRS procedures. Why did this discrepancy happen? We can think several influential factors. First, the absolute dose by SRS technique is higher than that by single dose of FSRT technique. Thus even small percentage implied higher dose. Second, the size of the tertiary collimators for FSRT technique was larger than that for SRS technique. So likelihood of overlapping of exit dose with larger collimators was higher in head and neck area than with smaller collimators. Third, the probability of TLD chip within the direct exit region of single beam or overlapping beams was also higher because FSRT technique adapted larger collimators. But the last 2 factor might be contrary to the fact that smaller number of arcplane was used for FSRT technique.

Here, we must take the total dose into consideration. As we measured once, the total dose using FSRT technique should be multiplied with fractionation numbers. Thus the total dose using FSRT had a chance to be equal or even higher than that using SRS because SRS was without exception applied just once clinically. But there are another factors. Principle of 4Rs of radiobiology confirms that fractionated irradiation of certain dose is of less biological effectiveness in comparison with single irradiation of the same dose because repair during interfraction interval reduces biological effectiveness(7). This was the very reason why FSRT technique was developed in order to reduce the complication rate of the normal tissue within or just adjacent to the target lesion. As ICRP recommended DDREF(dose and dose rate effectiveness factor) as 2 for radiation protection, simple summation of the dose is not enough to get estimation of adverse effect from unnecessary dose to the extracranial areas, and to choose favorable technique among the SRS and FSRT in pure terms of radiation protection regardless of clinical indication or effectiveness. A probable way to get reasonable estimation might be comparison of doses using tertiary collimators of the same diameter or within reasonable range of size.

The dose to body ranged from 0.4 to 1.78 Gy (0.02 to 0.07% of maximum intracranial dose) during SRS procedures, in the mean while, the dose to body ranged from 0.07 to 1.35 Gy (0.03 to 0.45% of maximum intracranial dose) during FSRT procedures. While the tendency was as nearly same as those were in the head and neck region, the magnitude of difference was halved probably because of distances. The dose to head and neck and body with our Green Knife system was lower than dose measured during Gamma Unit system (8).

So were these amount of exit dose negligible and without clinical consideration as expected or low but potentially hazardous? We can estimate, using ICRP-60, risk of carcinogenesis as 0.5 % and genetic effect as 0.01 % in SRS and as 0.01 % and as 0% in FSRT(9). But we need a balanced view. We must think the expected life-threatening risk from natural behavior of target disease if SRS/FSR technique were not delivered for the patient. For example, patients have risk of 2-6% of hemorrhage per year and probability of death or severe neurologic sequel following each intracranial hemorrhage is 50% in arteriovenous malformation(10,11). But 80-90% of vascular malformations can be cured with SRS/FSRT (12, 13). So average risk of death is approximately

1% per year. But it quite different in the case of malignant tumors, be it primary or malignant, the risk of death is 100% when the tumor was not controlled even if SRS/FSRT were delivered. But for benignancy, we should seriously consider again risk estimates especially in childhood cases.

Thus although the benefit is overwhelming with SRS/FSRT than the estimated risk in extracranial regions, it would be better if we can further reduce the unnecessary dose to the normal tissues. There might be some precautions to be observed during planning procedures to achieve this goal. First, with any means direct beam exit through critical areas such as thyroid or breast should be avoided during optimization step. If prevention of direct exit is impossible, we can reduce exit dose by modifying its arcangle, adding other small arc, or reducing the weight of the arcplane.

But the most important and responsible factor resulting extracranial dose is stereotactic radiotherapy technique itself. We should not forget this simple fact. With this technique any part of the body inferior to the basic reference frame should be irradiated, because we can only use axial or cephalo-caudad beam directions. As far as we use this method, the problem of unnecessary irradiation of extracranial cannot be solved, however low dose it is. Keeping this fact in mind, we should plan and deliver SRS/FSRT optimally as well as reduce extracranial dose as low as possible to annihilate potential detriment.

CONCLUSION

The extracranial doses from stereotactic radiotherapy such as stereotactic radiosurgery or fractionated stereotactic radiotherapy was less than 1.5% of maximum doses in the intracranial target. Although total dose from FSRT procedures was not measured especially, the effects on the extracranial site from the both stereotactic radiotherapy procedures mainly from exit dose did not seem to be detrimental. But more protection of normal tissues could be obtained by minimizing directly exiting beams especially toward to thyroid, breast, or lenses. Further detailed data management with long-term follow up is necessary for the generalization.

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