Radiol Oncol 1998; 32(4): 417-21.

Thyroid doses due to stereotactic radiosurgery of the brain

Claudio H. Sibata, Carlos E. de Almeida, Ku Shin

Roswell Park Cancer Institute, Department of Radiation Medicine Buffalo, N.Y.

Background and purpose: Radiosurgery is an irradiation technique in which one high dose fraction or more is applied to a small intracranial volume stereotactically located. The technique is presently in use at the Roswell Park Cancer Institute and it uses 6 non-coplanar arcs, delivered by a 6 MV photon beam from a linear accelerator. One of the issues discussed in the most recent BEIR Report V is the radiogenic aspects of solid tumours and the risks related to external radiation. Thyroid carcinoma has been observed to increase consistently in a number of irradiated populations. The thyroid gland in children under 15 years of age, has one of the highest risk coefficients of any organ and is the only tissue with convincing evidence of risk at about 10 cGy. Since children of different ages may also present clinical situations that requires radiosurgery, an investigation was conducted to assess the doses to the thyroid and other nearby organs.
Materials and methods: In-vivo patient measurements were conducted, using TLDs and diodes at the surface of the patient neck corresponding to the thyroid plane as well as with the Alderson phantom for similar geometry and at 0,6 cm of depth in the same plane.
Results: The measured thyroid doses in the order of 10 cGy are essentially independent of cone size since the typical doses used in radiosurgery increases considerably as the cone size decreases.
Conclusions: A recommendation is made to eliminate or to displace the treatment arc which projection passes through the thyroid plane. This procedure must be adopted for children under 5 years of age and strongly recommended for children up to 15 years of age.

Key words: radiosurgery; thyroid gland - radiation effects; radiation dosage; thyroid neoplasm; arterio-venous malformations

Introduction

Stereotactic radiotherapy is an irradiation technique in which one high dose fraction or more is delivered to a small intracranial volume stereotactically located.[1-3]

It is used mainly for treating surgically inoperable arterio-venous malformations (AVM), brain metastasis and other small brain tumours. Radiosurgery can be generally performed in two ways:

Correspondence to: Prof. Carlos Eduardo de Almeida, PhD, Chairman, Laboratorio de Ciencias Radiologicas - LCR, Instituto Nacional de Cancer and Universidade do Estado do Rio de Janeiro, Rua Sao Francisco Xavier 524, Pav. Haroldo Lisboa, Rio de Janeiro, Brasil, CEP 205050-013

The author was Visiting Scientist at the Roswell Park Cancer Institute during the realisation of this work. This work was partially sponsored by CNPq.

1. Using the gamma-knife, a commercial unit that uses 201 focused beams from 201 Cobalt-60 sources, each with a nominal activity of 30 Ci, resulting in a dose rate of about 200 cGy/min at the isocenter.[4]
2. Using a linear accelerator with single plane full rotation or arcs,[5,6] multiple non-coplanar converging arcs[7,8] and dynamic radiosurgery,[9] all with small field sizes (1-3 cm).

The technique is presently in use at the Roswell Park Cancer Institute and it uses 6 non-coplanar arcs delivered by a 6 MV photon beam from a Varian linear accelerator model Clinac 2100 C and a stereotactic Fisher system. The stereotactic frame is fixed to the patient's skull by four screws and the localising rods attached to the base.

A CT image enables the localisation of the tumor and the internal structures of the brain in relation to the fidutial points in the stereotactic frame. The same mental assembly used during the CT examination is attached to the linac treatment couch in order to reproduce the patient's position during the CT images. The dose distribution is calculated using a treatment planing system also elaborated by Fisher.

Statement of the problem: Radiogenic cancer of the thyroid

One of the issues discussed in the most recent BEIR Report V[10] is the radiogenic aspects of the solid tumours and the risks related to external radiation. Thyroid carcinoma has been observed to increase consistently in a number of irradiated populations. Indeed, it was the first solid tumor to increase in frequency in the Japanese atomic bomb survivors, among persons exposed to therapeutic doses of X-rays as infants[10] and, on the Marshall Islands inhabitants exposed to radioactive fallout.[10]

Based on the on-going studies, the BEIR V Report suggest that:

1. The susceptibility to radiation-induced thyroid cancer is greater in early childhood than at any time later in life. Moreover the tumours usually become apparent after sexual maturation in those exposed before puberty.
2. Females are two to three times more susceptible than males to radiogenic as well as spontaneous thyroid cancer.
3. Radiogenic cancer of the thyroid is frequently preceded or accompanied by benign nodules, being generally a papillary growth.

The incidence of thyroid cancer as result of low LET radiation therapy of benign diseases in children is reported in five cohort studies; the Israel Tinea Capitis Study[10] the Rochester Thymus Study,[10] studies of children irradiated for enlarged tonsils in addition to two case control studies (patients with cervical cancer and childhood cancer) enhances the correlation between solid tumours and exposure to external radiation. The combined studies include almost 120 000 people (58 000 exposed and 61 000 unexposed). The thyroid gland in children under 15 years of age, has one of the highest risk coefficients of any organ and is the only tissue that shows convincing evidence of risk at about 10 cGy.[11]

During the radiosurgery treatment planing procedure, special attention is given to the potential doses to the brain stem or to the optical chiasm but the thyroid dose is normally overlooked since its plane is not imaged in the CT scans. Since children of different ages may also present clinical situations that require radiosurgery, an investigation was conducted in order to assess the doses to the thyroid and other nearby organs.

As a result of this study recommendations are proposed in order to minimise the potential risks involved with this procedure.

Materials and methods

This study was done using as a reference, the technique in use at the Roswell Park Cancer Institute which uses 6 non-coplanar arcs of a 6 MV photon beam from a Varian linear accelerator model Clinac 2100 C. In addition, the 18 MV photon beam from the same machine was used to verify the dose level in case this beam is used for radiosurgery.[12]

A complete treatment simulation of several clinical cases was done using an Alderson phantom and placing the TLDs at 0,6 cm of depth of a phantom slab corresponding to the thyroid plane and the diode at the surface in order to verify the adequacy of the two measuring techniques. *In-vivo* patient measurements were conducted, using a pair of TLDs and one diode per each irradiation (both systems with full build-up material for 6 MV photon) placed at the surface of the patient neck in a region located between the thyroid cartilage and the furcula.

The general specifications of the dosimetric systems used are:

1. Thermoluminescent dosimeters. Lithium fluoride LIF-100 conventional chips were selected from a large batch of the existing chips with a reproducibility better than 2% and sensitivity high enough for the doses used in this study. The annealing routine for pre-irradiation was 400 °C for 1 hour and 100 °C for 2 hours and a pre-reading treatment of 100 °C for 15 min.
2. Energy compensated diodes. The photon diodes model Isorad used were manufactured by Nuclear Associates. They have cylindrical shape, diameter of 7.1 mm, sensitive volume of 0.25 cc, wall thickness equivalent to 600 mg. cm^{-2} and dose linearity better than 0.5%. The angular dependence was not considered once the diodes were always placed with its main axis perpendicular to the beam direction, geometry similar to the one used for its calibration.

Both systems were calibrated at 5 cm of depth in a lucite phantom, using a 6 MV photon beam and a calibrated 0,6 cc Farmer type ionisation chamber.

An individual calibration factor for 6 MV was assigned to each individual diode and the TLD as well.

In order to improve the signal measured the exposure time of each arc was increased by 3 times and the doses measured were normalised for the typical prescribed dose of 1500 cGy.

The combined uncertainties of Type A and Type B for 1 sigma, involving all steps of the calibration and measurement procedures are smaller than 3%, largely due to the intrinsic characteristics of the detectors such as 2,0 % for the TLDs, 1,5 % for the diodes and 1,0% for the beam calibration with the ion chamber.

Results

The results of the measurements made at the phantom and patient surface with TLDs and diodes were identical to the ones made with TLDs at 0,6 cm of depth in the phantom.

The measurement results of the added doses due to the complete treatment simulation using the 6 arcs as well as of each individual arc clearly indicates that the thyroid doses are essentially due to the contribution of the beam when it passes through the midline of the brain with negligible contributions from room scatter and machine leakage.

The magnitude of the thyroid doses is essentially the same, in the order of 10 cGy, as indicated in Figure 1 curve D, being slightly independent of the cone diameter since the prescribed tumour doses may vary significantly according to cone diameter. The typical maximum doses for a treatment of an AVM at the 80% isodose line may range from 1200 cGy for a 35.2 mm cone diameter at the isocenter to 4000 cGy for a 10 mm cone diameter depending on each clinical situation.[13,14]

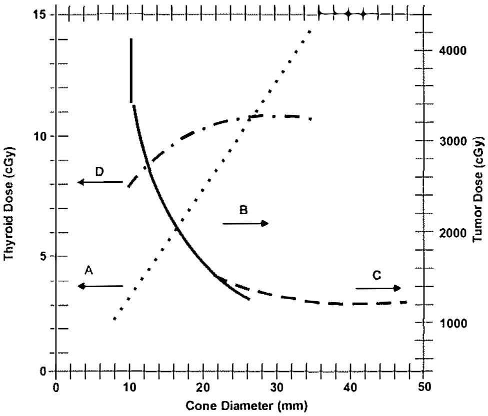

Figure 1. Thyroid doses to radiosurgery of the brain.
Curve A - Thyroid doses measured in the Aldreson Phanton for different cone sizes and a fixed tumor dose of 1500 cGy.
Curve B - Typical tumor doses used by Flickinger.
Curve C - Typical tumor doses used by Kjellberg.
Curve D - Thyroid doses as described in Curve A, normalized for the typical doses shown in Curves B and C, as function of cone size.

Additional measurements have shown an appreciable thyroid dose reduction (50-70 %), for all cone diameters when the treatment target is located 5 to 20 mm laterally from the midline. On the other hand, the displacement of the isocenter depth only 2.5 cm towards the thyroid, is sufficient to increase the thyroid doses by 30 %.

However, when the treatment target is laterally displaced 5 to 20 mm from the midline, the eye doses may increase by as much as 80%.

Finally, the doses measured for the same sites and geometric situations where a 18 MV photon beam is used, are 30-40% higher than the ones measured with a 6 MV photon beams one would expect.

Conclusions and recommendations

The results of the present work clearly indicates that the thyroid doses due to radiosurgery may be easily reaching the current acceptable risk rate for this organ.

In order to reduce the thyroid doses to a minimum, it is recommended to eliminate the arc or plane of rotation that passes through the midline of the brain or whenever its projection is close to the thyroid. This procedure must be used for treating children under 5 years of age and strongly recommended to children up to 15 years of age.

References

1. Houdek PV, Fayos JV, vanBurren JM, Ginsberg MS. Stereotactic radiotherapy technique for small intracanial lesions. *Med Physics* 1985; **12:** 469-72.

2. Larsson B, Liden K, Sarby B. Irradiation of small structures through intact skull. *Acta Radio Ther Phys Biol* 1974; **13:** 513-34.

3. Lecksell L. Stereotactic method and radiosurgery of the brain radiosurgery. Acta Chi *Scan* 1951; **102:** 316-19.

4. Wu A, Lindner G, Maitz AH, Kalend AM, Lunsford LD, Flikinger JC, Bloomer WD. Physics of gamma knife approach on convergent beams in stereotactic radiosurgery. *Int J Radiat. Oncol Biol Phys* 1990; **18:** 941-9.

5. Betti OO, Derechinsky VE. Hyperselective encephalic irradiation with linear accelerator. *Acta Neurochir* 1984; **33** Suppl: 385-90.

6. Lutz W, Winston KR, Maleki N. A system for stereotactic radiosurgery with a linear accelerator. *Int J Radiat Oncol Biol Phys.* 1988; **14:** 373-81.

7. Colombo F, Benedetti A, Pozza F, et al. External stereotactic irradiation by linear Accelerator. *Neurosurgery* 1985; **16:** 154-160.

8. Blomgren H, Lax I, Naslund I, Svanstrom R. Stereotactic high dose fraction radiation therapy of extracranial tumors using an Accelerator. *Acta Oncol* 1995; **34:** 861-70.

9. Podgorsak EB, Olivier A, Pla M, Lefebvre PY, Hazel J. Dynamic stereotactic radiosurgery. *Int J Radiat Oncol Biol Phys* 1988; **14:** 115-25.

10. Committee on the Biological Effects of Ionizing Radiation. BEIR report. *Health effects of exposures to low levels of ionizing radiation.* Washington, DC: National Academy Press; 1990.

11. Ren G, Lubin JH, Shore RE, Mabuchi K, Modan B, Pottern LM, Schneider AB, Tucker MA, Boice JD.

Thyroid cancer after exposure to external radiation: A pooled analysis of seven studies. *Radiat Res* 1995; **141:** 259-77.

12. Radiation Therapy Committee. *AAPM report no. 54. Stereotactic radiosurgery. Report of the Task Group 42.* 1995.

13. Flickinger JC, Schell MC, Larson LD. Estimation of complications for linear accelerator radiosurgery with the integrated logistic formula. *Int J Radiat Oncol Biol Phy.* 1990; 19:143-8.

14. Kjellberg RN, Hanamura T, Davis KR, et al: Bragg-peak proton beam therapy for arteriovenous malformations of the brain. *N Engl J Med* 1983; **309:** 269-74.