Image Guided Intensity Modulated Helical Radiation (Tomotherapy) Used as a Radiosurgical Tool

Radiación helicoidal (Tomoterapia) guiada por imágenes de intensidad modulada utilizada como herramienta radioquirúrgica

Eduardo E. Lovo MD
Victor Caceres MD
Fidel Campos MD
Emelda Molina BSc

RESUMEN

Introducción: Tomoterapia (HT) es un acelerador lineal sobre una Tomografía Computarizada (CT), es helicoidal por naturaleza e implica un CT de megavoltaje diario el cual es fusionado con el plan radioquirúrgico previo antes de entregar la dosis radioterapéutica (Radiocirugía Guiada por Imágenes). Esta tecnología es nueva a nivel mundial; hasta nuestro conocimiento, este es el primer reporte de radiocirugía intracraneal en Latinoamérica utilizando HT. Se describe la distribución de dosis en dianas pequeñas, así como también el flujo normal de un paciente y nuestra experiencia inicial.

Material y métodos: En el análisis de irradiación de pequeñas dianas (PTV), una esfera de 10 mm (0.51cc volumen) fue elaborada. Los PTVs fueron puestos en el isocentro y a 100 mm por encima del isocentro, al PTV se le prescribió 6 Gy a la línea del 85% de la isodosis, con un máximo de 9.0 Gy y un mínimo de 4.7 Gy. Describimos el flujo normal del paciente y de manera retrospectiva nuestra experiencia inicial desde febrero del 2011 a agosto del 2011 en radiocirugía intracraneal.

Resultados: Los resultados del control de calidad (DQA) muestra una conformalidad (CI) de 1.14, homogeneidad (HI) de 1.51 y comportamiento de la caída de dosis al 50% con relación al PTV de 4.6 mm. Trece pacientes fueron tratados recibiendo 36 sesiones de radiocirugía.

Conclusiones: Radiocirugía con HT, es altamente conformal, homogénea, con caída de dosis rápida, comparable con otros sistemas de radiocirugía estereotáctica (SRS) ya conocidos, es no invasivo y usualmente requiere de poco tiempo para su aplicación.

Palabras-clave: Tumor cerebral, radiocirugía, Cirugía, Radioterapia de intensidad modulada.

ABSTRACT

Introduction: Tomotherapy (HT) is a Linear accelerator mounted on a Computerized Tomography (CT), it is helical in nature, its application implies a megavoltage CT image acquisition which is fused daily to the radiosurgical plan that has been done previously (Image Guided Intensity Modulated Radiosurgery). This technology is new worldwide; to our knowledge this is the first report of intracranial radiosurgery in Latinamerica with HT. We describe dose distribution in a small target, as well as normal case flow and our initial intracranial experience.

Methods: For the analysis of irradiation of a small target (PTV), one 10 mm spherical (0.51cc volume) target was elaborated. The PTVs where placed in the isocenter and 100 mm above the isocenter, the PTV received a 6 Gy prescription to the 85% isodose line, with a maximum dose of 9.0 Gy and a minimum of 4.7 Gy. We describe normal patient flow and retrospectively report our early experience from February 2011 to August 2011 of intracranial radiosurgical cases.

Results: The results of our Quality Assurance (DQA) on phantom studies show a very conformal (CI) 1.14, and homogeneous (HI) 1.51 dose behavior with a fall-off to 50% with regards to PTV of 4.6 mm, thirteen patients had been treated receiving 36 radiosurgical sessions.

Conclusions: Radiosurgery with HT, it is a highly conformal, homogeneous with steep dose falloff, comparable to other stereotactic radiosurgical (SRS) tools, it is non invasive and it usually is a very low time consumption technique.

Key words: Brain tumor; Radiosurgery; Surgery; intensity modulated radiotherapies; Cerebral Neoplasm.
INTRODUCTION

Radiosurgery is the delivery of a high dose of radiation to a small area in the body, using high precision in order to destroy tissue without the need of incisions, it is generally carried out on a single dose but fractionation to multiple sessions (less than 5) is possible. Its precision is defined by conformality and high precision in spatial localization and dose delivery to target. It is widely used for malignant lesions such as metastasis or primary tumors in the brain or elsewhere, but it can also be used to treat benign tumors such as meningiomas or vestibular schwannomas, its radiobiological effect is also used to treat other non oncological pathologies such as arteriovenous malformations (AVMs) or trigeminal neuralgia.

Stereotactic Radiosurgery (SRS) was developed by Professor Lars Leksell in Stockholm, Sweden in 1967 when he introduced the first Gammaknife prototype. Stereotactic localization methods were the first adjuncts developed for localizing targets inside the cranium, relying in the principle that external fiducials, can convert an irregular structure such as the brain in to a “virtual box” where targets inside of it could be localized with millimetric precision utilizing the cartesian (X,Y, and Z) method.

Since then, great technological evolution has occurred in radiology, computer capacity as well as significant advances in the understanding of radiation, radiobiology and beam modulation, this has allowed radiosurgery to be accomplished by means of image guided technology (Cyberknife and Tomotherapy are current examples), machines that no longer rely on stereotactic principles or fixed isocenters, allowing one day single fraction treatments in a similar way than Gammaknife but extending their capacities from the brain to the whole body.

The introduction of the newer technologies of Image Guided Radiation Therapy (IGRT) and Intensity Modulated Radiation Therapy (IMRT) were two of the most important technical developments introduced recently in the use of external beam radiation therapy to treat cancer or benign lesions. The Tomotherapy system provides both technologies; IGRT and IMRT, as it is the marriage of a megavoltage Computerized Tomography (MV-CT) scanner and a 6 MV linear accelerator (LINAC), sharing the same source of radiation and delivery system. The radiation delivery is helical in nature, hence the denomination Helical Tomotherapy (HT) (Figure 1). The Tomotherapy Hi-Art treatment system is described extensively elsewhere, in short: a linear accelerator that is decoupled to an end point energy of 3.5 MV for MVCT imaging purposes and for radiation therapy is used with and end point energy of 6 MV. Both the imaging procedure and radiation delivery, are helical in nature as the radiation is delivered to a plane of the patient while he/she is axially translated by a moving couch. Its difference in design with regards to the traditional C-arm LINACs allows it to perform a daily MV-CT that assures that the treatment delivery is the same every day as previously explained, the design also allows beams to be delivery from 360 degrees around the patient allowing modulation of energy to approximately 50,000 beamlets, in fields as small as 5 mm to fields as large as 1600 mm, making it extremely conformal in dose distribution, superior to cone based LINAC radiosurgery, or other dynamic conformal arc systems used for intracranial radiosurgery.

This technology is new worldwide the first human that was treated was in 2002 at the university of Minnesota by Professor Metha. In Latin America it is currently very sparse, there are only two systems currently operational, the Centro Internacional de Cancer of the Hospital de Diagnostico of El Salvador was the second institution in Latin-America to incorporate Tomotherapy as the technology for radiation delivery and the first to incorporate a Body Radiosurgery Program (BRS) in the region.

This article describes the process our program experienced in order to determine conformality, homogeneity and dose fall-off in small targets, it describes how immobilization, and image fusion, as well as the normal “flow” of an intracranial radiosurgical procedure is carried out in our center, lastly it summarizes treatment and patient characteristics to date. To our knowledge this is the first paper to report radiosurgery with Tomotherapy in the Latin-American literature.
METHODS

All procedures including the DQA (Dosimetry Quality Assurance) plans for small targets where done using the Tomotherapy-Hi Art System (Tomotherapy Incorporated, Madison WI, USA) which uses a singular binary multi-leaf collimator with 64 leafs of 3 mm at its minimum thickness. The study was carried out in the Centro Internacional de Cancer of the Hospital de Diagnostico of El Salvador, Central America with collaboration from SouthWest Oncology Centers (Arizona USA).

For the DQA of a small target, one 10 mm target was elaborated to demonstrate the variations and adequacy of planned versus delivered dose of radiation in small targets in an ion chamber inside our cheese phantom (Exradin, model A1SL, Standard Imaging Inc Middleton WI, USA), being the volume of the chamber 0.057cm3. The plans simulated was a spherical lesion of 10 mm and where placed in the isocenter of the cheese phantom and 100 mm above the isocenter, the target (PTV) was irradiated to an internal 5 mm structure with 7.5 Gy to the 95% isodose line in order to give an 85% coverage to “true” PTV of 10 mm (0.51cc volume) which would receive the desired dose of 6 Gy, (Figure 2), in the midline of the cheese phantom a film was placed for irradiation to the entire volume of the target for all cases. The film was scanned by VIDAR Film Digitalizer (Vidar System Corporation, Herndon VA, USA) and analyzed by the Film Analyzer by Tomotherapy Inc.

Conformity Index (CI=The volume described by the prescription curve/volume of the PTV), Homogeneity Index (HI= Dmax/Dpresc) and Dose fall-off distance to the 50% isodose where calculated (R50 Radius of 50% isodose – R100% Radius of 100% isodose).

NORMAL PATIENT FLOW FOR RADIOSURGICAL PROCEDURES

First, a Magnetic Resonance Image (MRI) is performed using the Magneton Avanto (Siemens Inc., Erlanger, Germany) with the gantry at a 0 angle, a T1 axial sequence with gadolinium (Gadoversetamide 0.5%, OptiMark, Mallinckrodt, USA) is what we normally use with 1 mm slices without any spacing in between them, using a 256x256 field of view format. This image is transferred via intranet to the MIM Vista Planning Software (MIM software Inc. Cleveland OH, USA) at the Centro Internacional de Cancer where organs at risk (OAR), normal cerebral structures or extracranial anatomical structures are contoured as well as the lesions to be treated. On a different day or the same day a CT image (Somatom Sensation 6, Siemens Inc. Erlangen, Germany), is taken of the patient fixed to a non invasive immobilization devise either via thermoplastic facemask or Aktina PinPoint System (Aktina Medical Inc. Congers NY, USA) with Alpha Cradle setup (figure 3). Once the patient is fixed in position and adequately immobilized a CT image without contrast is acquired. The CT is set to obtain 1 mm slices without spacing, with the gantry at 0 degrees (in the same fashion as MRI), this image is sent to MIM Vista planning station via intranet as well.

At MIM Vista planning station both MRI with contours and CT are fused and this image is sent to the Tomotherapy Planning System to give way to the treatment distribution of dose and...
optimization according to medical prescription to target and structures at risk. Once the plan is approved by Neurosurgeon and Radiation Oncologist a final application is done for treatment and opened at the operator (therapist) station.

A specific DQA is done for every patient in the same way it was described earlier for small targets. The profile differences are analyzed between the calculated and measured dose which should be below two percent.

On treatment day the patient is placed in the Tomotherapy unit mimicking as close as possible the immobilization parameters taken on CT during simulation, once this is achieved (guided via lasers) a megavoltage CT is taken by Tomotherapy, treatment table adjustments can be done on a sub-millimetric fashion so the image fusion between Tomotherapy (Megavoltage CT) and simulation (Kilovoltage CT) match adequately, being this a true Image Guided Radiosurgery (Figure 3 and 4). Once fusion has been approved (Neurosurgeon and Radiation Oncologist), the dose of radiation is delivered.

Figure 4. (A). Axial T1-Gadolineum MRI that shows in red circles two of the three metastatic lesion to be treated of a nasofaringeal carcinoma. (B). Screen shot of optimization process that determines the way energy will be distributed. (C). Screen shot of image fusion process, the axial CT view has a checkered overlay of megavoltage CT in blue that was done before treatment by Tomotherapy, over the planed kilovoltage CT in white and gray. (D). Axial T1-Gadolineum MRI, three months after treatment red circles encompass were the tumors used to be, now areas of encephalomalacia.

Normally for radiosurgery we use a size of voxel equal to 1 mm (Fine by Tomotherapy parameters) a field of width of 10 mm jaw, using a PITCH of 0.1 (Distance traveled by the treatment table per rotation of the gantry, divided by the width of the field which is 10 mm).

RESULTS

DQA for small targets
Dosimetry Quality Assurance dose profiles comparison of calculated to measured dose where calculated: being the dose variation in the ion chamber for 10 mm and at 100 mm from isocenter of +1.2% overall. Conformity Index (CI) was 1.14 (with a recommended tolerance of 1-2 according to RTOG), Homogeneity Index (HI) was 1.51 (< than 2 RTOG recommendation). Dose fall of distance to the 50% isodose was 4.6 mm on average (Figure 2). The minimum dose to PTV was 80% (minor variation according to RTOG recommendations)

Clinical cases
From the first of March to the first of August of 2011, 13 patients had received intracranial radiosurgery treatments, nine where female (69%), four where male (31%), median age was 43 (14-74), with a total of 36 intracranial radiosurgical sessions, six patients were treated on a single session, the rest using fractionated radiosurgical schemes. The amount of tumors treated were 17 (Figure 5 for histology), median tumor volume was 5.5 cc (0.05-11.96), isodose line was targeted to the 95% on average (90-98) of the tumor volume, median dose to single session treatment was 16.9 Gy (16.06- 17.53) and for 22.8 Gy (20.4-26) for fractionated treatments. The overall treatment time (Beam “on” Time) was 12.6 minutes (3.1-23) an additional seven minutes on average where invested in positioning and MV-CT. There were 2 (16%) grade 1 (headache) Central Nervous System Morbidity (Fully functional status, according to RTOG Acute Radiation Morbidity Scoring Criteria).

Figure 5. Tumor histology.
**DISCUSSION**

Helical Image Guided Radiotherapy by ways of Tomotherapy is less than a decade old, less to say radiosurgical procedures with this system, none the less, experience and knowledge on its radiosurgical capacities has been gained in various centers around the world.

Tomotherapy has the possibility to open its jaws at 1 cm, 2.5 cm, y 5 cm in the longitudinal direction (Y) and up to 40 cm in the transversal direction. The multileaf collimator projects a beam width of 6.25mm on the transversal axis for each leaf at the isocenter. This allows having a physical minimum field width of 6.25mm x 10 mm. None the less conformality of radiation to smaller targets is possible with acceptable penumbral effects. This is what was demonstrated in our DQA and already described by others. With regards to dose falloff our results are slightly better than what has been documented already with HT, which is normally around 5.4 mm ours was on average 4.6 mm, this is probably attributed to the internal ring inside the PTV as this “PTV” is the one we truly target with a purposely higher dose, allowing dose to begin its fall-off inside the true PTV to the real prescribed dose, and the true PTV (10 mm target) functions as a restriction structure to make the dose fall-off even steeper. This is what we clinically perform in our plans as we have seen that we can “model” dose away from OAR more efficiently and this can be done heterogeneously inside the tumor to give more dose or less dose intra-tumor according to the OAR we wish to protect. What we have seen with this approach is that usual isodose lines of 98% to PTV might be lower (89-95%) but intra-tumoral dose is higher.

It has been in our experience that modulation with Tomotherapy is different than most radiosurgical systems, as the latter conform multiple isocenters (small spheres of energy) to try and “fill” the tumor with energy; Tomotherapy tries to solve the problem by shaping the radiation dose to the tumor and “containing” the energy in accordance to the restrictions applied and to the importance assigned to them. This explains why Gammaknife targets usually to the 50% isodose line and Tomotherapy to the 90-98% isodose line.

An advantage that Tomotherapy has to other systems is that it does not depend on a mechanical isocenter, so it can treat various lesions simultaneously virtually in any part of the body. Our center to date has given more than 30 (unpublished data) radiosurgical session to lung, liver, spine and head and neck area.

Radiosurgery has demonstrated to be an efficient way of treating intracranial and extracranial lesions independently of what machine delivers it or what type of energy is used, all systems have all ready been analyzed carefully with regards to dose distribution and precision. It is fair to say that all systems have strengths and weaknesses. Tomotherapy was chosen by us as our principle way of administering radiation and radiosurgery because it seemed as the most versatile system in the market, it is more costly than regular C-Arm Linear Accelerators but it seems to have advantages such as not requiring any additional “add-ons” such as cones or special collimators in order to give radiosurgery, so normal workflow of radiosurgery is no different than radiation therapy workflow, augmenting the amount of patients that can be treated daily. Intracranial radiosurgery is totally non-invasive, free of pain, and usually the amount of time that the patient is in the clinic lasts less than thirty minutes.

The down side we see in this technology is that the dose-falloff reported is inferior in comparison to Gammaknife and healthy tissue sparing is less when Tomotherapy is used, at least in dosimetric comparisons.

Although this work is descriptive in nature and does not share clinical results, we believe that its value lays in the description of a treatment modality that due to its novelty radiosurgery with Tomotherapy is still rarely performed in the world, and it is completely new to Latin America.

**CONCLUSIONS**

Tomotherapy DQA plan analysis for radiosurgery in small targets proved to be compliant to current RTOG standards. Although the experience here reported is limited, intracranial radiosurgical treatments have been carried out without invasive fixation and with little discomfort to patients. Clinical results are yet to be analyzed.

**ACKNOWLEDGMENTS**

A very special token of appreciation to Carlos Caballero PhD, and to all the staff of South West Oncology Centers, Arizona.
for transmitting to us so much knowledge in the use of this technology, your effort will be perceived for generations to come and endless patients that are being benefitted in their treatments.

REFERENCES


CORRESPONDING AUTHOR

Dr. Eduardo E. Lovo.
Centro Internacional de Cáncer, Hospital de Diagnóstico de El Salvador. 3ra calle poniente, Block #122, Colonia Escalon, Zona 11.
Phone. (503) 2528-2001 Fax: (503) 2264-5183
E-mail: info@drlovo.com

Disclosure
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.