Technical Note

Radiosurgical third ventriculostomy: Technical note

Guillermo Axayacalt Gutiérrez-Aceves[1], Sergio Moreno-Jiménez[1], Miguel Ángel Celis[1],
Mariana Hernández-Bojórquez[1,2]

[1]Radioneurosurgery Unit, Department of Neurosurgery, National Institute of Neurology and Neurosurgery, [2]Escuela Superior de Física y Matemáticas, Instituto Politécnico
Nacional, México City, México

E-mail: *Guillermo Axayacalt Gutiérrez-Aceves - neuroaxa@gmail.com; Sergio Moreno-Jiménez - ser_radioneurocirugia@yahoo.com.mx;
Miguel Ángel Celis - dirmedica@innn.edu.mx; Mariana Hernández-Bojórquez - mariana.hernandez.b@gmail.com
*Corresponding Author

Abstract

Background: We describe a minimally invasive technique to perform a radiosurgical third ventriculostomy in a patient with mild obstructive hydrocephalus secondary to malignant pathology.

Methods: A 42 years old woman with diagnosis of clear cells renal carcinoma and with right nefrectomy performed last year. Cranial Magnetic Resonance Imaging showed two brain metastasis: one right temporal, and other in the pons with Sylvian aqueduct partial obliteration and mild ventricular enlargement. The patient received radiosurgical treatment for brain metastasis; after this procedure a new target was defined on the floor of the third ventricle, in the midpoint between the mamillary bodies and the infundibular recess where we delivered 100 Gy delivered by an isocentric multiple noncoplanar arcs technique, with a 6 MV Novalis® dedicated LINAC. A series of 21 arcs was arranged with a radiation field generated by a 4 mm circular collimator.

Results: One week pos-irradiation in the head CT we did not find significant changes in the metastatic lesions; however the VSI diminished 4%, despite of persistent aqueduct obliteration. At three months we perform 3.0 T MRI where we confirmed the presence of the third ventriculostomy (2.63 mm diameter).

Conclusion: This report demonstrates, for the first time, the ability of a dedicated LINAC to perform a precise third ventriculostomy without associate morbility in short term.

Key Words: Linear accelerator, minimally invasive, obstructive hydrocephalus, radiosurgery, third ventriculostomy

"A technique for the non-invasive destruction of intracranial tissues or lesions…(in which) the open stereotactic method provides the basis…"

Larks Leksell

BACKGROUND

Hydrocephalus has been recognized as a clinical and pathological entity since the days of Hippocrates. Dandy and Blackfan proved the existence of two distinct types of

hydrocephalus: (1) the obstructive or noncommunicating type, and (2) the nonobstructive or communicating type.[2,23] For the treatment of obstructive hydrocephalus, Von Bramann in 1908 reported the puncture of callosum for draining ventricular cerebrospinal fluid (CSF) into the subarachnoid space (the Balkenstich operation).[19] In 1922, Dandy devised third ventriculostomy, an operation by which a surgical opening is made through the thinned-out floor of the third ventricle and the interpeduncular subarachnoid cistern.[23]

In 1923, Mixter performed the first endoscopic third ventriculostomy on a 9-month-old girl with noncommunicating hydrocephalus. He used a urethroscope directed into the third ventricle and a flexible sound for fenestration under visual guidance. Since its introduction many operative techniques have been proposed and applied.[2,11,31]

We report the use of linear accelerator (LINAC)-based radiosurgery (stereotactic radiosurgery [SRS]) as a tool to perform the third ventriculostomy in a patient with mild obstructive hydrocephalus.

CASE DESCRIPTION

We present a 42-year-old woman with diagnosis of clear cells renal carcinoma (Furhman 2 and Robson II), and with right nefrectomy performed last year. She was referred with a 5-month history of: dizziness, vomiting, diplopia in the horizontal gaze, quadriparesis predominantly in the inferior limbs, headache, disphagia, and disarthria. Cranial magnetic resonance imaging (MRI) and computed tomography (CT) showed two metastasis: one in the fifth right temporal circunvolution, and other in the pons, with fourth ventricle compression, Sylvian aqueduct partial obliteration and mild ventricular enlargement with a ventricular size index (VSI) of 36%.[21] In the thoraco-abdominal CT we found multiple metastasic affection in lung and liver. The Karnofsky score was 70% and it was classified in recursive partitioning analysis class 2. Under these conditions, we offered the endoscopic third ventriculostomy, the ventricular CSF derivation and radiation. The patient refused both surgical treatments; therefore we considered the radiosurgical procedure.

Pretreatment imaging and treatment planning

The patient underwent a nonstereotactic 3.0 T MRI scan (General Electric (GE) Signa Twin Excite MRI Scanner, GE Medical Systems, Milwaukee, WI), which consisted of T2-weighted and fat saturation sequences, axial and coronal – 1.5 mm slice thickness – and sagittal – 1.0 mm slice thickness – acquisitions with a 512 × 512-matrix size, 0.45 mm pixel size and without gap.

The stereotactic frame (BrainLab, Heimstetten, Germany) was fastened to the patient's head placing two occipital

and two anterolateral pins. After this fixation system was attached, a CT (GE Hi-Speed, GE Medical Systems, Milwaukee, WI) head acquisition was made with the BrainLab localization box mounted on the frame (1 mm slice thickness, 512 × 512-matrix size and no spacing).

Fusion of CT and MRI images was then performed using the Novalis BrainScan treatment planning system (TPS) (Version 5.31, BrainLab), to obtain sufficient anatomical references and accurate geometrical information to perform precise dose and integral dose volume histograms (DVHs). The image fusion system used is a fully automatic intensity based algorithm capable of registering medical MRI and CT images sets based on mutual information and an automated three dimension (3D) registration.[27,29,30]

This TPS calculates and displays 3D isodose distributions using the Clarkson Dose Algorithm.

The dose prescribed to the isocenter was 100 Gy delivered by an isocentric multiple noncoplanar arcs technique. A series of 21 arcs was arranged with a radiation field generated by a 4 mm tertiary circular collimator and a "sand clock" dose distribution was then achieved [Figure 1].

A total table angle of 65° was covered, placing the couch at a stationary position every 5°, from 55° to 305° (according to the International Engineering Consortium [IEC] 1217 Varian scale convention) [Table 1].

### Target and organs at risk definition

The target was localized in the MRI midsagittal plane and it was defined on the floor of the third ventricle, in the midpoint between the mamillary bodies and the infundibular recess [Figure 1]. The organs at risk (OARs) considered were: visual pathways, brainstem, hypothalamus, mamillary bodies, and pituitary gland, including the infundibulum.

Treatment

The patient underwent SRS with a 6 MV Novalis (BrainLab, Heimstetten, Germany) dedicated LINAC. During dose delivery, the patient was fixed to the couch by the BrainLab stereotactic frame to prevent any head movement. To minimize the potential problems arising from fixation, we looked for minimize duration of irradiation using the highest dose rate available (800 MU/min). The irradiation procedure took approximately 60 minutes. During this time we were in close communication with the patient, to make sure she was in a comfortable position to prevent any movement.

Accuracy of treatment

Winston-Lutz Quality Assurance test was made to measure the accuracy of treatment. It demonstrated rotational accuracy of the LINAC gantry and couch to better than 0.4 mm. Dosimetric studies showed a variation from the prescribed dose less than 2%.[9]
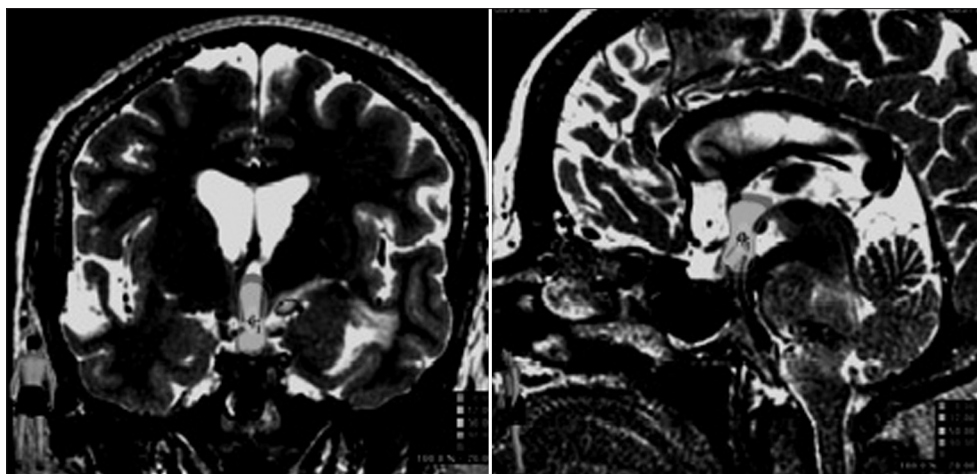
Figure 1: T2-weighted sagittal MRI acquisition through the target point (axial and coronal plane reconstructions), showing the dose distribution of the 4 mm collimator arcs arrangement including the contributions of the metastasis single dose treatment

Table 1: Technical aspects of third-ventriculostomy linear accelerator-based radiosurgery technique, International Engineering Consortium varian Scale

Arcs No.	Couch stationary position (°)	Start–stop angle or arc angle	Dose/arc (Gy)
3	90	70–140	3.34
2	85	70–140	4.50
2	80	70–140	4.50
3	75	80–130	2.33
3	70	80–130	2.33
2	65	80–130	2.50
2	60	80–130	2.50
2	55	90–120	1.50
2	305	240–270	1.50
2	300	230–280	2.50
2	295	230–280	2.50
2	290	220–290	3.50
2	285	220–290	3.50
2	280	220–290	4.50
2	275	220–290	4.50

Pons metastasis

This metastasis was treated under a 10 fractions regime: 8 sessions with a planning target volume (PTV) of 8.90 cm^3 and 2 more with a PTV reduction of 4.33 cm^3 (corresponding to a 2 mm tri-dimensional PTV boost shrink) in order to maintain the overall absorbed dose to the brainstem below the tolerance. The prescription doses were: 4.2 Gy/fraction to the isocenter and 3.4 Gy/fraction to the periphery.

The treatment consisted of 6 noncoplanar 70° dynamic conformal arcs.

Single dose right temporal metastasis

The metastasis located at the fifth right temporal circunvolution received SRS, which was applied previous to the third ventriculostomy treatment.

The prescribed doses were: 18 Gy to the periphery and 20 Gy to the isocenter. The treatment was delivered by an isocentric technique using 7 noncoplanar 60° circular arcs with a 20 mm tertiary collimator.

Stereotactic radiosurgery dose volume histograms

All the DVHs results presented correspond to the dose contributions from the two SRS treatments combined: third ventriculostomy and right temporal metastasis.

The range of maximum dose to the optic apparatus was from 1 Gy to the left optic nerve to 9 Gy to the right optic tract (>8 Gy in 0.0036 cm^3). The brainstem received a maximum dose of 9.60 Gy (calculation matrix grid size 0.5 mm). Only 7.07 cm^3 of normal tissue received 12 Gy.

Considering the fractionated treatment and the two SRS procedures, the final calculated cumulative doses to the OARs were below the reported tolerance doses.[5,12,25]

RESULTS

Postprocedural course

The clinical evaluation was done weekly and the image follow-up consisted of: a head CT acquisition each week for a month, then each 2 weeks during a month and 1 month after that we performed an MRI scan (3 months after SRS).

After the radiosurgical procedure the patient was treated with 60 mg/day of prednisone during 10 days with a progressive weekly decrease (10 mg/week). One week postirradiation, the patient presented improvement in diplopia, quadriparesis, and dysphagia; in the head CT we did not find changes in the mestastatic lesions, even in the peritumoral edema, however, the VSI diminished 4% (from 36% in preradiosurgery to 32% at a week posttreatment) [Figure 2] despite of persistent aqueduct obliteration [Figure 3]. In the follow-up head CTs, the ventricular index was maintained between 30% and 32%.

At 3 months postirradiation 3.0 T MRI scan was performed. The imaging included axial, coronal, and sagittal acquisitions in T1-weighted, enhanced T2-weighted and SPGR sequences. In these imaging series we confirmed the presence of the third ventriculostomy (2.63 mm diameter disruption in the third ventricle floor) [Figure 4]; cine phase MRI studies were performed in the sagittal plane, in which we found the patency in CSF circulation from the third ventricle to the interpeduncular cistern and the diminishing of the ventricular size compared with the pretreatment condition.

Regarding to the evolution of both metastasis, we found an adequate tumor control during the complete follow-up characterized by progressive diminished volume [Figure 5]. The patient never presented alteration in the pituitary hormonal levels or in the ophthalmologic examination. Four months after irradiation she had systemic tumor progression (lung, liver, and abdomen)
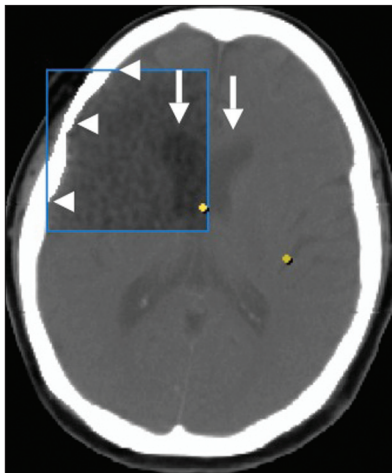
Figure 2: CT comparison beetwen the frontal horns (arrows), preradiosurgery (window) and 1-week postradiosurgery. We observe the adequate image fusion correspondence in the bone (head arrows)
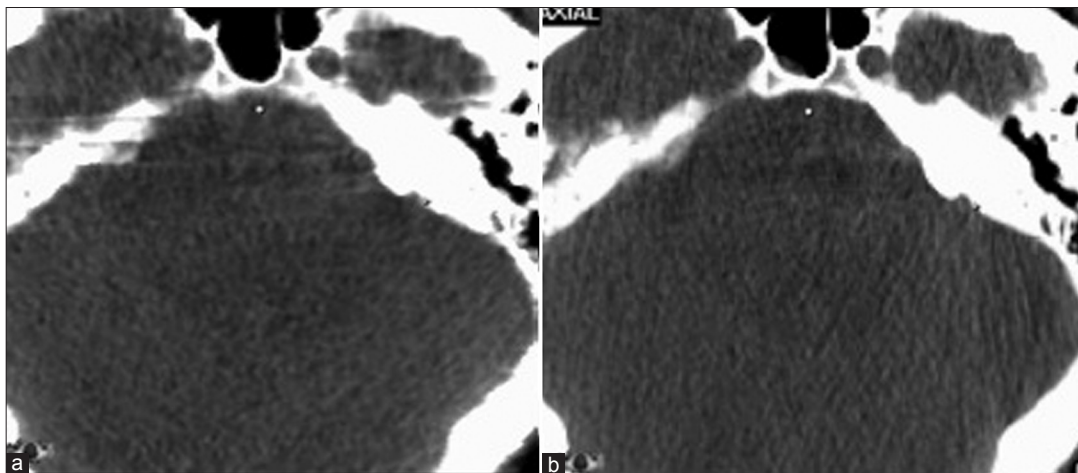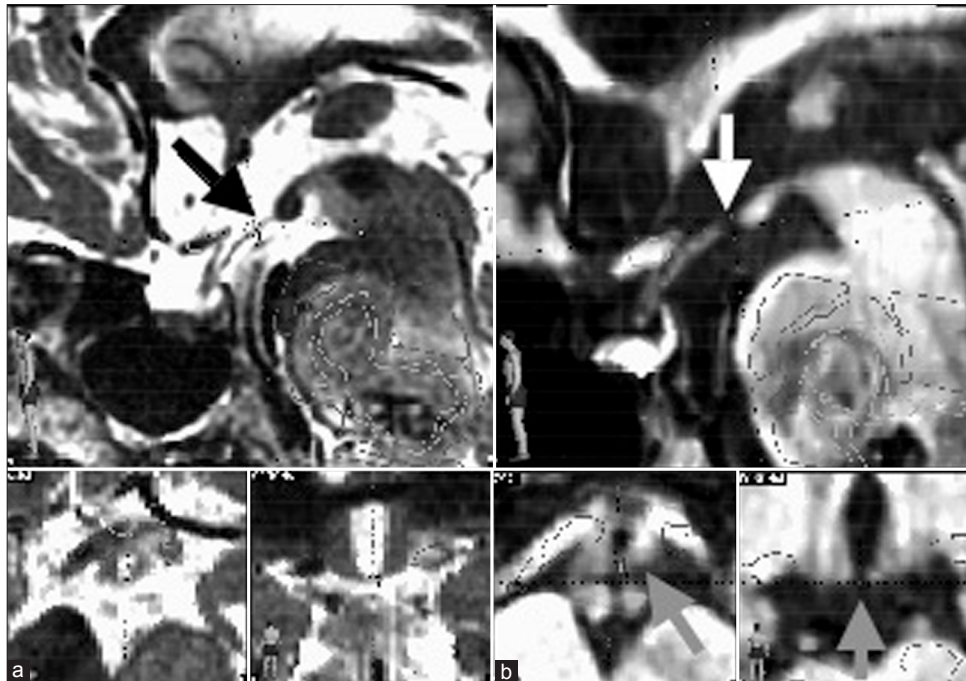
being necessary the interferon administration, during this time she presented 90% in Karnofsky index and it persisted during the next 2 months. One month after, the extracranial progression continued, leading to clinical deterioration without neurological alteration and finally, she died in the 8th month postradiosurgery.

During the complete follow up the patient never presented neurological progression or alteration secondary to radiosurgery. The impairment was always secondary to systemic progression.

DISCUSSION

The extensive and heterogenous concept of hydrocephalus (HC) embraces a number of different etiological, pathological, and age-dependant conditions. Based on its underlying mechanisms, hydrocephalus can be historically classified into communicating and noncommunicating. Both forms can be either congenital or acquired and the management can be complex and challenging. The treatment in the noncommunicating is the ventriculoperitoneal (or ventriculoatrial, mainly) shunt or more commonly accepted endoscopic third ventriculostomy. However, both techniques report complications. Despite new devices, shunt-related problems are still common (with a frequency of up to 50% in the first 2 years), including obstruction, malposition, disconnection, and infection, among others. Any of these complications implies at least one further operation adding potential morbidity and mortality.[28] In patients who underwent endoscopic third ventriculostomy, the authors found a clinically significant complication rate of 9%. Most data of severe complications have been published as case reports. Overall complication rates range from 0% to 20%. Lethal complications or permanent deficits have rarely been reported.[18,24] Randomized studies comparing ETV with shunts have not yet been published, nevertheless ETV is considered with widespread acceptance as the treatment of choice for

Figure 3: CT images comparing the CSF obstruction at Sylvian aqueduct level: (a) preradiosurgery image and (b) 1-week postradiosurgery

Figure 4: Three plane MRI show: target localization (a, black arrows) in the treatment planning procedure and third ventriculostomy patency (b, white and gray arrows) at 3 months postradiosurgery
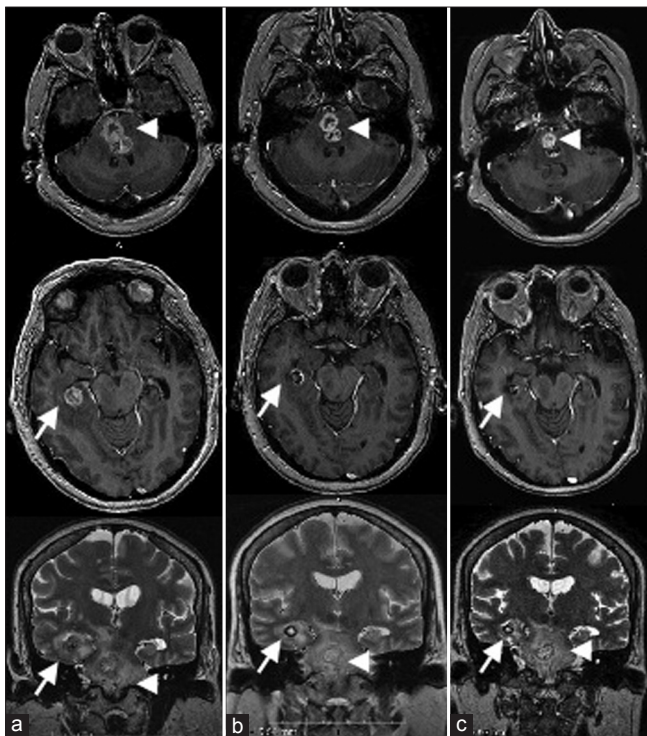
Figure 5: Pons (head arrows) and temporal metastasis (arrows) MRI images: treatment day (a), 3 months postradiosurgery (b), and 6 months postradiosurgery (c)

noncommunicating hydrocephalus, congenital as well as secondary to any obstructive lesion.[28]

In 1923, Mixter performed the first endoscopic third ventriculostomy. He used a urethroscope directed into the third ventricle and a flexible sound for fenestration under visual guidance.

In recent years, the major advances have been made in the endoscopical technique, mainly in the floor of the third ventricle opening. The method to open the floor depends on the individual surgeon's preference: leucotome, puncturing needle, the scope tip itself, saline torch, monopolar electrode, Fogarty balloon, yttrium aluminum garnet (YAG) laser, forceps, YAG diode laser, flexible or rigid bipolar electrodes, sharp perforation, and unipolar wire electrodes.[4,11,14,18]

SRS has become a well-accepted modality for the treatment of various neurological indications, from primary and metastatic malignancies to benign tumors, arteriovenous malformations and some functional procedures such as thalamotomies, pallidotomies, etc.[7,27] This technique was conceived to be more analogous to conventional surgery than to conventional radiotherapy. Similar to other neurosurgical procedures, it is one ablative, precisely localized and limited to a well-defined volume. This concept was proposed and developed by the Swedish neurosurgeon Larks Leksell in 1951. He originally proposed radiosurgery as a noninvasive means for delivering small precise lesions to treat functional disorders. He thought that the resulting interruption in neural pathways could be useful in the treatment of neuropathologies such as epilepsy and Parkinsons disease. Precise localization of the target is an absolute requirement for this therapy.[1,15]

There are two fundamental types of SRS systems. The prototype radiosurgical system is the Gamma Knife

(GKS). The precision and accuracy of GKS remain the standard by which intracranial SRS is defined; the second type of radiosurgical system is based on LINACs. The radiation source is mounted on a robotic arm that moves around the patient. The following are devices that use LINACs in its system: Cyberknife (Accuray), X-Knife (Integra Radionics Inc., Burlington, MA, USA, Trilogy (Varian Medical Systems, Palo Alto, CA), and Novalis (BrainLAB, Heimstetten, Germany). Nowadays, these are the standard radiation oncology tools.[26,32]

The Novalis precision and accuracy have been compared with the Gamma Knife system;[13] both have been tested in animal models and finally, demonstrated for functional procedures in humans (thalamotomies or trigeminal neuralgia) with excellent outcomes.[8-10,20] Nowadays, the accuracy of dedicated LINACs is 0.3 mm and it has been reproduced in several Novalis centers.[8,10]

Since 2003, we have used a dedicated LINAC for SRS, and in this matter, our target accuracy tests reproduce the results from other Novalis centers. We have used this technology for epilepsy[3] and functional procedures such as pallidotomies, thalamotomies, etc.

The radiobiological animal models are capable to describe brain lesions that are dose-time depending; Kondziolka, for example, described rat brain necrosis after 21 days of a 200 Gy irradiation. At this time the necrosis diameter was similar to the collimator used (4 mm).[13] The human lesioning has been published in numerous functional SRS procedures, with higher doses than the one we employed in this patient.[6,8,16,17] There are no reports that describe the radiation effects in brain tissue submitted to hydrostatic pressure; however, we believe that this condition could have a synergic participation with radiosurgery to accelerate the ventriculostomy. Under these premises, we decided to use a dose to the isocenter of 100 Gy; and in addition, this dose led us to protect the OARs. The 4 mm collimator led us to deliver a high dose in a precise millimetric target with a pronounced follow-up dose that respected neighboring structures. The arcs spatial configuration was important to perform a "sand clock" dose distribution with elongation of the 90% isodose in the *z*-axis plane to guarantee the coverage of the whole thickness of the third ventricle floor plus the spatial uncertainties associated to the dosimetric parameters and the natural movement during the respiratory cycle (although it should be diminished in the hydrocephalus).

Although the corticosteroids remain the most efficacious agents for the treatment of peritumoral cerebral edema;[22] In this case, we found an early indirect demonstration of the third ventricular floor disruption suggested by the diminished ventricular size without concomitant resolution in CSF obstruction (despite this pharmacological treatment, we do not find changes in the tumoral size or even in the peritumoral edema, that can explain the changes in the ventricular size due to steroid use). These findings were appreciated in the head CT scan acquired 1-week after SRS. This hallmark was directly confirmed 3 months postprocedure in the cine phase MRI, where we found the ventricular floor disruption and the patency of this pathway demonstrated by the CSF circulation from the third ventricle to the interpeduncular cistern [Figure 4].

Despite the high dose delivered in a structure neighbored by several OARs, during the follow-up, the patient never presented impairment related to: vision, memory, hormones, or hypothalamus.

The use of a dedicated LINAC system, with high dose rate delivery, was effective not only to create a precise lesion, but also in dose delivering and lesion shaping with an acceptable radiation treatment time.

This procedure confirms its capacity to perform lesions in targeted areas without producing early morbidity in selected cases with bad prognosis disease. We cannot compare the radiosurgical procedure with the actual hydrocephalus treatment options because this is only one and very selective case.

CONCLUSIONS

This report demonstrates, for the first time, the ability of a dedicated LINAC to perform a precise third ventriculostomy without associate morbidity in short-term.

The radiosurgical third ventriculostomy is a minimally invasive technique, which could be an option for selected patients with obstructive ventricular dilatation without acute decompensate hydrocephalus, who have posterior fossa metastasis or primary malignant tumors that need to be treated with radiosurgery or stereotactic radiotherapy.

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Commentary

This is an interesting and innovative approach to noncommunicating hydrocephalus in a patient with terminal disease and high surgical risk. The authors have presented a very thorough description of their technique and result in a single case report. Their pictures are convincing, proving the precision of the technique they used to perform a lesion in the third ventricular floor. Using a precise device, as are the dedicated commercially available radiosurgery techniques that the authors described in their discussion, the proposed approach to treat sub-acute hydrocephalus, in patients not amenable to an open approach, is attractive. The target allows for drop-off of the radiosurgery dose within the cerebral spinal fluid, posing very little risk of radiation necrosis to the eloquent structures related to the third ventriculostomy, again, providing that the radiosurgery technique is precise to better than 0.4 mm. This approach should become available in the armamentarium for treatment of very selected cases of noncommunicating sub-acute hydrocephalus.

Antonio A. F. De Salles

Professor of Neurosurgery – UCLA, Department of Neurosurgery and Radiation Oncology, Head of Stereotactic Surgery Section, E-mail: ADeSalles@mednet.ucla.edu