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Verification of gamma knife based fractionated radiosurgery with newly developed head-thorax phantom

Raj Kishor Bisht [a, *], Shashank Sharad Kale [a], Gopishankar Natanasabapathi [a], Manmohan Jit Singh [a], Deepak Agarwal [a], Ajay Garg [b], Goura Kishore Rath [c], Pramod Kumar Julka [c], Pratik Kumar [d], Sanjay Thulkar [e], Bhawani Shankar Sharma [a]

[a] Department of Neurosurgery, All India Institute of Medical Sciences, New Delhi, India
[b] Department of Neuroradiology, All India Institute of Medical Sciences, New Delhi, India
[c] Department of Radiotherapy, All India Institute of Medical Sciences, New Delhi, India
[d] Department of Medical Physics, All India Institute of Medical Sciences, New Delhi, India
[e] Department of Radiology, All India Institute of Medical Sciences, New Delhi, India

HIGHLIGHTS

- Performance of the Extend™ system of Gamma knife in multi-session radiosurgery.
- Extend™ system based treatment verification using a patient simulating phantom.
- Designed head-thorax phantom suitable for other dosimetric audit purposes.

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ABSTRACT

Objective: Purpose of the study is to verify the Gamma Knife Extend™ system (ES) based fractionated stereotactic radiosurgery with newly developed head-thorax phantom.
Methods: Phantoms are extensively used to measure radiation dose and verify treatment plan in radiotherapy. A human upper body shaped phantom with thorax was designed to simulate fractionated stereotactic radiosurgery using Extend™ system of Gamma Knife. The central component of the phantom aids in performing radiological precision test, dosimetric evaluation and treatment verification. A hollow right circular cylindrical space of diameter 7.0 cm was created at the centre of this component to place various dosimetric devices using suitable adaptors. The phantom is made of poly methyl methacrylate (PMMA), a transparent thermoplastic material. Two sets of disk assemblies were designed to place dosimetric films in (1) horizontal (xy) and (2) vertical (xz) planes. Specific cylindrical adaptors were designed to place thimble ionization chamber inside phantom for point dose recording along xz axis. EBT3 Gafchromic films were used to analyze and map radiation field. The focal precision test was performed using 4 mm collimator shot in phantom to check radiological accuracy of treatment. The phantom head position within the Extend™ frame was estimated using encoded aperture measurement of repositioning check tool (RCT). For treatment verification, the phantom with inserts for film and ion chamber was scanned in reference treatment position using X-ray computed tomography (CT) machine and acquired stereotactic images were transferred into Leksell Gammaplan (LGP). A patient treatment plan with hypo-fractionated regimen was delivered and identical fractions were compared using EBT3 films and in-house MATLAB codes.
Results: RCT measurement showed an overall positional accuracy of 0.265 mm (range 0.223 mm −0.343 mm). Gamma index analysis across fractions exhibited close agreement between LGP and film measured dose with ≥90% (max 93%) pixel pass rate at 1 mm of spatial and 1% of dosimetric tolerances. The focal precision test showed the variation of 0.465 mm between radiological and planned iso-centre.

* Corresponding author. Gamma Knife Unit, Department of Neurosurgery, All India Institute of Medical Sciences, New Delhi, 110 029, India.
E-mail address: raaj_bisht@rediffmail.com (R.K. Bisht).

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Conclusions: The study demonstrated the suitability of newly developed head-thorax phantom for dosimetric verification of fractionated stereotactic radiosurgery using Extend™ system of Gamma Knife.
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1. Introduction

The Leksell Gamma Knife (GK) is a non-invasive surgical tool used to deliver highly conformal radiation dose to anatomically well-defined target lesions within the brain. A single high dose fraction with GK offers efficient radiosurgical treatment to number of clinical indications, functional neurological disorders and others (Firlik et al., 1998; Haselsberger et al., 2009; Iwai et al., 2001; Javalkar et al., 2009; Kim et al., 2008). Treating the tumor with relatively lower radiation dose fractions (also called hypofractionation) increases the radiobiological effect on tumor in addition to sparing adjacent normal tissue (Kim et al., 2008; Niranjan et al., 2004; Adler et al., 2008; Tuniz et al., 2009; Milker-Zabel et al., 2009). Multiple session stereotactic radiosurgery extends the volume and radiation dose constraints due to lower dose fractions (Adler et al., 2008; Tuniz et al., 2009; Milker-Zabel et al., 2009). Extend™ system (ES) on Gamma Knife is intended to deliver radiation dose in multiple fractions (Adler et al., 2008; Tuniz et al., 2009; Milker-Zabel et al., 2009).

Treatment verification using phantoms is well established in radiotherapy. There are various commercial phantoms available to record radiation dose and verify radiotherapy treatments. The human body shape mimicking Alderson RANDO phantom (Radiology Support Devices Inc., Long Beach, CA) is accepted within medical physicists and has been in use for many years in radiotherapy departments. Bigger size, multiple slices, high weight and complex positioning of RANDO phantom makes it prone to asymmetrical movement for this study. Spherical Lucy 3D QA phantom (Standard Imaging Inc., Middleton, WI) is useful in ideal dosimetric conditions. This phantom does not simulate patient head, which makes it non ideal for mimicking skull geometry and treatment setup along with Extend™ system. Imaging and Radiation Oncology Core (IROC) at MD Anderson cancer centre, University of Texas, Houston, TX, has designed various phantoms for precise estimation of dose delivery in advanced modern radiation treatment methodologies (Adler et al., 2008; Tuniz et al., 2009) All these phantoms are standards and popular among various users but they lead to complexity in use with extensive care. An in-house phantom (Gopishankar et al.) specially designed for 3D gel dosimetry (Adler et al., 2008; Tuniz et al., 2009) could be used to verify smaller radiation field using films but multiple slice design of the phantom makes it difficult to maintain skull contour integrity. One common issue with all these phantoms is that the Extend™ frame with mouth bite assembly could not be fixed in them. Hence none of the above mentioned phantoms meet the requirement for verification of fractionated stereotactic radiosurgery with Gamma Knife. The phantom; provided by manufacturers to verify fractionated stereotactic radiosurgery with Gamma Knife is a hollow head phantom with vacuum assisted mouth bite fixation arrangement. The phantom principally designed to check focal precision of the treatment in coronal and/or sagittal planes however the phantom could be use to verify higher doses in very small field treatments (Adler et al., 2008; Tuniz et al., 2009). Due to smaller measurement area; verification of routine patient treatment is impracticable with this phantom. The phantom designed under this study is “comprehensive treatment setup simulation model” (CTSSM) for stereotactic treatments. This patient simulating head-thorax phantom could replace various dose verification phantoms which are being extensively used to check resultant quality of various radiotherapy modalities. The upgradable thorax component of the phantom could be used to estimate scattered doses at the critical organ sites like thyroid, breast and others in future studies. The designed phantom is useful to standardize immobilization techniques, image verification and strive as an ideal dosimeter to evaluate/compare dose plans with available multi-dimensional dosimetric tools like ion chamber, film, TLD/OSL, gel and online dosimetric methods.

The presented work is an investigation of positional integrity provided by vacuum assisted immobilization technique and treatment consistency check in identical dose fractions using ES of Gamma Knife. The phantom and in-house developed MATLAB computations have promising features in performing inter-fraction dosimetric comparison. The radiological verification for RCT supported positional stability was evaluated statistically using smallest available 4 mm collimator shot. In this work, we demonstrate the suitability of designed phantom for dosimetric comparison of fractions delivered through fractionated radiosurgery regimen.

2. Materials and methods

2.1. Phantom design and description

The phantom is made of poly methyl methacrylate (PMMA), commercially known as acrylic material. The dimensions of designed patient simulating phantom were kept slightly bigger than standard adult patient size for increased measurement volume inside phantom however fabricated size is suitable for fixing standard Leksell frame to evaluate single fraction stereotactic radiosurgery as well (Fig. 1a) (Table 1).

The phantom has four components:

(i) The first or superior component of the phantom was designed to establish a link between Hounsfield unit (HU) and physical parameters of various density materials. The density inserts are replica of widely used CIRS (USA, Model 062) equivalent electron densities plugs (Fig. 1b). Leksell GammaPlan TMR 10 planning algorithm is being used for the dosimetric computations in this study which counsel to use homogeneous phantom environment using similar acrylic plugs.

(ii) The second component aids in performing treatment quality checks and dosimetric evaluation of the executed treatment plan. A right circular cylindrical hollow space of volume 269.39 cc with 7.0 cm depth was created at the centre of this component to place various dosimetric devices like film, ion chamber, TLD, OSL, gel and others, however in this study the treatment was investigated using conventional dosimeters like film and ion chamber (Fig. 1b,c,d).

In presented study; two types of disk assemblies were used to verify the executed treatment plan with films. A set of disk assemblies was designed to place films in axial (xy) planes (Fig. 1c). The contiguous combination of these disks was used to map planar dose distribution (2D). The second disk assembly or coronal-

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