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Original Article

Achieving the Relocation Accuracy of Stereotactic Frame-based Cranial Radiotherapy in a Three-point Thermoplastic Shell

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Abstract

Aims: To compare the accuracy of fractionated cranial radiotherapy in a standard three-point thermoplastic shell using daily online correction with accuracy in a Gill–Thomas–Cosman relocatable stereotactic frame.

Materials and methods: All patients undergoing fractionated radiotherapy for benign intracranial tumours between March 2009 and August 2010 were included. Patients were immobilised in the frame with those unable to tolerate it immobilised in the shell. The ExacTrac imaging system was used for verification/correction. Daily online imaging before and after correction was carried out for shell patients and systematic and random population set-up errors calculated. These were compared with frame patients who underwent standard departmental imaging/correction with fractions 1–3 and weekly thereafter. Set-up margins were calculated from population errors.

Results: Systematic and random errors were 0.3–0.7 mm/° before correction and 0.1–0.2 mm/° after correction in all axes in the frame, and 0.6–1.5 mm/° before correction and 0.1–0.4 mm/° after correction in the shell. Isotropic margins required for patient set-up could be reduced from 2 mm to <1 mm in the frame and from 5 mm to <1 mm in the shell.

Conclusion: Similar set-up accuracy can be achieved in the standard thermoplastic shell as in a relocatable frame despite less precise immobilisation. The use of daily online correction precludes the need for larger set-up margins.

Key words: Cranial; online verification; radiotherapy; stereotactic; thermoplastic shell

Introduction

External beam radiotherapy provides excellent tumour control for a wide range of benign brain tumours, including meningiomas, pituitary adenomas, schwannomas and craniopharyngiomas [1–4]. However, late sequelae, although uncommon, remain a concern in this population of patients with an essentially normal life expectancy [5,6]. The aim of modern radiotherapy is to minimise normal tissue irradiation by using improved methods of immobilisation, advanced imaging techniques for accurate target delineation and treatment verification, and focused techniques of conformal delivery.

High-precision radiotherapy for benign brain tumours can be achieved with stereotactic techniques using non-invasive relocatable frames for immobilisation, such as the Gill–Thomas–Cosman (GTC) frame, which has a relocation accuracy of 2 mm [7,8]. This has allowed safe reduction of the clinical target volume (CTV) – planning target volume (PTV) margin to 3 mm [9] and consequent reduction in the volume of normal brain receiving radiation. However,

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15–20% of patients are unsuitable for or cannot tolerate the frame and are immobilised in a less firm thermoplastic shell with movement up to 3–5 mm [10] with a need for a larger a CTV–PTV margin of 4–5 mm.

Frameless solutions for high precision cranial radiotherapy generally use either a mouthbite or a specialised firm mask combined with image guidance to achieve the accuracy of a frame-based system [11–17]. It is also possible to use the conventional three-point thermoplastic mask, readily available as part of routine radiotherapy practice with a relocation set-up accuracy of 2–5 mm [10,18,19], but results have been inferior to frames and specialised frameless systems [20,21]. Although this accuracy can be improved using four- or five-fixation point masks [22] or jaw fixation [23] these are resource intensive and may be uncomfortable.

The use of image guidance with either kilovoltage planar imaging or cone beam computed tomography may compensate for the reduced relocation accuracy, even in the three-point shell [21,24–27], but this requires validation for protracted fractionated treatment, where interfraction movement may be a greater source of error.

The ExacTrac image-verification system combines stereoscopic planar kilovoltage imaging with a robotic couch capable of correction in 6 degrees of freedom. Stereoscopic kilovoltage image acquisition is fast, requires low radiation dose exposure and has submillimetre accuracy, and can be used for daily image guidance and correction. The robotic couch is able to apply corrections to within 1 mm and 1^{o} in all translational axes and rotational directions.

This study compared the set-up accuracy of daily fractionated stereotactic radiotherapy achieved with three-point thermoplastic shell immobilisation and daily online correction with GTC frame immobilisation using standard quality assurance imaging protocols, using ExacTrac for verification of both groups.

Materials and Methods

All patients treated for benign brain tumours with fractionated radiotherapy using the ExacTrac imaging system for verification between March 2009 and August 2010 at the Royal Marsden Hospital were included in this retrospective analysis. This evaluation was approved by the Royal Marsden Hospital Clinical Audit Committee.

Radiotherapy Computed Tomography and Magnetic Resonance Imaging Scans and Planning

Frame

Patients were evaluated for suitability of GTC frame immobilisation by assessing their dentition and probable ability to tolerate the mouthbite. The procedure for frame fitting has been reported previously [9]. Planning computed tomography was carried out with the patient supine on a flat-topped couch, with a fiducial cage attached for stereotactic localisation. Images were acquired from the vertex to the inferior edge of the frame with 2.5 mm slice thickness and spacing of 2.5 mm.

Shell

Patients unable to tolerate the frame or with poor dentition were fitted with a three-point thermoplastic shell (Civco posicast). Five or six infrared-reflective body markers with radio-opaque stems were fixed to the shell in a non-symmetrical arrangement to provide a reference between the patient's computed tomography dataset and the ExacTrac system. Reference marks were placed on the shell for initial set-up (to reference the position of the isocentre and infrared-reflective body markers) and marked with radio-opaque markers. Computed tomography acquisition was carried out with the patient supine on a flat-topped couch, immobilised in the shell. Images were acquired from the vertex to third cervical vertebra with 2.5 mm slice thickness and spacing of 2.5 mm.

Computed tomography images for both groups of patients were reconstructed with 2.5 mm slice thickness and 1 mm spacing for improved image quality to aid online co-registration.

All patients underwent a high-resolution T1 magnetic resonance imaging scan, which was registered with the planning computed tomography in the BrainLab planning system (I. Plan 3.0.1) for target delineation. The CTV (assumed to be the same as the gross tumour volume) was delineated on the magnetic resonance image and grown symmetrically to create the PTV by 3 mm for frame and 4 mm for shell immobilisation. Delineated contours were exported to the Eclipse planning system (Varian: Eclipse version 8.6) and treatment planned as described previously [28].

Patients treated in the frame had an additional limited length computed tomography scan before starting treatment to verify the isocentre position with a tolerance of $\leq$1 mm/°.

Treatment Set-up and Verification using the ExacTrac System

All patients were treated with 6 MV photons on a linear accelerator (linac) with a micro-multileaf collimator (5 mm width at the isocentre) and the ExacTrac verification system. Initial set-up was carried out daily using in-room lasers and external marks on the verification box (frame) or infrared-reflective markers fixed to the shell (shell). Image verification and correction using ExacTrac was carried out daily for patients in a shell and for fractions 1–3 and weekly thereafter if pre-correction errors were $\leq$2 mm/° for frame patients. If a systematic error (>2 mm/°) was found for a frame patient, daily correction was carried out.

Planar kilovoltage image pairs were acquired ('pre-correction images'), and co-registered to the planning computed tomography dataset using the automated ExacTrac software. Errors were recorded in six degrees of freedom, namely three translational axes (superior–inferior, anterior–posterior and right–left) and three rotations (rotation around the vertical [yaw], longitudinal [roll], and lateral [pitch]). Corrections were applied using the robotic couch (limited to $\pm$2.5° pitch and $\pm$4° roll [reduced to 3° when pitched to 2°]) and repeat image pairs acquired after correction (before treatment) to assess the post-correction residual error ('post-correction images'). Clinical tolerance was 2 mm/° for treatment to proceed.