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**PHYSICS CONTRIBUTION**

# LOCAL SETUP REPRODUCIBILITY OF THE SPINAL COLUMN WHEN USING INTENSITY-MODULATED RADIATION THERAPY FOR CRANIOSPINAL IRRADIATION WITH PATIENT IN SUPINE POSITION

Eva Maria Stoiber, M.D., M.Sc.,*† Kristina Giske, M.Sc.,† Kai Schubert, Ph.D.,* Florian Sterzing, M.D.,* Gregor Habl, M.D.,* Matthias Uhl, M.D.,* Klaus Herfarth, M.D.,* Rolf Bendl, Ph.D.,†‡ and Jürgen Debus, M.D., Ph.D.*

*Department of Radiation Oncology, University Hospital Heidelberg, †Department of Medical Physics, German Cancer Research Center, Heidelberg; and ‡Medical Informatics, Heilbronn University, Heilbronn, Germany

**Purpose: To evaluate local positioning errors of the lumbar spine during fractionated intensity-modulated radiotherapy of patients treated with craniospinal irradiation and to assess the impact of rotational error correction on these uncertainties for one patient setup correction strategy.**
**Methods and Materials: 8 patients (6 adults, 2 children) treated with helical tomotherapy for craniospinal irradiation were retrospectively chosen for this analysis. Patients were immobilized with a deep-drawn Aquaplast head mask. Additionally to daily megavoltage control computed tomography scans of the skull, once-a-week positioning of the lumbar spine was assessed. Therefore, patient setup was corrected by a target point correction, derived from a registration of the patient's skull. The residual positioning variations of the lumbar spine were evaluated applying a rigid-registration algorithm. The impact of different rotational error corrections was simulated.**
**Results: After target point correction, residual local positioning errors of the lumbar spine varied considerably. Craniocaudal axis rotational error correction did not improve or deteriorate these translational errors, whereas simulation of a rotational error correction of the right–left and anterior–posterior axis increased these errors by a factor of 2 to 3.**
**Conclusion: The patient fixation used allows for deformations between the patient's skull and spine. Therefore, for the setup correction strategy evaluated in this study, generous margins for the lumbar spinal target volume are needed to prevent a local geographic miss. With any applied correction strategy, it needs to be evaluated whether or not a rotational error correction is beneficial.** **© 2011 Elsevier Inc.**

**Craniospinal irradiation, Intensity-modulated radiation therapy, Image-guided radiation therapy, Setup uncertainties, Registration.**

## INTRODUCTION

Current practice in the management of completely resected medulloblastoma in children and adults is to deliver reduced-dose craniospinal irradiation (CSI) in combination with chemotherapy (1). To deliver CSI, a variety of different radiation techniques are used. Among them, highly conformal radiation techniques like intensity-modulated radiation therapy (IMRT) or proton therapy are applied more and more often. In comparison to conventional radiation techniques, conformal techniques offer several advantages, like the potential of better sparing of organs at risk (*e.g.*, the optical nerves or cochleae) (2). In addition, IMRT provides an improved target dose uniformity and target coverage (3, 4).

Recent studies have analyzed the quality of radiotherapy in medulloblastoma patients and have shown that radiotherapy targeting deviations are clearly correlated to patterns of disease relapse. When treating the craniospinal axis, accurate patient positioning is particularly necessary to prevent a geographic target miss and reduce the potential of disease relapse in these missed areas. Special attention should be paid on the positioning of the cribriform plate and the termination of the thecal sac, inasmuch as isolated relapses in these areas have been reported (5–8).

Modern radiation therapy (RT) units are equipped with imaging devices that allow assessment of the patient setup before treatment. In case of a setup error, patient positioning can be corrected immediately before treatment. Yet, the use of image-guided radiotherapy lead to the mistaken

Reprint requests to: Eva Maria Stoiber, M.D., M.Sc., Department of Radiation Oncology, University Hospital Heidelberg, INF 400, 69120 Heidelberg, Germany. Tel: (+49) 6221-42-2579; Fax: (+49) 6221-42-5353; E-mail: eva.stoiber@med.uni-heidelberg.de

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assumption that the margins applied in the preimaging era can now be reduced markedly with this technique. One specific technical difficulty in treating patients with CSI is the flexibility of the spinal column. Different patient positions and fixation devices are thus used to minimize possible interfractional and intrafractional spine motion. Nevertheless, interfractional positioning variations of the different levels of the spine can still occur during fractionated radiotherapy, and they need to be considered when using newer radiation techniques and margin calculation for the clinical target volume (CTV).

The aim of this study was to quantify the amount of deformations occurring between the base of the skull and the lumbar spine when treating patients with CSI in a supine position. The results were assessed for the patient fixation method used in our department. The benefits and limitations of one selected patient setup correction strategy were demonstrated. For this specific correction strategy, the margins minimally required for the lumbar part of the CTV were calculated to prevent a potential target miss in this region. Additionally, the impact of different possible rotational error corrections on the positioning of the lumbar spinal cord was examined for discussion.

## METHODS AND MATERIALS

### *Patients and fixation*

Eight patients consecutively treated with CSI between 2007 and 2009 at the University Hospital of Heidelberg were retrospectively chosen for this analysis. Of those patients, 6 were adults, and 2 were children age 5 and 9 years, respectively. All patients were treated in a supine position and immobilized with a commercially available deep-drawn Aquaplast head mask in combination with a head-and-neck rest. No additional molds were used.

### *Treatment device, RT treatment planning, and technique*

All patients underwent computed tomography (CT) simulation in the treatment position for radiotherapy treatment planning. Beekly spots as external fiducial markers were attached to the head masks for patient setup on the treatment table. Patients were additionally tattooed in the chest and abdominal region to allow for correct patient setup of the lumbar spine and to minimize rotational errors in this region. The planning CT slice distance was 5 mm, with an in-slice resolution of $0.98 \times 0.98$ mm$^2$. A CTV including a brain CTV and a spinal CTV was defined. This CTV included the whole space containing cerebral fluid down to the second sacral vertebra and all intervertebral diverticula. CSI was carried out using helical tomotherapy (Madison, Wisconsin, USA).

### *Local registration boxes*

For each patient three local registration boxes (LRBs), designated 1 through 3, were determined in the planning CT scan. To define these registration boxes, anatomic landmarks were identified in the planning CT scan of each patient. The corresponding LRBs surrounded these landmarks. The LRBs included (Fig. 1): LRB 1: base of skull (excluding the anterior parts of the base of skull, which were included in LRB 3); LRB 2: lumbar vertebral bodies 1–3, LRB 3: nose/parts of the maxillary and frontal sinuses. LRBs 1 and 2 were expected to show interfractional positioning variations, whereas LRBs 1 and 3 were rigidly anatomically connected and therefore not subject to deformations. Based on this assumption, the additional registration box in the head region was used to assess the uncertainty of the applied registration method. The correlation of both MV control CT scans in space was possible because of the coordinates of the treatment table.

### *Megavoltage control CT scanning procedure*

After thorough positioning of the patient in regard to the markers and tattoos on the head, chest, and lumbar region, the patient received daily MV control CT scans before irradiation. The scanned volume included the base of the skull (Fig. 2) only. At least once a week, after scanning the skull, an additional second control CT scan was performed. The scanned volume of this second scan included the upper abdomen and included the lumbar spinal vertebrae. No patient setup correction was carried out between the two control CT scans. The resolution of the MV control CT scan was $0.75 \times 0.75$ mm$^2$, with a slice distance of 6 mm. A median of five (range, 2–8) pairs of skull and lumbar control CT scans per patient were evaluated in this analysis. Altogether, a total of 38 lumbar CT scans from 8 patients were obtained.

### *Patient setup correction strategy*

The daily patient setup process included positioning of the patient with Beekly spots followed by scanning of the skull. A target point correction derived from a registration of this CT scan with the planning CT scan was applied, and the patient was treated.

For this study, we retrospectively evaluated the deformations of the spine referenced to the skull after this target point correction. Evaluation of the daily offset error was not subject of this study. For our analysis, the registration was repeated using a rigid-body registration algorithm based on mutual information. This algorithm considered translational and rotational shifts (9).

*Registration error measurement.* To assess the measurement error of the registration algorithm, we assumed that no deformation or motion occurred between the two subvolumes LRBs 1 and 3 (base of skull and nose/maxillary/frontal sinuses, Fig. 1) because they are rigidly anatomically connected. The distance between the two landmarks was determined in each control CT scan, and the standard deviation (SD) of this distance was calculated for each patient. These values were averaged over all patients, resulting in a mean value, which was considered the registration measurement error.

*Quantification of deformations of the lumbar spine referenced to the skull (without rotational error correction).* The local positioning errors of LRB 2 in reference to LRB 1 were evaluated by matching the two corresponding control CT cubes onto the planning CT. The rotational errors of the skull registration were calculated, but not corrected in the simulation of this target point correction. The residual translational and rotational errors of the lumbar spine were reported for all three axes (craniocaudal, CC; right–left, RL; and anterior–posterior, AP).

*Influence of CC axis rotational error correction (roll) on the residual translational errors of the lumbar spine.* Helical tomotherapy offers the possibility to correct for rotational errors around the CC axis (roll correction) by adapting the starting angle of the rotational beam application. The impact of a roll error correction on the remaining translational errors of the lumbar spine was assessed. Therefore, the described setup correction strategy was slightly modified: Additionally, to the three translational errors described in the previous paragraph, the rotational error around the CC axis of LRB1 was corrected.

*Influence of rotational error correction of all three axes on residual translational errors of the lumbar spine.* The availability of a robotic table would enable to correct rotational errors around all three axes. To assess the impact of this correction on the residual