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Original article

Intrafraction variations in linac-based image-guided radiosurgery of intracranial lesions

Variations pendant les fractions dans la position du patient au cours de la radiochirurgie stéréotaxique guidée par imagerie pour lésions intracrâniennes

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ABSTRACT

Purpose. – This study investigated image-guided patient positioning during frameless, mask-based, single-fraction stereotactic radiosurgery of intracranial lesions and intrafractional translational and rotational variations in patient positions.
Patients and methods. – A non-invasive head and neck thermoplastic mask was used for immobilization. The Exactrac/Novalis Body system (BrainLAB AG, Germany) was used for kV X-ray imaging guided positioning. Intrafraction displacement data, obtained by imaging after each new table position, were evaluated.
Results. – There were 269 radiosurgery treatments performed on 190 patients and a total of 967 setups within different angles. The first measured error after each table rotation (mean 2.6) was evaluated (698 measurements). Intrafraction translational errors were (1 standard deviation [SD]) on average 0.8, 0.8, and 0.7 mm for the left–right, superior–inferior, and anterior–posterior directions, respectively, with a mean 3D-vector of 1.0 mm (SD 0.9 mm) and a range from −5 mm to +5 mm. On average, 12%, 3%, and 1% of the translational deviations exceeded 1, 2, and 3 mm, respectively, in the three directions.
Conclusion. – The range of intrafraction patient motion in frameless image-guided stereotactic radiosurgery is often not fully mapped by pre- and post-treatment imaging. In the current study, intrafraction motion was assessed by performing measurements at several time points during the course of stereotactic radiosurgery. It was determined that 12% of the intrafraction values in the three dimensions are above 1 mm, the usual safety margin applied in stereotactic radiosurgery.

Mots clés :
Variation intrafractionnelle
Guidée par imagerie
Radiochirurgie stéréotaxique

RÉSUMÉ

Objectif de l'étude. – Cette étude concernait le positionnement du patient pendant la radiochirurgie stéréotaxique guidée par imagerie pour lésions intracrâniennes et des variations pendant les fractions, translationnelles et rotationnelles dans la position du patient.
Patients et méthode. – Pour l'immobilisation de la tête et la nuque du patient, un masque thermoplastique non invasif a été employé. Nous avons utilisé le système Exactrac équipant un Novalis de BrainLab pour le positionnement guidé par image. Les données de déplacement pendant la fraction, tirées d'images après tous les changements de position, ont été évaluées.
Résultats. – Au total, 269 traitements ont été effectués sur 190 patients, soit 967 configurations avec des angles différents. La première erreur après chaque rotation de table (valeur moyenne de 2,6) a été évaluée par 698 mesures. Le taux d'erreur moyen pour la translation pendant la fraction (1 écart-type) était respectivement de 0,8, 0,8 et 0,7 mm pour les directions gauche–droite, supérieure–inférieure et antérieure–postérieure, avec un vecteur tridimensionnel en moyenne de 1,0 mm (écart-type de 0,9 mm), allant de −5 mm jusqu'à +5 mm. En moyenne, 12 %, 3 % et 1 % de l'écart translationnel ont dépassé 1, 2 et 3 mm, dans les trois directions.

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Conclusion. – La gamme de mouvement pendant la fraction du patient en radiochirurgie stéréotaxique n'est souvent pas complètement documentée par image avant et après le traitement. Dans cette étude, le mouvement pendant la fraction a été évalué par des mesures à plusieurs moments au cours de la radiochirurgie stéréotaxique. Il s'avéré que 12 % des valeurs pendant la fraction dans les trois directions étaient de plus de 1 mm, ce qui correspond à la marge de sécurité habituellement appliquée en radiochirurgie stéréotaxique.

1. Introduction

Frameless linac-based image-guided radiosurgery has, currently, a significant role in the treatment of cranial lesions, including primary brain tumors, brain metastases of solid tumors, and functional disorders of cranial nerves. The recent paradigm changes in oncologic practice, including more individualized and focused treatment for any individual patients, requires from the technical perspective highly sophisticated infrastructures. More patients survive primary tumor therapy today compared to the last decades. Later in the trajectory of the disease, there will have metastases, for example: survivors of breast cancer and brain metastases, which could be singular or in limited in number and size, thus, oligometastasized. Treating brain metastases (1–4 in number) with stereotactic radiosurgery has been a fundamental change in clinical practice. It needs, indeed, a safe and effective radiosurgery that is supposed to minimize normal tissue toxicity by employing sharp dose gradients which must be placed accurately at the margins of the tumor and, simultaneously, to be tumor effective [1]. Retrospectively seen, radiosurgery has relied on an invasive setting, encompassing a head frame for patient immobilization and target localization. This invasive frame-based setup was related to a high degree of geometrical accuracy based on reliable immobilization and precision of tumor localization, thus, a gold standard for a long time [2]. It was, indeed, also associated with relevant problems with regard to the patient's comfort, while more and more patients underwent stereotactic radiosurgery: invasive frame placement as traumatic experience, risk of bleeding and infection, premedication and the logistic management on the day of care in terms of resources. In this context, issues related to the planning procedure, to be completed following frame placement on the same day, making a sophisticated preplanning difficult. In the meantime, a growing body of valid evidence had been demonstrating the clinical relevance of stereotactic radiosurgery, in terms of improvement of local control and, consequently, influencing prognosis of patients with brain metastases and even of benign cranial lesions [3,4]. This dynamics of technology and of concepts made it important to optimize patient comfort and treatment efficiency. The implementation of image-guided stereotactic localization using either optical image guidance, or stereoscopic X-ray imaging has provided the exertion of frameless stereotactic radiosurgery [5,6]. The Novalis Body ExacTrac, using dual floor-mounted kV X-ray tubes, generates stereoscopic oblique images through gantry's isocenter. It creates an image fusion of the images with a digital reconstructed radiograph (DRR) library generated at the time of planning and generates a predicted position shift to place the patient such that the target is coincident with the planning isocenter. An infrared tracking system is used to verify relative shifts and to provide initial patient position [6]. Additionally, a frameless setup is more convenient for the patient and demands less logistic resources. Yet, the thermoplastic masks used facilitate intrafractional movement of the patient's head inside the immobilization mask and increase the magnitude of positional errors compared with frame-based stereotactic radiosurgery, which is presumably a major source of geometrical uncertainty [7]. Frameless linac-based image-guided radiosurgery is becoming a good alternative to the frame-based settings in clinical terms [8].

A relevant concern after implementation of frameless image-guided stereotactic radiosurgery with mask head immobilization is that of intrafraction motion during a treatment session. As an accurate assessment of real-time seems to be difficult, one could measure intrafraction displacement as a proxy to estimate intrafraction motion. When considering the time frame is about 15 min, there is a lack of data describing the range of intrafraction motions that occur. Table rotations are required in nearly all stereotactic radiosurgery procedures to obtain the intended conformation. It makes sense to image and reposition after each table angle before the new radiation beam and this procedure has been included in our institutional protocol. The frequent repositioning corrects patient misplacements, and the geometrical error can be reduced to a submillimeter range as documented by verification images [9].

We set out to measure intrafraction displacement using a mask-based immobilization system and the above-mentioned setup in a prospective cohort of 190 patients, representing 269 stereotactic radiosurgery sessions. The large data set, prospectively generated, would allow making substantial statements on intrafraction motion for intracranial lesions in regard to overall geometrical accuracy of frameless image-guided stereotactic radiosurgery.

2. Materials and methods

A Novalis linear accelerator equipped with a micro-multileaf collimator and the Novalis Body/ExacTrac X-ray 6D positioning system (NT/NB, BrainLab) was used. In addition, the Robotic Tilt Module™ was mounted underneath the Varian Exact Couch™ top (Varian Medical Systems, Milpitas, CA, USA), which allowed for translational and rotational setup corrections. Between June 2006 and October 2008, the setup accuracy was evaluated during 269 treatment sessions in a consecutive non-randomized cohort of 190 patients undergoing definitive single-fraction stereotactic radiosurgery for cranial lesions.

The treatment setup has previously been described in detail [9]. The treatment planning computer tomography (CT) was performed at 1.25 mm slice spacing and thickness followed by stereotactic localization. The typical treatment plan consisted of 3 to 5 non-coplanar arcs or 6 to 9 convergent shaped beams. Irradiation times ranged from 12 to 20 minutes per lesion for most lesions. Doses between 12 and 26 Gy were prescribed, to the 80% isodose line level. Conformal arc or conformal field radiotherapy was delivered with a 6 MV photon beam through the m3™ mini-multileaf collimator (Novalis™, BrainLab). After infrared-guided patient setup, a first pair of two non-coplanar oblique isocentric (stereoscopic) kV X-ray images of the skull bony structures were acquired by means of two detectors. A set of shift and rotational corrections was calculated by comparison with digitally reconstructed radiographs (DRRs). The patient's position was corrected in cases exceeding the preset tolerance limits of the system; otherwise, treatment was started. The process of kilovolt imaging with table shift correction was repeated until linear offsets were less than 0.7 mm and angular