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Original paper

Validation of frame-based positioning accuracy with cone-beam computed tomography in Gamma Knife Icon radiosurgery

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A B S T R A C T

Background: Frame based positioning accuracy in Gamma Knife (GK) stereotactic radiosurgery (SRS) is extremely high but removal of a post may be necessary to enable the treatment in selected patients.
Objective: To verify the positioning accuracy in clinical scenarios with 4 and 3 posts in patients and phantoms using cone-beam CT (CBCT) of Gamma Knife Icon™.
Methods: We analyzed positioning accuracy for 12 patients with standard 4 post setup using pretreatment CBCT (pre-CBCT) on GK Icon™ and report 4 patients with different clinical scenarios (removal of a post). We performed phantom measurements to verify the frame accuracy via CBCT in different clinical scenarios without the influence of the human patient.
Results: Mean frame accuracy for 12 patients with 4 posts was 0.35 mm/0.34 degree. Mean motion during treatment was 0.11 mm/0.04 degree. For two of the clinical scenarios where a post was removed, we found acceptable deviations within 0.66 mm/0.61 degree. For 2 patients, a deviation of 2.94 mm/−3.47 degree and 1.85 mm/−0.74 degree was found and replanning was necessary. Phantom measurements showed good agreement when planning MR/CT was performed with 4 or 3 post. Larger deviations of 0.86 mm/0.88 degree were detected when a post was removed after planning MR/CT.
Conclusion: The frame accuracy with 4 posts before and during GK treatments is as high as expected. For clinical situations, where a post is removed after planning-CT/MR, pre-treatment position verification is strongly suggested using stereotactic CBCT or the P-CT/MR should be repeated to avoid possible mistreatments.

1. Introduction

Stereotactic radiosurgery (SRS) for multiple brain metastases with and without whole brain radiation therapy (WBRT) has been analyzed in multiple randomized trials [1–8]. Leksell Gamma Knife (GK) (Elekta AB., Sweden) was the first device designed for SRS. The GK Perfexion/Icon uses 192 cobalt-60 sources that converge in one point with submillimeter accuracy [9]. For patient positioning and fixation, a stereotactic frame is used which is docked to the table of the GK. To attach the frame to the patient, 4 posts on each corner of the frame are used. These 4 posts, each equipped with a screw, are used to fixate the stereotactic frame to the patient skull and to provide an optimal and stable localization and fixation. Before treatment, a magnetic resonance imaging (MRI) or computed tomography (CT) with mounted frame and indicator box is performed. The indicator box defines the stereotactic coordinate system for the irradiation. The frame stays on the patient from MRI/CT until the end of the treatment. Rojas-Villabona et al. analyzed the frame position from pretreatment MRI to posttreatment CT and found a submillimeter accuracy of the frame throughout the whole treatment procedure [10].

Some rare clinical situations prevent the use of the frame with 4 posts. For example, extremely anterior or posterior located lesions which may cause a possible collision with the GK or the position of a screw close to a bone flap from neurosurgery. One solution is reframing, which causes additional stress to the patient, re-examination and replanning [11]. Another possibility is the removal of one post. Ho et al. analyzed 20 patients treated with 3 posts (20 metastases) and 4 posts (116 metastases) and they found only 1 local failure and no differences in toxicity for the metastases treated with 3 posts [12]. MacKenzie et al. validated the localization stability of frames with 3 posts in phantom measurements with markers. They found in most cases accurate localization. Only when a high torque of ~27.8 Nm and a posterior post was removed, they found a disagreement in localization of 1.2 mm [13].

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To our knowledge, only phantom measurements or analyses of patient follow-up have been reported to prove the stability of frame fixation using 3 posts. The recently introduced Gamma Knife Icon™ (Elekta AB, Sweden) is equipped with a cone-beam CT (CBCT) and allows the verification of the patient position with frame or thermoplastic mask [14]. Here, we analyze the localization accuracy of the frame mounted with 4 and 3 posts via CBCT in patients and phantoms.

2. Material and Methods

2.1. Patients with frame and 4 posts

We retrospectively analyzed 12 patients with brain metastases treated with GK-SRS at our institution. The patients received a preplanning MRI one day before the treatment. On the day of treatment, the frame was mounted to the patient's head using 4 posts and a torque of 30 cNm. A regular planning CT (P-CT) (Brilliance Big Bore CT, Philips, The Netherlands) with indicator box was performed. After finalizing the treatment plan on the treatment planning system (Gamma Plan v.11.0.3, Elekta AB, Sweden) the patients received a CBCT on GK Icon. The system automatically matches the P-CT including stereotactic information to the CBCT and calculates the tranlational deviation [x (lateral), y (vertical) and z (longitudinal)] and rotational deviation. Possible deviations are displayed but not corrected because the P-CT is still the stereotactic reference. For patient 1–9 we performed an additional CBCT after treatment to analyze patient motion in the frame during treatment and we recorded the treatment time.

The study was approved by the local ethical committee and was conducted according to the principles of the declaration of Helsinki [15]. All patients gave informed consent.

2.2. Patients with frame and 3 posts

To verify the frame accuracy when only 3 posts are used for fixation, we analyzed 4 patients treated in our department with only 3 posts in different scenarios (Fig. 1).

Patient 1 [male, 61y, 7 brain metastases, 22 Gy to 50–60%]: The frame was mounted using 4 posts and a P-CT was performed. Due to a possible collision with the GK, the anterior left post was removed and a CBCT was performed before irradiation.

Patient 2 [male, 64y, recurrence of fibrous tumor, 14 Gy to 50%]: The frame was mounted using 4 posts and a P-CT was performed. One screw was too close to a bone flap from previous surgery and potentially not stable or may cause irritations to the bone flap, the posterior right post was removed and a CBCT was performed before irradiation.

Patient 3 [female, 53y, recurrence of meningioma, 14 Gy to 50%]: The frame was mounted to the patient using 4 posts and a P-CT was performed. One screw was too close to a bone flap from previous surgery and potentially not stable or may cause irritations to the bone flap, the anterior left post was removed and a CBCT was performed before irradiation. A large deviation was found and it was necessary to repeat the P-CT (P-CT2) with 3 posts, replanning and an additional CBCT before irradiation were done.

Patient 4 [male, 52y, 3 brain metastases, 10 Gy to 50%, 22 Gy to 45% and 22 Gy to 50%]: The frame was mounted to the patient using 3 posts (anterior left post was excluded due to possible collision and pain), a P-CT was performed and planning was finalized. Using the CBCT before irradiation, a large deviation was found and in this situation a new P-CT would not reduce the deviation. We decided that the patient stays in position on the GK and we performed a standalone CBCT. This standalone CBCT provides the same stereotactic information as the indicator box on the P-CT. The treatment plan was replanned based on the standalone CBCT information while the patient stayed in position on the Gamma Knife Icon. Before starting the irradiation an additional CBCT was performed to verify that the patient was still in position defined by standalone CBCT.

2.3. Phantom measurements

In order to complete the study, we performed phantom measurements using an Alderson head phantom (RSD Radiology Support Devices, USA). The screws which fixate the frame to the phantom were screwed with a force of 30 cNm and the screw length was between 25 and 45 mm. 5 different clinical scenarios were simulated as shown in Fig. 2. For each scenario a new P-CT and treatment plan was generated and the posts were, similar to the clinical setup, removed before the phantom was docked to the treatment couch.

3. Results

3.1. Patients with frame and 4 posts

We compared the recorded deviations by the CBCT to the standard radiosurgery setup on the GK (frame equipped with 4 posts). Table 1 shows the deviations of all 12 patients and the mean absolute values with standard deviation (SD). The mean absolute deviation between P-CT and CBCT for the frame setup with 4 posts was smaller than 0.35 mm and 0.34 degree.

For patient 1–9 we performed an additional CBCT after treatment to analyze the movement of the patient in the frame during treatment and recorded the treatment time (Table 2). The mean absolute deviation between CBCT before (pre-CBCT) and after GK treatment (post-CBCT) was smaller than 0.11 mm and 0.04 degree.

3.2. Patients with frame and 3 posts

In this section we analyzed 4 patients when the frame was mounted with only 3 posts in different scenarios (Table 3).

For patient 3, we analyzed the plan quality if the patient would have been treated without reacting on the recorded shift from CBCT 1. Table 4 shows the plan quality factors from the original plan and the plan if the patient would have been treated after CBCT1 without correction. Fig. 3 shows the discrepancy between the P-CT and CBCT1 after image co-registration. The co-registration of the patient anatomy between P-CT and CBCT matches well but the position of posterior post and its screw does not match. Due to the fact that the frame cannot move on the treatment couch, the patient head must have moved in the frame. This deviation in z direction is also visible by the shift vector from the CBCT1 (Table 3). After replanning the visual agreement of P-CT2 and CBCT2 is shown in Fig. 3.

3.3. Phantom measurements

In this section, we analyze the theoretical possible deviation for 9 different clinical scenarios without the human influence based on phantom measurements. Table 5 shows the deviations based on the

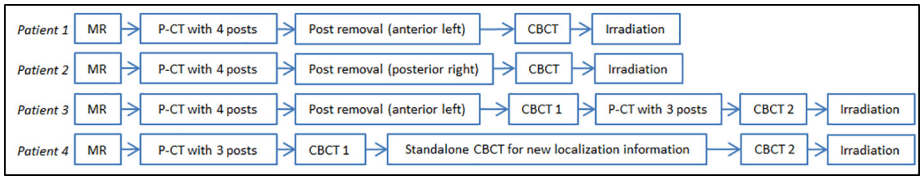

Fig. 1. 4 scenarios of clinical patients.