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Scientific Article

Orthogonal image pairs coupled with OSMS for noncoplanar beam angle, intracranial, single-isocenter, SRS treatments with multiple targets on the Varian Edge radiosurgery system

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Abstract

Purpose: To characterize the accuracy of noncoplanar image guided radiation therapy with the Varian Edge radiosurgery system for intracranial stereotactic radiosurgery (SRS) treatments by assessing the accuracy of kV/kV orthogonal pair registration with Optical Surface Monitoring System (OSMS) monitoring relative to cone beam computed tomography (CT).

Methods and materials: A Computerized Imaging Reference System head phantom and Encompass SRS Immobilization System were used to determine collision-free space for orthogonal image pairs (kV/kV) for couch rotations (CRs) of 45°, 30°, 15°, 345°, 330°, and 315°. Couch-induced shifts were measured using kV/kV orthogonal image pairs, OSMS, and cone beam CT. The kV/kV image pairs and OSMS localization accuracy was also assessed with respect to cone beam CT.

Results: Mean orthogonal image pair differences for 315°, 330°, 345°, 15°, 30°, and 45° CRs were $\leq\pm 0.60$ mm and $\pm 0.37°$. OSMS localization accuracy was $\leq\pm 0.25$ mm and $\pm 0.20°$. Correspondingly, kV/kV localization accuracy was $\leq\pm 0.30$ mm and $\pm 0.5°$. Shift differences for various image pairs at all CRs were $\leq\pm 1.10$ mm and $\pm 0.7°$. Cone beam CT deviation was 0.10 mm and 0.00° without patient motion or CR.

Conclusion: Based on our study, CR-induced shifts with the Varian Edge radiosurgery system will not produce noticeable dosimetric effects for SRS treatments. Thus, replacing cone beam CT with orthogonal kV/kV pairs coupled with OSMS at the treatment couch angle could

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reduce the number of cone beam CT scans that are acquired during a standard SRS treatment while providing an accurate and safe treatment with negligible dosimetric effects on the treatment plan.
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Introduction

Noncoplanar beam angles are commonly used in LINAC stereotactic radiosurgery (SRS) treatments and provide high dose conformality and sharp dose falloff outside of the target volume.[1,2] One consequence of this increased dose conformality is the necessity of precisely delivering the radiation. Small misalignments result in diseased tissues not receiving the required therapeutic dose. The minimization of these uncertainties is especially critical for new techniques in which multiple brain metastases are treated using a single isocenter.[3-5] With these techniques, small rotational misalignments at the isocenter (>0.5°) can cause larger errors at the target.[6]

Conventional SRS employs an invasive head frame for immobilization and precise target localization. Today, frameless SRS has become standard, with an accuracy that is similar to frame-based treatments.[7,8] Precision frameless SRS delivery is most commonly achieved through image guided radiation therapy (IGRT) using x-ray imagers that are attached to the treatment machine. These imagers can be used to obtain orthogonal planar images for patient localization, or they can be rotated around the patient to produce cone beam computed tomography (CT) scans. Although cone beam CT scans provide powerful tools for patient alignment, the configuration of these systems does not allow imaging at all patient orientations. Hence, when noncoplanar radiation beams are used for radiation treatment, the patient cannot be imaged in the final treatment position, resulting in potential misalignments and treatment misses.

To detect and correct uncertainties in LINAC radiosurgery treatments at noncoplanar beam angles, orthogonal or stereoscopic x-ray image pairs or surface tracking systems such as the Optical Surface Monitoring System (OSMS; Varian Medical Systems, Palo Alto, CA) potentially can be used.[9,10] At our clinic, multiple cone beam CT images are acquired during treatment (once for initial registration and following 2 consecutive beams). With the Varian Edge radiosurgery system, cone beam CT scans can only be acquired at the 0° (±2.5°) couch rotation (CR). This practice is inefficient when administering additional doses to the patient with an opportunity for intrafractional patient movements.

To reduce the number of cone beam CT scans during SRS treatments, we characterized the accuracy of noncoplanar IGRT with the Varian Edge radiosurgery system for intracranial SRS treatments by determining the collision-free space in which orthogonal pairs can be obtained (available as supplementary material online only at www.advancesradonc.org) and assessing the accuracy of kV/kV orthogonal pair registration with OSMS monitoring relative to cone beam CT as the gold standard.

Methods and materials

The Computerized Imaging Reference Systems (CIRS Inc., Norfolk, VA) head phantom with the Encompass SRS Immobilization System (Qfix, Avondale, PA) was used for this study. A Phillips Brilliance Big Bore 16-slice CT scan of the phantom (120 kVp; 1.5 mm slice thickness) was acquired with lasers that were aligned laterally at the ball bearings (BBs) on the Encompass mask and midline on the phantom. A generic treatment plan was created with the treatment isocenter placed on a BB located 3 cm lateral and midline inside the phantom head.

Multiple fields were created to allow digitally reconstructed radiographs to be created on demand at varying CRs. Digitally reconstructed radiographs were created with the standard Varian Edge algorithm and were not user altered. The kV/kV orthogonal image pairs (OPs) were acquired with the On-Board Imager (OBI) at Head Lateral (LAT) (70 kVp; 5 mAs) and Head Anterior-Posterior (AP) (85 kVp; 5mAs) and preset to kV acquisition parameters. The mV/kV OPs were acquired with the Electronic Portal Imaging Device (EPID) using a high-quality 2.5 mV imaging beam. Daily Winston-Lutz (W/L) tests at our institution demonstrated a mean isocentric accuracy of 0.35 mm (range, −0.36 to 0.53 mm). This was within the SRS tolerances for the coincidence of radiation and mechanical isocenter as recommended by the American Association of Physicists in Medicine Task Group 142 (±1.0 mm).[11] Thus, cone beam CT was considered the gold standard in this study as per Xu et al.[12]

Orthogonal image pairs

Four or more different sets of OPs were acquired at CRs of 45°, 30°, 15°, 345°, 330°, and 315° to quantify the reliability of OPs at different gantry angles. For example, the OPs acquired at the 30° CR were 15° and 105°, 0° and 90°, 345° and 75°, and 330° and 60°.

Couch rotation–induced shifts

Cone beam CT–, kV/kV-, MV/kV-, and OSMS-suggested shifts were acquired at couch angles of 45°, 30°, 15°, 345°, 330°, and 315° following the procedure detailed in Figure 1. CR-induced (CRI) shifts were quantified as shift deviations between OPs and cone beam CT scans. Cone beam CT shifts were considered the gold standard. The cone beam CT and kV/kV image pair data acquisition was repeated for 10 trials. All other data were repeated for 5 trials.

Cone beam computed tomography localization accuracy and hidden target test

To test cone beam CT localization accuracy, a W/L-type test (hidden target test) was performed at the 0° couch position with a 3 cm × 3 cm field, 6X MV beam, and 0.78 cm diameter tungsten BB in the CIRS head phantom. We acquired integrated AP and LAT portal images of the BB and assessed the images using commercial software.

Additionally, an end-to-end hidden target test was performed at couch angles of 315°, 330°, and 345°. The target was localized at the angle using kV/kV OPs. Portal images at orthogonal angles were acquired at these angles for the W/L analysis. An additional hidden target test was performed using OSMS-suggested shifts at the couch angles. Additional portal images were acquired for the W/L analysis.

Effects of rotational inaccuracies on single-isocenter, multiple-met treatments

Translational misalignments are minimal with the use of either kV/kV registration or OSMS tracking at noncoplanar beam angles. Rotational misalignments, although small, can result in large translational errors at points distant from the isocenter.

A margin was developed using an equation from Stanhope et al: $m = d\tan\Theta_p$, where d is the target-to-isocenter distance and Θ_p is the magnitude of rotation below which a fraction p of all rotational uncertainties falls, assuming a Gaussian distribution.[13]

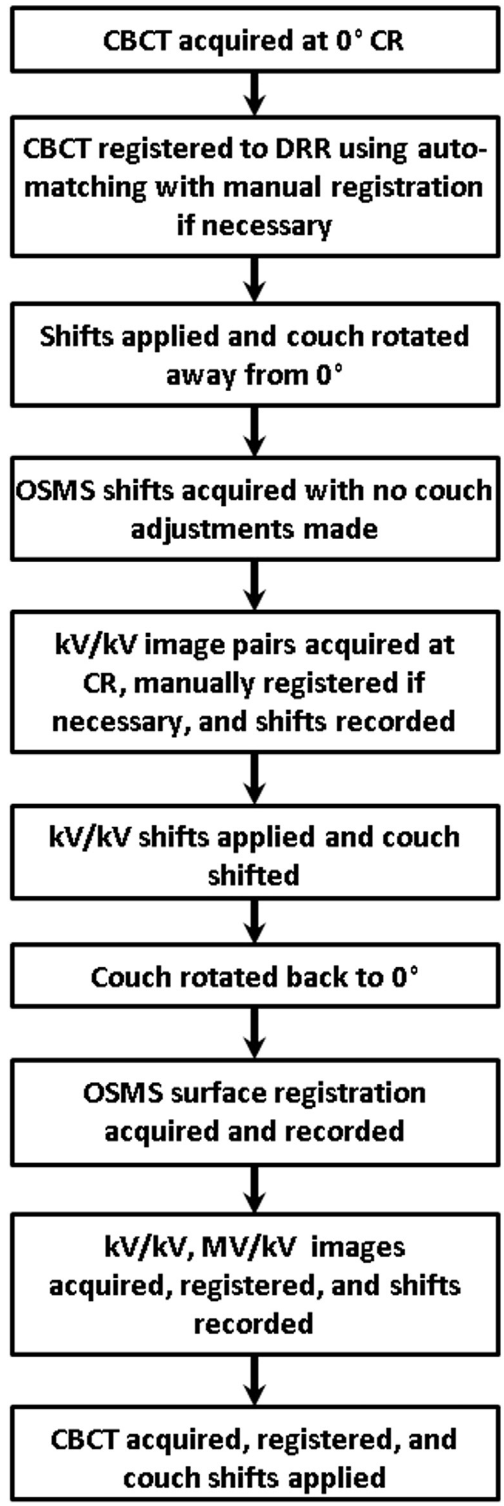

Figure 1 Couch rotation–induced shift acquisition method. This figure details the method of acquiring couch rotation–induced shifts for the couch angles of 315°, 330°, 345°, 15°, 30°, and 60°. Registration with auto-matching involved a predefined phantom setting and bounding box surrounding the head phantom to capture bony anatomy.

Statistical analysis

A paired 2-tailed Student *t* test was used to measure the significance of the difference between kV/kV, OSMS, MV/kV, and cone beam CT shifts. Parameters with $P < .05$ were considered statistically significant. A Gaussian distribution was assumed. A 2-way analysis of variance (ANOVA) was used to measure the significance of the difference between OSMS and cone beam CT at 0° CR without CR or patient motion influence. A 2-way ANOVA was used to measure the significance of the difference between OSMS shifts at 0° following various CRs. The same was applied to cone beam CT shifts at 0° following various CRs. A 2-sided Grubbs' test or extreme studentized deviate method was measured to determine any significant outliers ($P < .05$).

Results

Orthogonal image pairs

Localization shifts were acquired for multiple OPs at various CRs. The deviation between the suggested shifts from various OPs is shown in Table 1 (mean with range). Mean translational deviations were highest for 30° CR (1.1 mm). Mean rotational deviations were highest for 330° and 45° CR (0.27°). A 2-sided Grubbs' test found shifts for 1 trial of OPs at 30° CR to be statistically significant outliers. No optimal kV/kV pair was identified. Translational deviations exhibited a standard deviation of 0.27 mm. Rotations exhibited a standard deviation of 0.14°. A few unfavorable couch angles were detected during this study, including the kV/kV pair combinations of 295° and 205° or 310° and 220° gantry rotations at 330° CR.

Couch rotation–induced shifts

Cone beam CT, kV/kV, MV/kV, and OSMS mean suggested shifts at 0° CR post-CR to −45°, −30°, −15°, 15°, 30°, and 45° were ≤±0.20 mm and ≤±0.20° (Fig 2). Mean translational shifts were larger in the lateral direction (≤±0.60 mm) for kV/kV-, MV/kV-, OSMS-, and cone beam CT–suggested shifts compared with the longitudinal or vertical directions (≤±0.40 mm; Fig 2). Figure 3 shows a deviation between cone beam CT–suggested shifts and kV/kV-, MV/kV-, or OSMS-suggested shifts at 0° CR. A paired 2-tailed Student *t* test revealed that kV/kV and cone beam CT shifts had $P < .05$ in the vertical, longitudinal, yaw, and pitch directions, which demonstrate that these shifts were statistically different. *P* values were below .001 in the yaw direction. Cone beam CT and OSMS shifts exhibited significant differences in the longitudinal direction.

The mean cone beam CT and MV/kV deviation was ≤±0.32° for rotations and ≤±0.20 mm for translational shifts. The maximum cone beam CT and MV/kV rotational deviation was an outlier at a CR of −45° (315°) in the yaw direction. All other rotational deviations were ≤0.18°, with the next largest mean rotational deviation of 0.18° in the yaw direction at 30° CR. The longitudinal deviation was greater than the lateral and vertical deviations at all CRs except 15° CR. The MV/kV images were of poor quality and thus difficult to register, allowing for low-deviation results.

The mean cone beam CT and kV/kV deviation was ≤±0.44° (range, 0.00°-0.44°) for rotations and ≤±0.22 mm (range, 0.00-0.80 mm) for translations. The deviation in the yaw direction was greater than the pitch and roll differences at all CRs except −15° (345°), where roll deviation exceeded the yaw deviation. Image pairs (kV/kV) suggested larger rotations than cone beam CT, with suggested shifts up to 0.9° in the roll direction. The mean cone beam CT and OSMS deviation was ≤±0.18° (range, 0.00°-0.40°) for rotations and ≤±0.20 mm (range, 0.00-0.50 mm) for translations. OSMS-suggested shifts deviated less from cone beam CT–suggested shifts compared with kV/kV-suggested shifts (mainly for rotations). Image pairs (kV/kV) and OSMS deviation at all couch angles ranged from 0.0 to 0.4 mm and 0.0° to 0.5°.

Mean kV/kV CRI shifts (ie, the deviation between suggested shifts at couch angle and suggested shifts at 0° CR) were ≤0.71 mm (total range, 0.00-1.10 mm) and ≤±0.62° (total range, 0.00°-1.40°; Table 2). Mean OSMS CRI shifts were ≤0.90 mm (total range, 0.00-0.60 mm) and ≤±0.58° (total range, 0.00°-0.80°; Table 2). Figure 4 and Table 2 show the mean and range of kV/kV and OSMS CRI shifts. A 2-way ANOVA also demonstrated that OSMS

Table 1 Deviation (mean with range) between 4 or more different orthogonal image pairs at various couch rotations

	CR 30°	CR 330°	CR 45°	CR 315°	CR 15°	CR 345°
Vrt (mm)	0.50 (0.20-1.10)	0.20 (0.10-0.30)	0.10 (0.00-0.20)	0.20 (0.10-0.30)	0.30 (0.20-0.40)	0.30 (0.20-0.30)
Lng (mm)	0.60 (0.20-1.10)	0.20 (0.20-0.20)	0.20 (0.10-0.20)	0.10 (0.10-0.20)	0.10 (0.10-0.20)	0.20 (0.10-0.30)
Lat (mm)	0.50 (0.20-1.00)	0.40 (0.30-0.40)	0.20 (0.10-0.30)	0.10 (0.00-0.20)	0.20 (0.10-0.30)	0.20 (0.10-0.30)
Yaw (°)	0.13 (0.10-0.20)	0.23 (0.10-0.30)	0.20 (0.20-0.20)	0.13 (0.10-0.20)	0.10 (0.10-0.10)	0.20 (0.20-0.20)
Pitch (°)	0.33 (0.10-0.50)	0.17 (0.10-0.30)	0.37 (0.30-0.40)	0.13 (0.10-0.20)	0.17 (0.10-0.20)	0.17 (0.10-0.30)
Roll (°)	0.37 (0.20-0.70)	0.37 (0.30-0.40)	0.23 (0.20-0.30)	0.17 (0.10-0.20)	0.33 (0.30-0.40)	0.30 (0.20-0.40)

CR, couch rotation; Lat, lateral; Lng, longitudinal; Vrt, vertical.

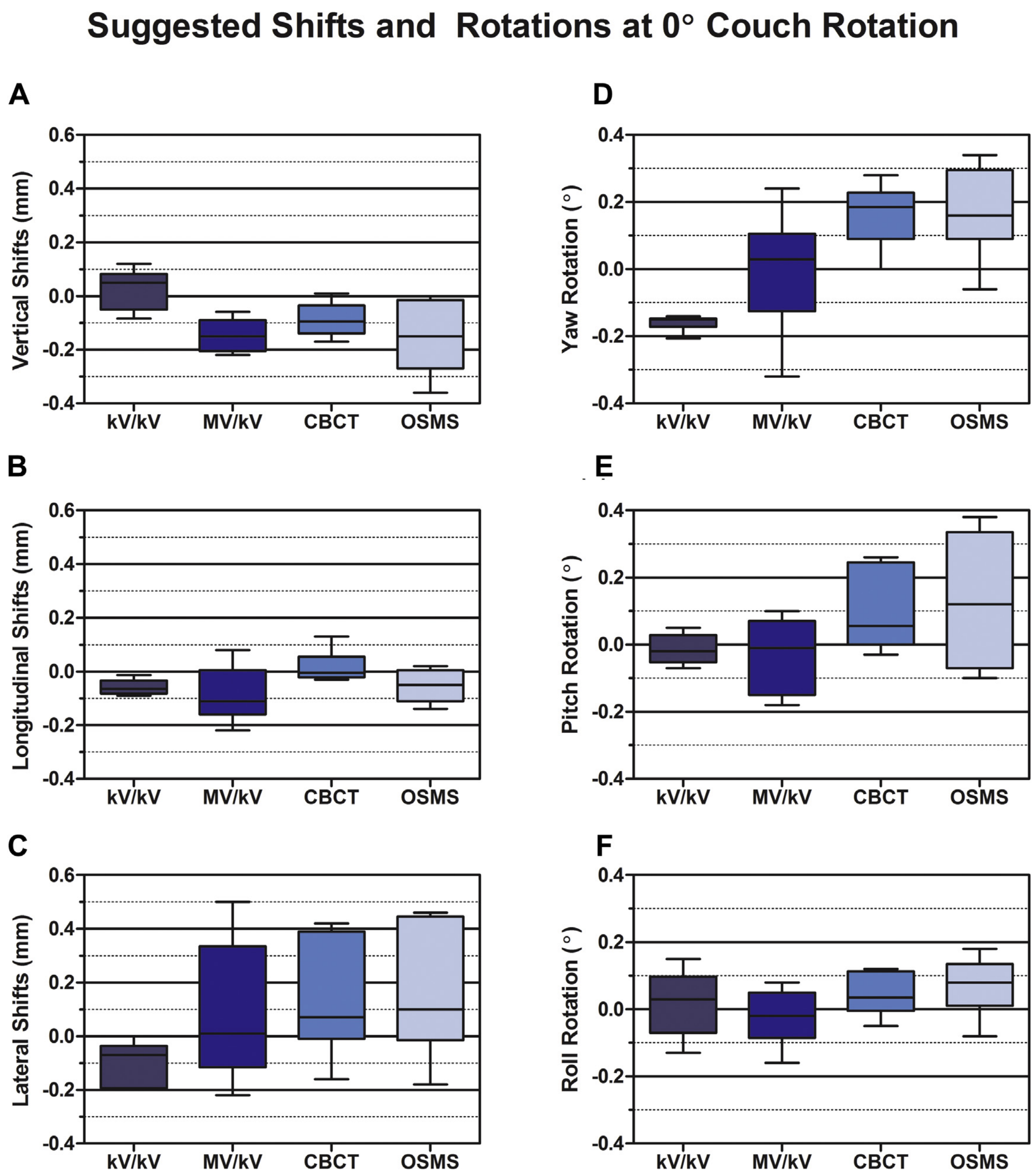

Figure 2 Cone beam computed tomography–, kV/kV-, MV/kV-, and Optical Surface Monitoring System–suggested shifts (mean with range) at 0° couch rotation post-rotation to −45°, −30°, −15°, 15°, 30°, and 45° couch positions. (A-C) Translational shifts (mm); (D-F) rotations (°).

shifts post-CR had a statistically significant effect on shift post-rotation at 0° ($P = .0064$). The same was true for cone beam CT shifts post-CR at 0° ($P < .0001$).

Maximum cone beam CT CRI shifts were 0.10 mm and 0.40° (in the yaw direction for 30° CR). Mean cone beam CT CRI shifts were 0.03 mm and 0.061° with no shifts in the pitch direction. The 315° CR exhibited no rotational or translational couch-induced shifts. For 5 successive acquisitions, cone beam CT and OSMS provided deviations of 0.10 mm and 0.00° without the influence of patient motion or CR. A 2-way ANOVA demonstrated that neither OSMS nor cone beam CT had statistically significant differences in shifts at 0° CR without the influence of CR or patient motion.

Cone beam computed tomography localization accuracy and hidden target test

Cone beam CT localization accuracy as defined by a W/L-type test at couch angle of 0° demonstrated a magnitude of error of 0.35 mm in the AP plane and 0.85 mm in the lateral plane with particular error in the superior-inferior direction. The total mean magnitude of

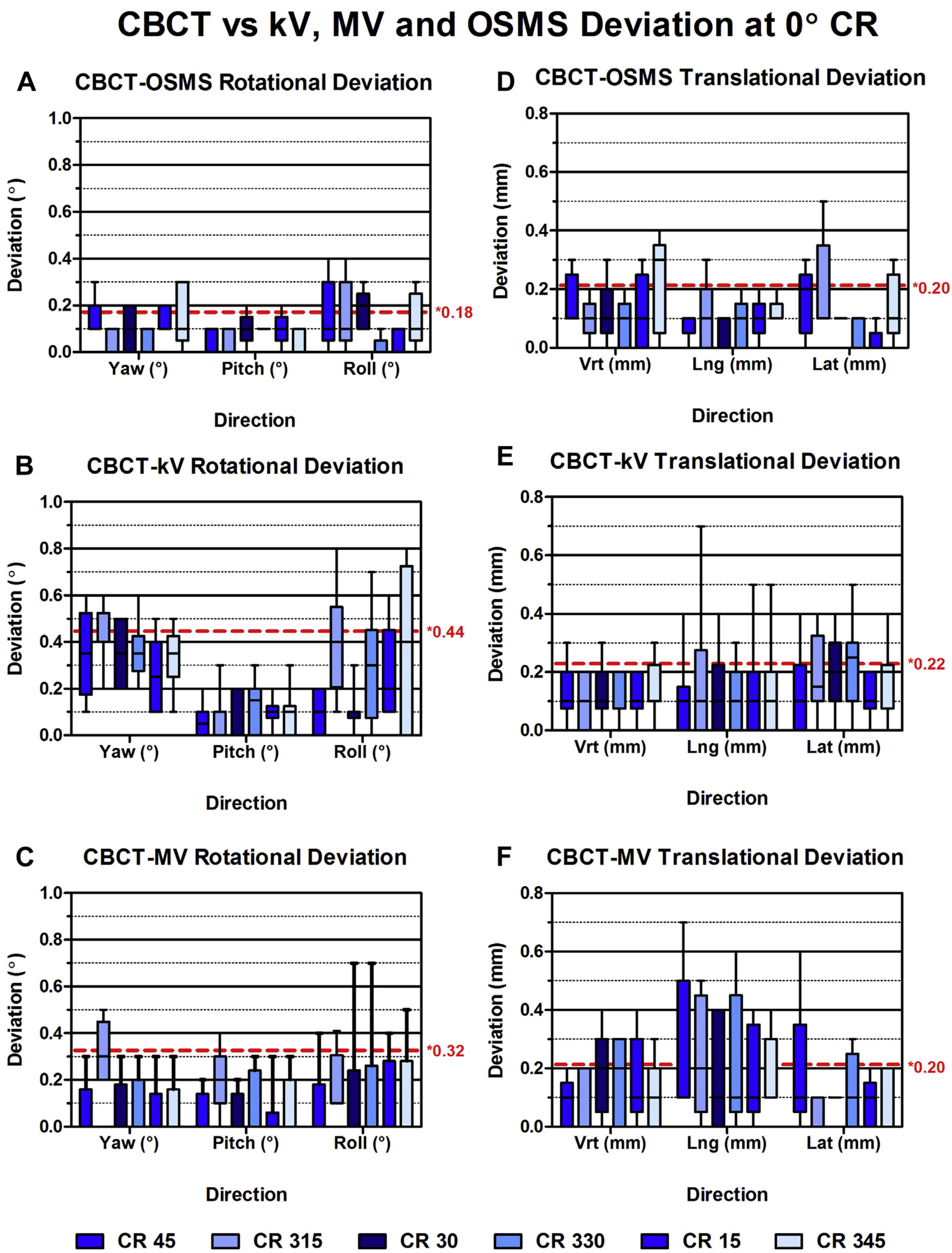

Figure 3 Couch rotation–induced shifts (ie, shift deviation between cone beam computed tomography–suggested shifts and kV/kV-, MV/kV-, or OSMS-suggested shifts at 0° couch rotation). Cone beam computed tomography shifts were considered the gold standard. (A-C) Rotational deviation (°); (D-F) translational deviation (mm). The red dotted line indicates the maximum value of the mean deviation (from each couch angle and rotation).

error was 0.60 mm for cone beam CT. A hidden target test at the couch angle for kV/kV pairs demonstrated a 0.36 mm mean magnitude of error for kV/kV pairs and 0.92 mm mean magnitude of error for OSMS.

The current gold standard for localization at noncoplanar couch angles at our clinic is orthogonal kV/kV pairs. The measured accuracy of the kV/kV orthogonal positioning at our clinic at each couch angle was at best

Table 2 kV/kV and OSMS image pair couch rotation–induced shifts (ie, difference between shift at angle and shift at 0)

	CR 45°	CR 315°	CR 30°	CR 330°	CR 15°	CR 345°
kV/kV Image Pairs						
Vrt (mm)	0.25 (0.00-0.50)	0.14 (0.00-0.40)	0.29 (0.10-0.60)	0.25 (0.10-0.40)	0.24 (0.00-0.40)	0.24 (0.00-0.80)
Lng (mm)	0.30 (0.10-0.60)	0.21 (0.00-0.40)	0.17 (0.00-0.40)	0.23 (0.00-0.40)	0.17 (0.00-0.70)	0.21 (0.00-1.00)
Lat (mm)	0.49 (0.30-0.90)	0.71 (0.30-1.10)	0.31 (0.00-1.00)	0.22 (0.00-0.50)	0.12 (0.00-0.20)	0.63 (0.20-1.10)
Yaw (°)	0.16 (0.00-0.40)	0.50 (0.20-1.10)	0.13 (0.00-0.30)	0.19 (0.00-0.50)	0.17 (0.10-0.40)	0.26 (0.00-0.60)
Pitch (°)	0.54 (0.00-1.00)	0.11 (0.00-0.40)	0.39 (0.00-0.90)	0.34 (0.10-0.60)	0.32 (0.00-0.60)	0.22 (0.00-0.50)
Roll (°)	0.31 (0.00-0.70)	0.44 (0.00-1.00)	0.50 (0.20-0.80)	0.48 (0.10-1.00)	0.38 (0.10-1.10)	0.62 (0.00-1.40)
OSMS						
Vrt (mm)	0.03 (0.10-0.50)	0.10 (0.00-0.10)	0.40 (0.10-0.70)	0.10 (0.10-0.20)	0.20 (0.00-0.30)	0.40 (0.10-0.70)
Lng (mm)	0.40 (0.10-0.60)	0.10 (0.00-0.30)	0.40 (0.30-0.40)	0.10 (0.00-0.30)	0.30 (0.00-0.60)	0.10 (0.00-0.10)
Lat (mm)	0.30 (0.10-0.60)	0.90 (0.70-1.10)	0.20 (0.10-0.30)	0.10 (0.10-0.20)	0.20 (0.20-0.20)	0.70 (0.50-0.80)
Yaw (°)	0.58 (0.40-0.80)	0.06 (0.00-0.10)	0.48 (0.30-0.60)	0.14 (0.00-0.40)	0.32 (0.20-0.40)	0.16 (0.00-0.40)
Pitch (°)	0.50 (0.40-0.60)	0.18 (0.10-0.30)	0.38 (0.30-0.50)	0.20 (0.10-0.40)	0.28 (0.20-0.40)	0.06 (0.00-0.10)
Roll (°)	0.24 (0.10-0.40)	0.24 (0.10-0.40)	0.36 (0.30-0.40)	0.10 (0.00-0.20)	0.08 (0.00-0.10)	0.28 (0.10-0.50)

CR, couch rotation; Lat, lateral; Lng, longitudinal; OSMS, Optical Surface Monitoring System; Vrt, vertical.

approximately 0.36 mm in each direction on the basis of a W/L-type test. However, published data on noncoplanar CRs demonstrate that the current gold standard for this type of target registration error has been measured with a stereoscopic kV imaging system due to the independence of the IGRT system from the gantry stand itself.[14] The accuracy of these stereoscopic systems has been reported at 0.2 mm in phantoms using a hidden target test to measure the target registration error of that IGRT system.[14]

Effects of rotational inaccuracies on single-isocenter, multiple-met treatments

On the basis of our maximum rotational errors using OSMS for monitoring at non-zero couch angles, an additional margin of 0.33 mm will be recommended for SRS treatments at our institution. This margin was developed using the previously defined equation by Stanhope et al.[13] The magnitude of rotation below which 95% of all rotational errors occurred, Θ_{95}, for a 5-cm separation (d) between the isocenter and the planning target volume (PTV) was calculated as 0.033 cm using the equation by Stanhope et al. In addition, intrafraction motion has been reported with frameless radiosurgery as approximately 0.35 ± 0.21 mm with maximums that range to 1.15 mm. This was not included in our study because it was a phantom study and dependent only on the one localization mask system we used.

Discussion

This study quantified couch-induced imaging shifts and assessed OSMS and kV/kV OP accuracy compared with cone beam CT at various CRs. The maximum cone beam CT CRI shifts were 0.10 mm and 0.40°, the mean kV/kV and OSMS deviations post-CR were ≤±0.71 mm and ±0.62°, the mean deviations between OPs and cone beam CT were ≤±0.29 mm and ±0.39°, and the mean deviations between OSMS and CBCT were ≤ ±0.23 mm and ±0.20°. Roper et al demonstrated that rotational deviations of <0.50° had negligible dose effects on single-isocenter treatments for multiple metastases (dose to 95% of PTV [D95] and volume receiving 95% of prescribed volume [V95] >95%).[6] In another study, Stanhope et al demonstrated that a clinical target volume margin of 1 mm is sufficient to account for any intraoperational rotational uncertainties for single-isocenter treatments for multiple metastases.[13] Guckenberger et al also reported that SRS accuracy must be within 1 mm to "avoid decreased target coverage and dose conformality >5%".[10]

OSMS demonstrated tight tolerances (≤±0.50 mm and ±0.40°). On the basis of this study, OSMS can be used safely to realign a patient at non-zero treatment couch angles. At our institution, a cone beam CT scan is acquired after every 2 beams. This typically results in approximately 4 to 11 cone beam CT scans during a single treatment. One cone beam CT scan provides 10 to 50 mGy (range, 110-550 mGy) to the skull whereas a kV/kV pair provides approximately 4 mGy (up to 44 mGy) to the skull.[15] Image pairs (kV/kV) coupled with OSMS at the treatment couch angle can be substituted for cone beam CT periodically during treatment to reduce the number of cone beam CT scans acquired during a standard SRS treatment while providing an accurate and safe treatment with negligible dosimetric effects on the treatment plan. This will ultimately reduce the dose bath outside the PTV. It must be noted, however, that this study was a phantom trial and thus devoid of patient motion. As such, additional studies that include patient motion are needed before this technique is adopted as a routine treatment.

According to one trial, cone beam CT and OSMS provided deviations of 0.10 mm and 0.00°

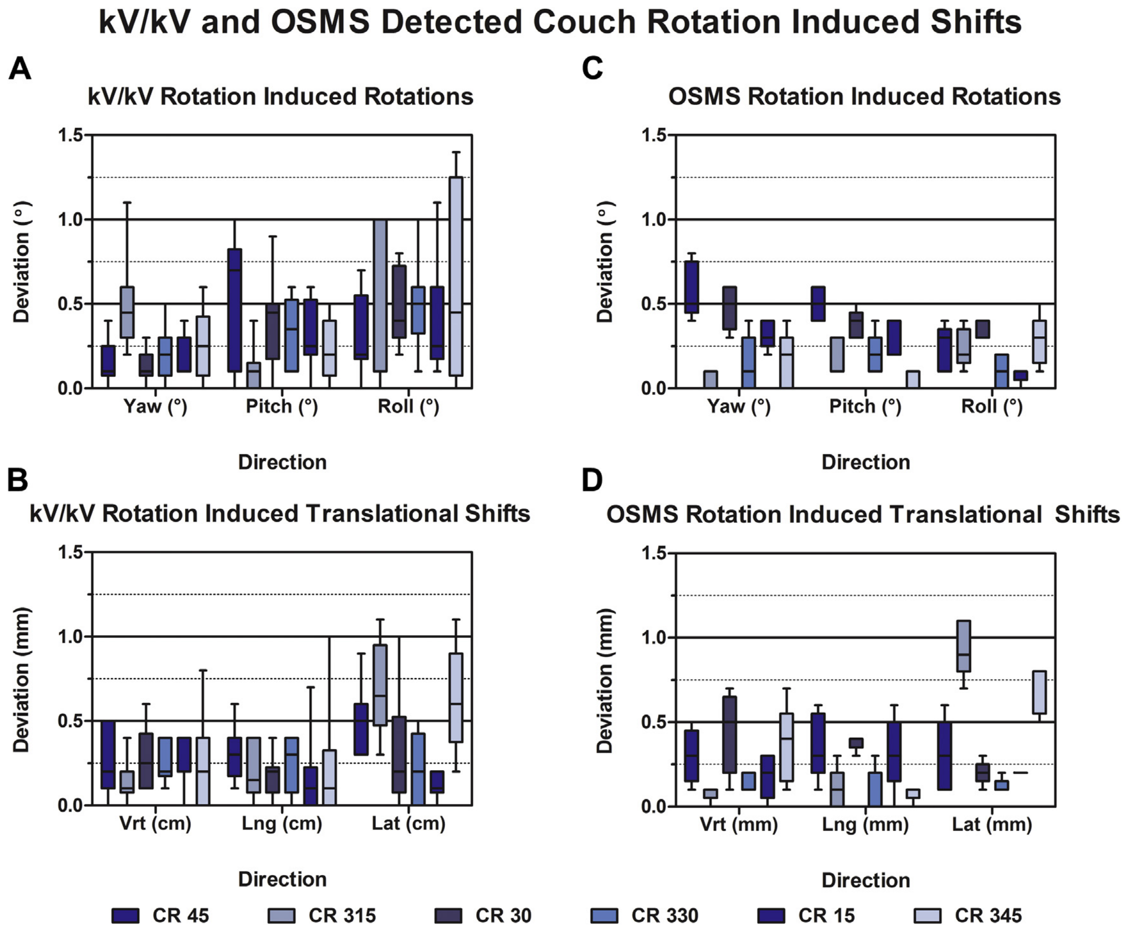

Figure 4 (A, B) kV/kV- and (C, D) Optical Surface Monitoring System–recognized couch rotation–induced shifts (ie, deviation between suggested shifts at couch angle and suggested shifts at 0° couch rotation). Mean and range are plotted.

without the influence of patient motion or CR. The mean kV/kV-suggested shifts for a particular CR at different orthogonal angles provide different shifts for each image pair with differences within 0.60 mm and 0.40°. Xu et al reported that changes in systematic error at different couch angles could be due to different regions of interest in 2- and 3-dimensional image registration as well as isocentric uncertainty due to CR.[12] Although CRI shifts exist, according to these results, the shifts will have negligible dosimetric effects even if not taken into account.[6]

This work is similar to others in the literature. Xu et al tested systematic deviations between OP registration for different treatment sites on the Edge system and reported systematic errors within 0.3° and 0.3 mm for rotational and translational directions where 2- and 3-dimensional image registration was considered the gold standard.[12] Another study tested OSMS accuracy with cone beam CT, its capability to recognize predefined shifts, accuracy at different couch angles, and reproducibility with one camera blocked.[9] To our knowledge, our study is the first to assess OPs coupled with OSMS accuracy at noncoplanar angles for the Varian Edge system with a specific focus on intracranial, SRS, single-isocenter treatments with multiple targets.

OSMS-suggested shifts were closer to cone beam CT–suggested shifts than kV/kV OPs were, with a mean deviation of ±0.22 mm and ±0.18° between OSMS and CT versus a mean deviation of ±0.22 mm and ±0.44° between kV/kV pairs and cone-beam CT. Wen et al reported systematic deviations between OSMS and cone beam CT on the Edge system of −0.4 ± 0.2 mm, 0.1 ± 0.3 mm, and 0.0 ± 0.1 mm in the vertical, longitudinal, and lateral directions, respectively.[16] Furthermore, OSMS produces an instant shift compared with kV/kV image pairs, which require the acquisition of 2 x-ray images, motion enable of the gantry for 90°, auto-matching, and manual verification of the auto-match (similar to the time required for cone beam CT). This again highlights the benefit of using OSMS. However, Williams et al demonstrated the effect of facial motion on OSMS. Because OSMS is a surrogate for tumor motion, there is an additional need for kV/kV OPs. An OSMS and cone beam CT agreement was within 1.0 ± 1.0 mm and ±0.6° for patients treated with an open face mask, much larger than our measured agreement of 0.20 mm (0.00-0.50 mm) and 0.18° (0.00°-0.40°) and likely due to patient motion, or the lack thereof, as in our study.[17]

For the OSMS end-to-end hidden target test, we unnecessarily shifted on the basis of the OSMS numbers at the couch angle, which created a larger error from the isocenter with our hidden target test. When using OSMS monitoring during treatment, a tolerance window is set (0.50 mm translational, 0.50° rotational) and a shift does not occur unless outside of the tolerance window. If outside of the tolerance window for an extended period of monitoring time, new shifts are determined through reimaging using a kV/kV pair at the CR or cone beam CT at a 0° couch angle. The magnitude of error from true isocenter using the hidden target test with the kV/kV pair at the CR was 0.36 mm.

Conclusion

On the basis of the results from this study, CRI shifts on the Varian Edge radiosurgery system will not produce noticeable dosimetric effects for SRS treatments. OSMS and kV/kV OPs had mean shifts within ≤0.30 mm and ≤0.5° of cone beam CT shifts and thus are safe to use periodically during SRS treatments in lieu of cone beam CT for localization. The use of these 2 additional localization methods may provide more efficient and equally safe treatments while reducing the dose bath to the skull caused by cone beam CT. Thus, to reduce the number of cone beam CT scans at the 0° CR, we conclude that OSMS and kV/kV OPs could be substituted for intratreatment cone beam CT for SRS treatments. A time study of OSMS and kV/kV OPs with cone beam CT to provide the most efficient localization strategy for SRS treatments is recommended.

Supplementary data

Supplementary material for this article (http://dx.doi.org/10.1016/j.adro.2017.04.006) can be found at www.advancesradonc.org.

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