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Scientific Article

Clinical Experience of Intrafractional Motion Monitoring of Patients Under Head and Neck Radiation Therapy Using ExacTrac Dynamic System

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Purpose: The combination of surface-guided radiation therapy (SGRT) and image-guided radiation therapy (IGRT) can provide complementary information of patient positioning throughout treatments. The ExacTrac Dynamic (EXTD) system is a combined SGRT and IGRT system that can provide real-time motion detection via optical surface and thermal tracking during treatment delivery, with stereoscopic x-ray for positional verification. The purpose of this study was to examine the performance of EXTD for intrafractional motion monitoring using real clinical cases.

Methods and Materials: Treatment log files exported from EXTD for 40 patients with 335 fractions were retrospectively analyzed. Frequency of beam-hold triggered during treatments were recorded, with the comparison of shifts detected by optical surface tracking (EXTD_Thml) and x-ray verification (EXTD_Xray).

Results: Among the 335 fractions, automatic beam-holds were triggered 41 times, followed by x-ray positional verification with internal anatomy. The difference of shifts detected by EXTD_Thml and EXTD_Xray were less than 1 mm and 1° in translational and rotational directions, respectively. After x-ray verification, none of them required the application of positional correction.

Conclusions: The availability of x-ray imaging with optical surface tracking in EXTD is essential to verify whether geometric shifts are required to correct patient position. Considering the ability of continuous monitoring of patient positions with optical surface tracking and internal imaging, EXTD is an effective tool for intrafractional motion monitoring during radiation therapy.

Introduction

Real-time intrafraction motion monitoring and position correction are essential to ensure accurate target irradiation while sparing the neighboring normal tissues.[1-7] The use of surface-guided radiation therapy (SGRT) for motion monitoring has been increasing recently. Such a system is usually composed of a projector and one or several cameras to acquire live 3-dimensional surfaces of the patients.[8] Through comparing the live surfaces and the reference surface, the system can calculate the geometric shifts of patient positions in both translational and rotational directions. Also, an additional level of safety and accuracy can be guaranteed through

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automatic beam-hold during treatment when the deviation of live and reference surface exceeds a preset threshold. Therefore, it has the potential to improve the clinical outcomes with accurate target localization and irradiation.[9]

ExacTrac Dynamic (EXTD) (BrainLab AG) is an SGRT system combined with thermal mapping capability and equipped with stereoscopic x-ray for image-guided radiation therapy (IGRT).[9] Previous phantom-based studies had demonstrated that EXTD could offer comparable accuracy for shift detection with cone beam computed tomography (CBCT) on both cranial and pelvic phantoms.[10,11] The purpose of this study was to further examine the performance of EXTD for intrafractional motion monitoring using real clinical cases. Frequency of beam-hold during treatment was recorded, followed by the comparison of shifts reported by optical surface tracking (EXTD_Thml) and x-ray verification (EXTD_Xray). Also, this study investigated frequency of applying correction remotely to the couch after x-ray verification.

Methods

Patient selection and treatment plan preparation

A retrospective analysis of 40 patients receiving head and neck radiation therapy in our institution from June 2022 to February 2023 using EXTD for intrafractional motion monitoring was performed. The characteristics of patients are listed in Table 1. Treatment log files of 335 fractions were analyzed in this study. All plans were generated using either 6-MV or 6-MV flattening-filter-free beams and a 120 high-definition multileaf collimator from a TrueBeam linear accelerator (Varian Medical Systems). The target volume of each patient was defined by the oncologist using magnetic resonance images fused with the planning CT with slice thickness of 1.5 mm. The planning target volume (PTV) included the clinical target volume with an addition of a 2-mm margin to account for organ movement and patient setup uncertainty. The treatment plans were generated using the iPlan treatment planning system, version 4.5 (Brainlab AG). At least 95% of the PTVs received the prescription dose with the optimization criteria following NRG-HN001 protocol.[12]

Patient immobilization and treatment monitoring

Patients were immobilized by the Brainlab cranial 4Pi stereotactic mask (Brainlab AG) to minimize movement. Throughout the treatment, EXTD_Thml was used to monitor the position of the mask, which acted as the surrogate of the patient's position. X-ray verification was used to confirm whether geometric shifts were required

Table 1 Characteristics of patients in the study

Characteristic	Patients*
Age, y	60 (26-76)[a]
Sex	
Male	18 (45)
Female	22 (55)
Diagnosis	
Brain metastasis	28 (70)
Pituitary	6 (15)
Nasopharyngeal carcinoma (boost)	3 (7.5)
Acoustic neuroma	2 (5)
Arteriovenous malformation	1 (2.5)
Prescription dose / number of fractions	
Brain metastasis	15-22 Gy / 1 fr
Pituitary	45 Gy / 25 fr – 52.2 Gy / 29 fr
Nasopharyngeal carcinoma (boost)	16 Gy / 8 fr
Acoustic neuroma	50.4 Gy / 28 fr
Arteriovenous malformation	32.5 Gy / 5 fr

* Data is presented as the number (percentage) of patients unless otherwise indicated.
[a] Age is presented as the average (range) of 40 patients.

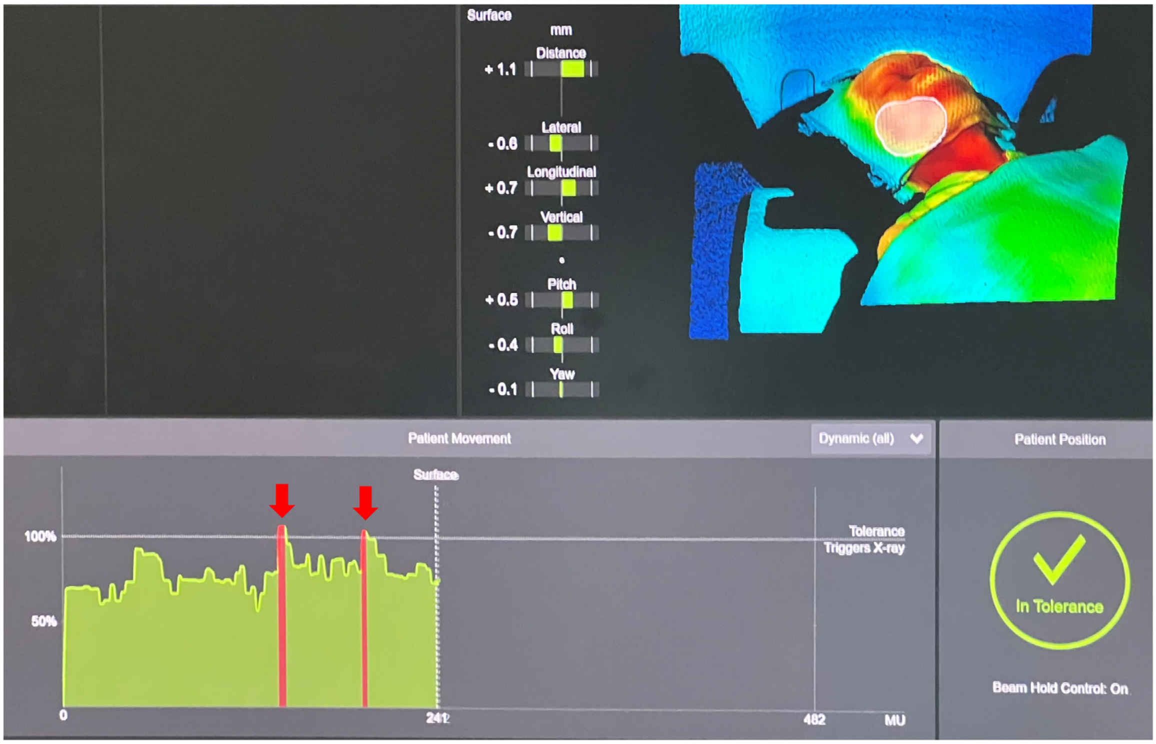

Figure 1 Treatment mode layout in the ExacTrac Dynamic (EXTD) system. Optical surface tracking (EXTD_Thml) is used to monitor patient position during treatment by comparing the live optical surface and thermal signals with the corresponding reference data. The shifts detected under surface tracking exceeded the preset tolerance, which might trigger beam-hold during treatment (indicated by red arrows).

for positional correction. The motion of the head relative to the mask was assumed to be negligible due to the tight fit of the mask. The face and mask surface area near the PTV was included in the area of interest for surface tracking.

The EXTD system was used to monitor the patient's position in real time during treatment using the EXTD_Thml, with EXTD_Xray being used for positional verification. There were 3 different settings available in EXTD for automatic triggering of x-ray, namely (1) when surface tracking exceeded tolerance, (2) when a set number of monitor units had been treated, and (3) when the gantry was at specific positions (0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315°) for arc treatment.[10] In our hospital, x-ray is set to trigger automatically when surface tracking exceeds predefined tolerance, as shown in Fig. 1. If the patient position deviated from the reference position with a magnitude greater than 1.5 mm in the composite translational direction ($vector_{translation}$) (Eq. 1) or 1.5 degrees in the composite rotational direction ($vector_{rotation}$) (Eq. 2) under EXTD_Thml for more than 1 second, beam-hold would be triggered, and the EXTD_Xray would be used for positional verification. Patients in the study were repositioned if the geometric shifts from x-ray verification were greater than 1 mm or 1° in 6 degrees of freedom, based on our local practice.

$$Vector_{translation} = \sqrt{\Delta^2_{vertical} + \Delta^2_{longitudinal} + \Delta^2_{lateral}} \quad (1)$$

$$Vector_{rotation} = \sqrt{\Delta^2_{roll} + \Delta^2_{pitch} + \Delta^2_{yaw}} \quad (2)$$

where $\Delta_{vertical}$, $\Delta_{longitudinal}$, $\Delta_{lateral}$, Δ_{roll}, Δ_{pitch}, and Δ_{yaw} were the shift detection of EXTD_Thml in vertical, longitudinal, lateral, roll, pitch, and yaw directions, respectively.

Data analysis

Positional information for each fraction of patient treatment under EXTD_Thml and EXTD_Xray were automatically recorded in log files in EXTD. These log files were extracted and analyzed in terms of (1) frequency of beam-hold, (2) difference of shifts reported by EXTD_Thml and EXTD_Xray, and (3) frequency of applying correction to the patient position after x-ray verification. Statistical analyses were performed using SPSS Statistics, version 17.0 (SPSS, Inc). The Wilcoxon signed-rank test was conducted to investigate if there was significant difference in the shift detection of EXTD_Thml and EXTD_Xray, and 0.05 was set to be the significance level (α) for rejecting the null hypothesis.

Results

Treatment log files exported from EXTD for 40 patients with 335 fractions from June 2022 to February 2023 were retrospectively analyzed in this study. Among the 335 fractions, automatic beam-holds were triggered 41 times, followed by x-ray positional verification with internal anatomy. The difference of shifts detected by EXTD_Thml and EXTD_Xray are shown in Table 2. The average translational and rotational differences between EXTD_Thml and EXTD_Xray among the 40 patients were less than 1 mm and 1°, respectively.

More specifically, the largest translational difference between EXTD_Thml and EXTD_Xray was observed in the lateral (0.88 ± 0.98 mm), followed by the vertical (0.51 ± 0.61 mm) and longitudinal (0.38 ± 0.35 mm) directions. For the rotational direction, the difference between EXTD_Thml and EXTD_Xray was largest in the roll (0.96° ± 1.28°), followed by the yaw (0.54° ± 0.57°) and pitch (0.47° ± 0.45°) directions.

Wilcoxon signed-rank tests showed that the differences between EXTD_Thml and EXTD_Xray were significant in the lateral, pitch, and yaw directions ($P < 0.05$). Also, none of them required the application of correction remotely to the couch for positional rectification, because x-ray verified that the geometric shifts were within 1 mm or 1° in 6 degrees of freedom.

Discussion

The EXTD system is a combination of SGRT and IGRT systems for intrafractional treatment monitoring. It can trigger automatic beam-hold if the deviation of live and reference surfaces under SGRT exceed the preset tolerance. X-ray would then be initiated for positional verification with internal bony structures. In a study conducted on phantoms to examine the shift detectability of EXTD_Thml and EXTD_Xray against CBCT, Chow et al demonstrated that the difference in translations and rotations reported by EXTD_Thml and EXTD_Xray against CBCT were less than 0.8 mm and 0.7° on both cranial and pelvic phantoms.[11] A similar study on both cranial and pelvic phantoms was performed by Da Silva Mendes et al to quantify the positional difference between EXTD_Xray and CBCT, with all differences within the submillimeter range.[10] Also, Ma et al conducted a study on the residual setup errors between ExacTrac x-ray 6D and CBCT using a cranial phantom and reported that the errors were less than 0.5 mm and 0.2° for translational and rotational directions, respectively.[13,14] All these studies demonstrated that EXTD could provide comparable accuracy on shift detection with CBCT using stationary phantoms. However, with the focus of phantom-based measurements, patient movements and anatomic changes during treatments were not considered.[11] This study therefore aimed to further examine the performance of EXTD for intrafractional motion monitoring using real clinical cases.

Da Silva Mendes et al reviewed the treatment records of 14 patients with intracranial tumors, who were immobilized using open face masks and under monitoring by stereoscopic x-ray imaging acquired at fixed gantry positions (0°, 90°, 180°, and 270°).[10] It was found that differences between EXTD_Thml and EXTD_Xray were close to 0 mm and less than 0.5° in all translational and rotational directions, respectively. This study, on the contrary, examined the performance of EXTD with another setting of automatic beam-holds and x-ray triggering. Automatic x-ray was triggered when the optical surface and thermal tracking exceeded the preset tolerance, instead of having the x-ray verification at fixed gantry angles. Among the 335 fractions, automatic beam-holds were triggered 41 times, followed by x-ray positional verification. The differences between EXTD_Thml and EXTD_Xray were less than 1 mm and 1° in all translational and rotational directions, respectively. After x-ray verification, none of the fractions required the application of positional correction.

Table 2 Differences of shift detected by EXTD_Thml and EXTD_Xray in all 6 directions

Direction	Average ± 1 SD	Range	*P* value*
Vertical $\Delta_{vertical}$, mm	0.51 ± 0.61	−2.31 to 1.45	0.371
Longitudinal $\Delta_{longitudinal}$, mm	0.38 ± 0.35	−1.07 to 0.99	0.717
Lateral $\Delta_{vertical}$, mm	0.88 ± 0.98	−1.14 to 3.9	0.000**
Roll Δ_{roll}, degree	0.96 ± 1.28	−5.76 to 1.47	0.114
Pitch Δ_{pitch}, degree	0.47 ± 0.45	−1.13 to 1.75	0.012**
Yaw Δ_{yaw}, degree	0.54 ± 0.57	−0.60 to 2.19	0.000**

Abbreviations: EXTD = ExacTrac Dynamic; EXTD_Thml = optical surface tracking; EXTD_Xray = x-ray verification.
* The p-value was calculated using the Wilcoxon signed-rank test.
** The p-value has a statistical significance of difference ($P < 0.05$).

Beam-holds could be triggered by sudden patient movement or deep breathing. There was a time difference in obtaining geometric shifts from surface tracking and x-ray. Therefore, sudden movement might have triggered beam-holds under surface tracking, whereas the x-ray showed no correction was required. In addition, surface tracking is easily affected by ambient room lighting conditions, leading to fluctuation in surface detection.[15] Because EXTD is an optical surface and thermal tracking system, the gradual temperature changes of masks in contact with patients might be detected by the thermal camera, hence inducing beam-holds. Another reason for pausing the beam was the close proximity of the blankets covering the patients for their comfort.[15] Patient movement might accidentally move the blanket inside the area of interest in surface tracking, especially for treatments involving the lower face and neck region. Therefore, the availability of internal x-ray imaging with optical surface tracking in EXTD was essential to verify whether geometric shifts were required to correct patient position.[16] Although patients received more imaging doses due to the x-ray verification, the additional dose exposure from EXTD_Xray was low, and the additional imaging was essential to guarantee accurate target irradiation.[14,17]

Conclusion

The EXTD system is a combination of SGRT and IGRT systems that can provide continuous motion monitoring via optical surface and thermal tracking, with positional verification via stereoscopic x-ray. With the availability of both surface tracking and internal imaging in a single system, EXTD is an effective tool for intrafractional motion monitoring during radiation therapy.

Disclosures

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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