Technical Innovations & Patient Support in Radiation Oncology 21 (2022) 58–63

Contents lists available at ScienceDirect

Technical Innovations & Patient Support in Radiation Oncology

journal homepage: www.sciencedirect.com/journal/technical-innovations-and-patient-support-in-radiation-oncology

Methodology of thermal drift measurements for surface guided radiation therapy systems and clinical impact assessment illustrated on the C-Rad Catalyst^{+} HD system

Joerg Lehmann [a,b,c,*,1], Therese S. Standen [a], Guneet Kaur [a], Joshua Wolf [a], Alex Wilfert [a], John Simpson [a]

[a] Calvary Mater Newcastle, Newcastle, Australia
[b] University of Newcastle, Newcastle, Australia
[c] University of Sydney, Sydney, Australia

A R T I C L E I N F O

Keywords:
SGRT
Drift
Quality assurance
Clinical impact
Thermal drift

A B S T R A C T

Thermal drift of optical systems employed for surface guided radiation therapy (SGRT) adds uncertainty to patient setup and monitoring. This work describes methods to measure the drift of individual camera pods as well as the drift of the combined clinical signal. It presents results for four clinical C-Rad Catalyst^{+} HD systems. Based on the measured clinical drift, recipes are provided on how to calculate relevant uncertainties in patient setup and patient position monitoring with SGRT. Strategies to reduce the impact of drift are explained. While the results are specific to the systems investigated, the methodology is transferable and the clinical recipes are universally applicable.

Introduction

Thermal drift of optical systems employed for surface guided radiation therapy (SGRT) adds uncertainty to patient setup and monitoring [1,2]. Drift is generally assessed as part of system commissioning [3]. Limited results have been reported related to the drift of thermal cameras for SGRT [4,5] and other [6] patient monitoring systems. Conceptually simple to measure [7], the implications of drift on clinical procedures are more complex and have not been described in the literature.

This work looks at drift for one popular SGRT system, the Catalyst^{+} HD (C-Rad, Uppsala, Sweden). The system is described in [7] and only selected, relevant details are given here. The system uses three camera pods spaced approximately 120° apart around the isocentre on the ceiling of the treatment room. For clinical operation the signals from all three camera pods are combined using internal algorithms considering the different angles and shadowing. Catalyst uses separate modules for patient positioning (cPosition) and treatment (cMotion and cRespiration). The observed surface of the patient within an operator-defined scan volume is compared to a reference surface. For positioning, the reference surface can be created from a DICOM imported body structure or a previously Catalyst captured surface can be used. For the treatment modes the reference surface is always captured when the mode is entered into, normally at the beginning of the treatment after positioning. There is an option to refresh the reference surface by replacing it with the currently observed surface. The Catalyst system generally uses a non-rigid registration algorithm [7,8] but it employs a rigid registration for cranial stereotactic treatments with open masks, referred to as "SRS mode".

While the specific results are hopefully interesting, there is an emphasis on the methodology for measuring, which is transferable to other systems. Likewise the discussion of a strategy on how to draw practical clinical conclusions from measured drift data in regard to margins and tolerances used with the SGRT system applies to all systems.

Abbreviations: SGRT, Surface Guided Radiation Therapy; DICOM, Digital Imaging and Communications in Medicine; SRS, Stereotactic Radiosurgery; IGRT, Image Guided Radiation Therapy.

* Corresponding author.
E-mail address: Joerg.Lehmann@calvarymater.org.au (J. Lehmann).
[1] ORCID: 0000-0001-7667-3090

https://doi.org/10.1016/j.tipsro.2022.02.005
Received 22 November 2021; Received in revised form 9 February 2022; Accepted 21 February 2022

Materials and methods

Measurement approach

Drift measurements have been performed for four clinical C-Rad Catalyst^{+} HD (Catalyst) systems running software version 6.1.2. The general approach to measure drift is to repeatedly measure the position of a stationary object using the reasoning that as the object itself does not move any movement detected is due to drift in the system. To evaluate drift of the Catalyst systems two types of measurements have been performed.

Drift of individual camera pods – Daily Check

Using the Daily Check procedure, the drift of individual camera pods was assessed. This measurement allows characterizing each individual camera pod and identifying any irregularities. For the measurements the vendor-provided phantom was setup to the linac isocentre using the in-room lasers. An effort was made to position the phantom accurately. However, its absolute position did not affect the final measurement results as the drift was assessed in relative terms in reference to the final measured position. While leaving the phantom in place, the system's Daily Check procedure, which assesses the isocenter location but does not change it, was performed every 5 min for 100 min. Each measurement outcome was saved, irrespective of the test result. Using the Daily Check history, the results, which included the timestamp of each measurement, were exported as csv files. The files were analysed and drift data was presented with the measurements for each of the three dimensions (reported as X, Y, and Z and corresponding to lateral, longitudinal and vertical, respectively) relative to the average of the final six measurement points. The system was assumed to be fully warmed up at that time and multiple points were chosen to average out small random fluctuations.

Drift was assessed with the described method from different starting points: system in standby and system off over night. Measurements were performed for different ambient lighting conditions covering typical room light settings during treatment and the extremes of all room lights being on and off. Drift was also assessed following breaks in system use as are encountered in clinical practice. A 5 min break was chosen corresponding to the approximate time a system would be off between two patient treatments. A 30 min break was used to simulate the situation where the system was not used for one or two patients. In these breaks the system was left on the main clinical screen, as would be done in the clinic, which turns off the projectors and cameras.

In first instance, it was assessed in which modes the Catalyst system was actually warming up and staying warmed up.

Combined system drift – Clinical mode

Drift in clinical mode was assessed using a test patient in cMotion and an anthropomorphic Virtual Human Male Pelvis Phantom Model-801-P (Computerized Imaging Reference Systems (CIRS), Norfolk, Virgina, USA). (Fig. 1). Per vendor advice for measurements in clinical mode the isocentre should be inside the phantom. Hence the daily QA phantom was not suitable.

The drift measurements were performed in cMotion mode for practical reasons, as in this mode the measured deviations are automatically recorded in the Catalyst software and can be exported for analysis. Agreement of the drift behaviour with that in cPosition mode was confirmed as described below.

The phantom was setup using the in-room lasers while the Catalyst system was still off. Perfect positioning was not required since cMotion acquires a new reference image every time it is entered into.

Measurements were performed by turning on the Catalyst system and directly entering the cMotion mode. This is best done by not enabling the cPosition mode for the test patient in the Catalyst software. If cPosition was enabled it would need to be entered into first, system warmup would happen during that time and the steepest part of the curve could be missed.

The system was left in cMotion mode without interacting with either the software or the phantom until the measurement time had passed. Care was taken that there was no disturbance of the phantom by restricting access to the treatment room. The measurement results were exported from the Catalyst software as deviations from the initial position (reference image taken when cMotion was entered into) over time for each of the three translational and the three rotational directions: lateral, longitudinal, vertical, rotation (yaw), roll, and pitch, as well as for the total deviation (vector length).

Drift measurements were done in both the non-SRS mode and the SRS mode. In addition to the above mentioned measurements on four different Catalyst systems, measurements on one system was performed multiple times to assess repeatability.

To confirm that the drift is the same in cPosition mode as it is in cMotion mode, additional measurements were performed in cPosition mode for one system and compared to those done in cMotion for the same system. The phantom was again setup using the lasers. The system was turned on, cPosition mode was entered into and a new reference image was quickly acquired via the corresponding button. Then the drift, here reported as corrections needed to return to the reference position, was manually recorded for each direction every 5 min for 90 min. To compare the results to those from cMotion, which reports deviations, the signs of the recorded values needed to be flipped.

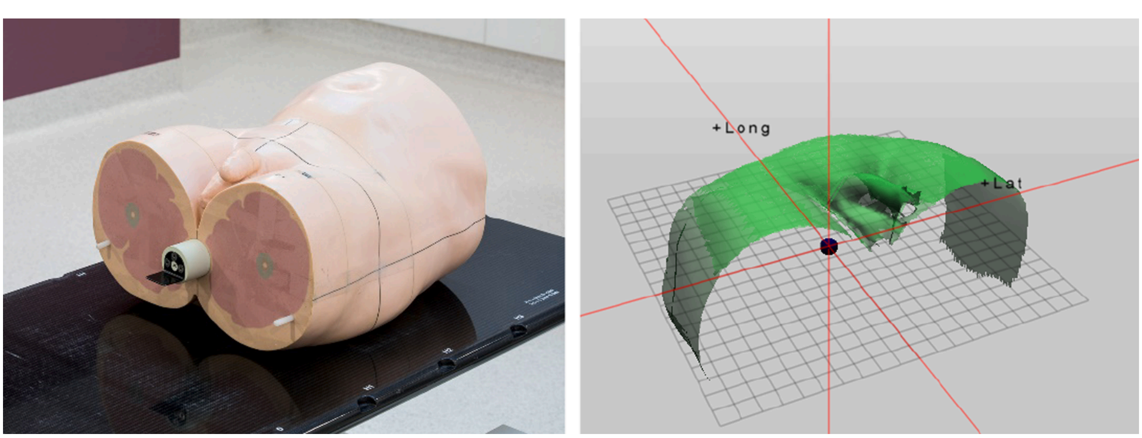

Fig. 1. Virtual Human Male Pelvis Phantom: photo of phantom and reference surface in the SGRT software interface.

Results and discussions

Drift of individual camera pods – Daily Check

Warmup occurs only during active scanning, not by the system being switched on alone. This means that the system starts to cool down in any break between usages, as would occur between patient treatments.

Individual camera pods were found to behave very differently in terms of drift direction and drift magnitude, as illustrated for of one system in Fig. 2. The graphs show the recorded positions (reported by Catalyst as X, Y, and Z and corresponding to lateral, longitudinal and vertical, respectively) of the stationary phantom over time for each of the three camera pods. The positions are each normalised to the fully warmed up state using the average of the 75 – 100 min time points. After a 5 min break, between the 100 min and the 105 min time points, the system had visibly cooled down, as the measurements at 105 min show. The 30 min break between the 134 min and the 164 min measurement points resulted in cool down to a state similar to that of the initial cold system.

Across all four measured systems, individual directions showed drifts of between 0 and 1.2 mm from start-up. A 30 min break cooled down cameras causing drifts of up to 0.84 mm.

Drifts from “Standby” and from “Power Off” status were the same. While the manufacturer recommends keeping this system under power in “Standby”, this means that if a power outage was to occur, no additional precautions needed to be taken in regards to drift. This behaviour is different to that from other SGRT systems, like the C-Rad Sentinel, and needs to be assessed for each system type individually.

Ambient light was found to not impact drift. This gives more freedom in the choice of lighting levels suiting the needs of patients and staff. However, again, this behaviour is different for other SGRT systems and needs to be assessed for each system type individually.

Combined system drift – Clinical modes

Measurements in clinical mode (cMotion) showed drifts up to 1 mm. In Fig. 3a drifts for one system are plotted as the deviations from the initial position in the lateral, longitudinal and vertical directions, as well as the vector length of the deviation. The rotational drifts for all systems were below 0.2° in all three directions: rotation (yaw), roll and pitch, and are not plotted.

As before with the individual camera pods, the clinical measurements also showed cool down effect with noticeable drifts after breaks. (Fig. 3b and c) After a 30 min break, which would be the clinical equivalent of a few patients not being treated with the SGRT system, the drift is almost as large as for a system from standby.

It should be noted that the four investigated systems not only varied in the magnitude of the drifts observed (0.7 – 1 mm), but also in the directions. While all systems showed a strong drift component in the positive vertical direction, some also had sizeable drifts in either the negative lateral or longitudinal directions, while others did not.

Repeated drift measurements for the same system produced the same results.

No difference was observed for drifts in SRS mode compared to those in non-SRS mode. Likewise, the results from the cPosition measurement matched those from the cMotion measurement with the same system.

Clinical impact recipes and management of drift

Drift needs to be considered when assessing overall setup error (e.g. in the margin calculations [9]) and when setting tolerances in the SGRT system. The amount (distance) of drift that actually impacts the clinical operation is less than the total drift reported above. Moreover, measures can be taken to predictably reduce the drift impact when needed, for instance in the monitoring of SRS treatments.

The explanation is illustrated in Fig. 4 which is based on the drift of the most drift-impacted system measured. For clarity only the total drift (deviation) is used. The methodology can be applied to each drift component separately. In the example it is assumed that the SGRT system has been calibrated (isocentre set) in a fully warmed up state.

For SGRT guided patient setup, the warmup status of the system at the time the final SGRT based position assessment is made determines the deviation between observed and real position. In the example such assessment is made after 5 min of on-time (blue line in Fig. 4), which would be the clinical situation where the system is turned on as soon as the patient enters the room and the setup takes 5 min. The remaining drift from the 5 min point onwards until full warmup results in a drift related setup error (0.67 mm), as noted in Fig. 4. If more time passes until the final position assessment is made (blue line shifts towards the right), this setup error is reduced. While SGRT-based setup often requires multiple iterations, only the time point of the final one is relevant here. It should be noted that the here derived deviation applies to the above mentioned situation where the SGRT system had been calibrated fully warmed up and where the reference image either comes from treatment planning (DICOM export) or was taken at the SGRT system also fully warmed up. If the reference image was taken on an SGRT system not fully warmed up, the deviation will likely be smaller. Theoretically, calibrating the system in a not fully warmed up state would likely also reduce this setup error; however such strategy cannot be recommended as the fully warmed up states is the only reproducible state.

Shown here for the total deviation of the Catalyst system, the recipe of subtracting the position at the time of assessment from the position for a fully warmed up system also yields the drift related setup error for each direction separately. It applies to all SGRT systems, as long as the above mentioned conditions regarding calibration and reference image are fulfilled.

This is a systematic error as it will always occur in the same direction and will have the same magnitude (for a given warm up time). For practical purposes rather than assessing the directions separately the drift related total deviation should be included as a systematic error in margin calculations. When setting the tolerances for the SGRT system, this error should also be considered.

For SGRT based patient position monitoring that starts with a new reference image, such as cMotion (and cRespiration) monitoring in Catalyst, only the relative drift since the starting point of the treatment is relevant. Going with the above example, if the treatment starts after 5 min of the SGRT system running during patient setup (blue line) and lasts 10 min (red line) the drift between the two lines (0.73 mm – 0.33 mm = 0.4 mm) will be the maximum drift impacting the SGRT operation. If the treatment lasts longer (red line moves towards the right), then the drift impact will increase. Letting the system warm up for a longer time will reduce the drift impact in a predictable manner. For instance, if the system was running for 15 min prior to start of the treatment instead of 5 min as assumed above (both lines move 10 min to the right), the drift would only be up to 0.27 mm for the 10 min treatment. It would also not increase further for longer treatments, as full warmup is reached at 25 min.

The recipe of subtracting the position at the end of the treatment from that at the beginning of the treatment, as shown here for the total deviation of the Catalyst system, yields the drift during the treatment also for each direction separately. It can be applied to other SGRT systems where a new reference image is taken at the beginning of monitoring. If an SGRT system uses an existing reference image, either reconstructed from treatment planning (DICOM export) or taken with the system at an earlier time point, for monitoring during treatment an error as calculated above for the setup will be present at the beginning of treatment (position at beginning of treatment subtracted from position of fully warmed up system). Throughout the treatment this error would be reduced by drift. The error at the end of treatment would be position at end of treatment subtracted from position of fully warmed up system. To use these recipes for a given SGRT system the drift of that system

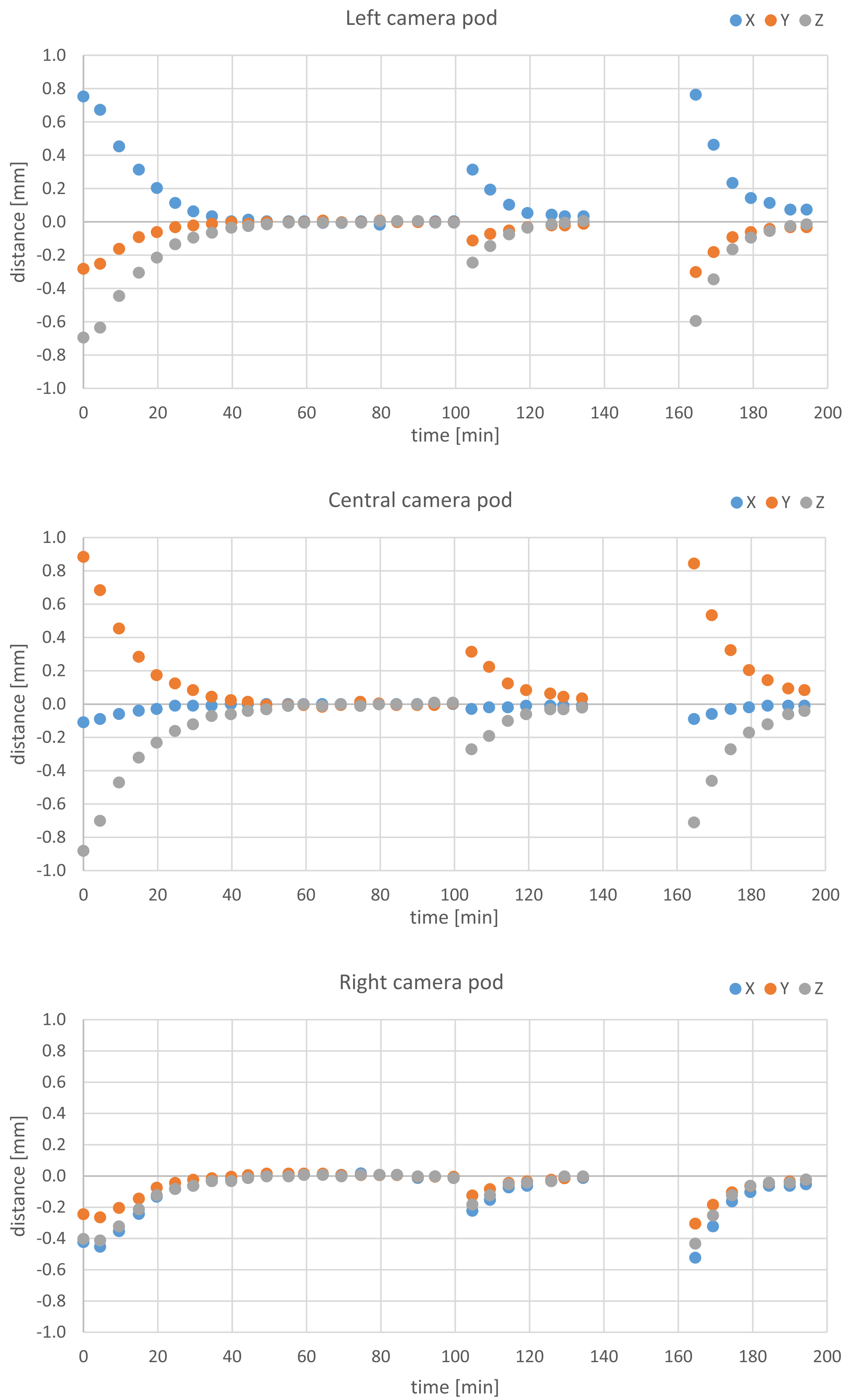

Fig. 2. Individual camera drift for all three camera pods as assessed by Daily QA measurements taken every 5 min immediately returning to the measurement screen after each measurement, except at 100 min and at 134 min where 5 and 30 min breaks, respectively, were taken. Measurements were normalised to the warm state using the average of the 75 – 100 min time points. The reported directions X, Y, and Z correspond to lateral, longitudinal and vertical, respectively.

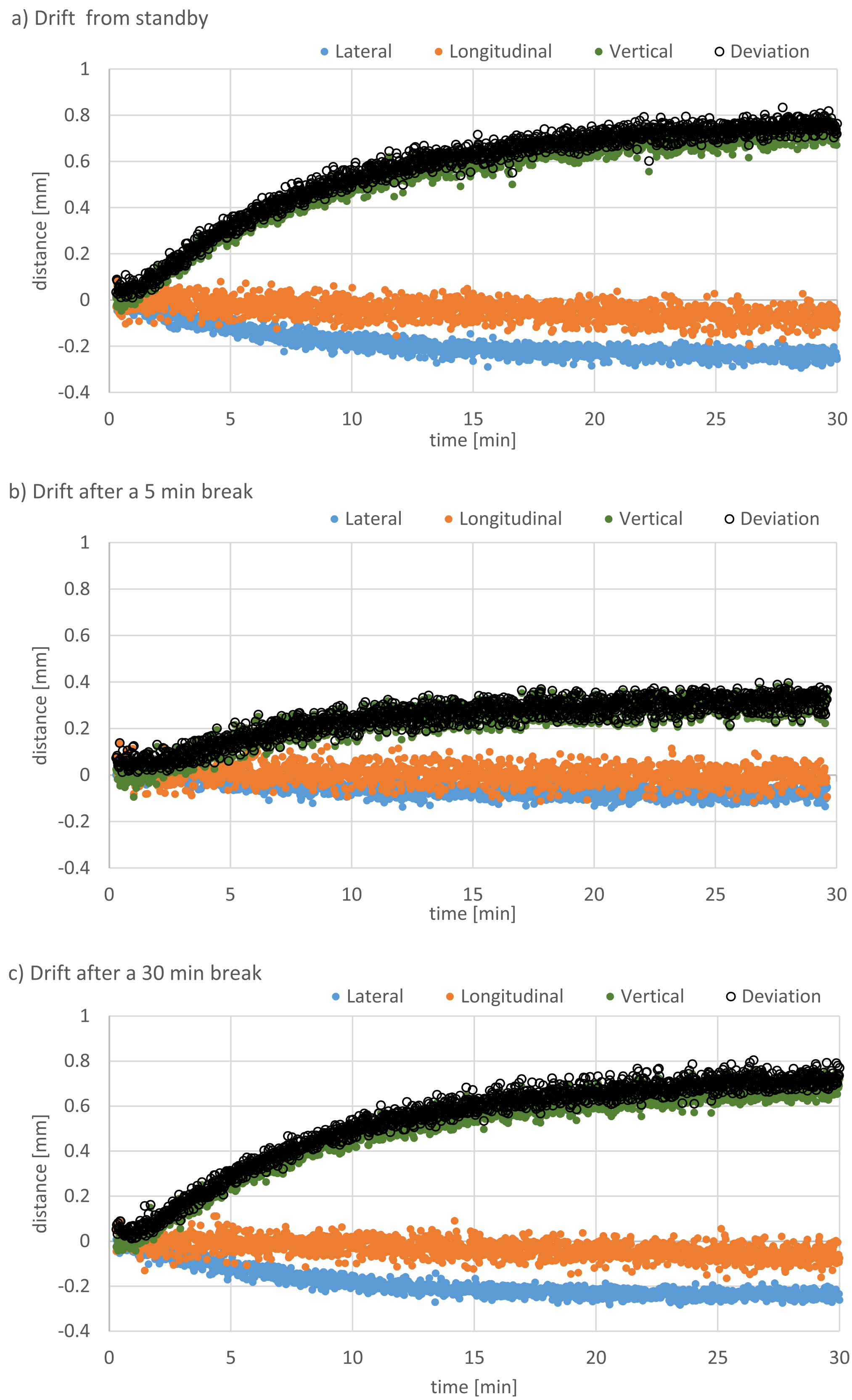

Fig. 3. Clinical mode, combined system drifts for one of the Catalyst systems. Drifts are plotted as the deviations from the initial position in the lateral, longitudinal and vertical directions, as well as the vector length of the total deviation. Shown are drift from a cold system (a), and after 5 and 30 min breaks (b and c).

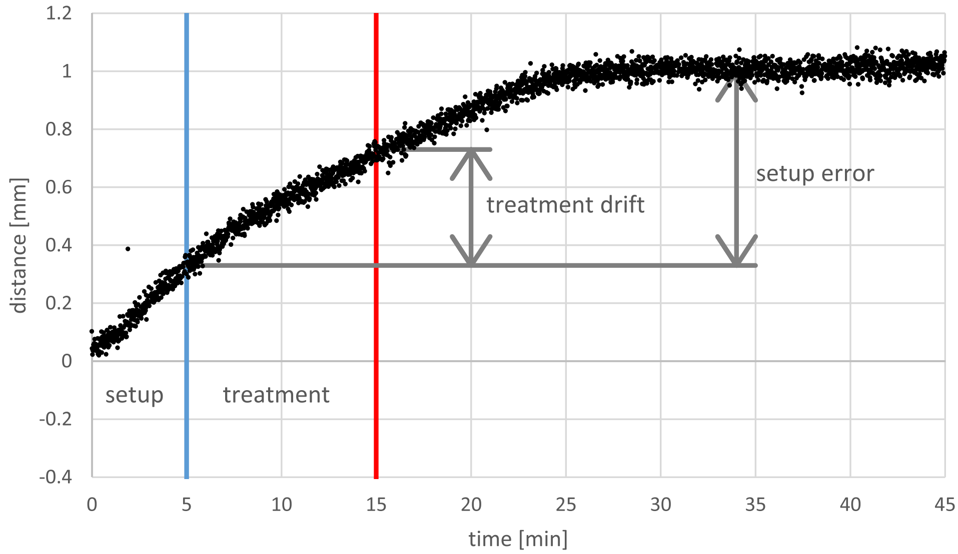

Fig. 4. Example for assessment of the clinical impact of drift on patient setup (setup error) and patient position monitoring during treatment (treatment drift) using the total drift measurement of one Catalyst system.

from a cold state needs to be assessed as described in the clinical mode methods above resulting in a curve as in Fig. 3. Such approach concerning the clinical impact of drift on the combined system will be applicable to all SGRT systems, while the assessment of individual cameras discussed earlier will likely differ between systems or might not be possible for all systems.

The drift related error during monitoring should be considered when setting the tolerances for monitoring. As the magnitude of the error is small compared to other factors like patient breathing this will mostly be applicable to SRS treatments.

Summary

Thermal drift is inherent to optical devices. For SGRT systems the drift can be measured and its impact can be described and quantified. Drift assessment should be done at commissioning in the two steps described above where possible. In ongoing quality assurance and after system upgrades, measurement of the combined drift suffices.

Drift for SGRT based patient setup depends on warm up time. The maximum clinical drift found for the four Catalyst^{+} HD systems was 1 mm. For the commonly implemented combined SGRT-IGRT workflow [10], which is also generally employed for SRS treatments, an IGRT measurement will be used for final setup, reducing the relevance of the of SGRT system drift on setup.

Drift during monitoring of patient treatment with SGRT depends directly on the duration of the treatment. Increasing the warm up time can efficiently reduce such drift.

SGRT vendors should incorporate methods into their software to actively manage drift. This was the case with C-Rad who released a new software version (6.1.2SP1) after review of the above presented data. The new version, which has been tested by the authors in beta, keeps the cameras and projectors running at all times, effectively eliminating cool down in most situations. Such improvements are welcome and simplify the clinical workflows. Quality assurance measurements to monitor their performance are still required as described above.

Declaration of Competing Interest

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. The Department of Radiation Oncology at Calvary Mater Newcastle is a reference site for C-Rad equipment.

References

[1] Freislederer P, Kuegele M, Oellers M, Swinnen A, Sauer T-O, et al. Recent advances in Surface Guided Radiation Therapy. Radiat Oncol 2020;15(1):187. https://doi.org/10.1186/s13014-020-01629-w.
[2] Freislederer P, Kügele M, Öllers M, Swinnen A, Sauer T-O, Bert C, et al. Correction to: Recent advances in Surface Guided Radiation Therapy. Radiat Oncol 2020;15(1). https://doi.org/10.1186/s13014-020-01661-w.
[3] Willoughby T, Lehmann J, Bencomo J, Jani S, Santanam L, Sethi A, et al. Quality assurance for nonradiographic radiotherapy localization and positioning systems: Report of Task Group 147. Med Phys 2012;39:1728. https://doi.org/10.1118/1.3681967.
[4] Chen Li, Bai S, Li G, Li Z, Xiao Q, Bai L, et al. Accuracy of real-time respiratory motion tracking and time delay of gating radiotherapy based on optical surface imaging technique. Radiat Oncol 2020;15(1). https://doi.org/10.1186/s13014-020-01611-6.
[5] Stanley D, et al. SU-F-J-20: Commissioning and Acceptance Testing of the C-Rad CatalystHD Surface Imaging System. Med. Phys. 2016;43(6):3410. https://doi.org/10.1118/1.4955928.
[6] Shi C, Tang X, Chan M. Evaluation of the new respiratory gating system. Precis Radiat Oncol 2017;1(4):127–33. https://doi.org/10.1002/pro6.34.
[7] Hoisak J, et al. Surface guided radiation therapy. 2019, Boca Raton: CRC Press.
[8] Meyer J, Smith W, Geneser S, Koger B, Kalet AM, Young LA, et al. Characterizing a deformable registration algorithm for surface-guided breast radiotherapy. Med Phys 2020;47(2):352–62. https://doi.org/10.1002/mp.13921.
[9] van Herk M. Errors and margins in radiotherapy. Semin Radiat Oncol 2004;14(1):52–64. https://doi.org/10.1053/j.semradonc.2003.10.003.
[10] Batista V, et al. Surface Guided Radiation Therapy: An international survey on current clinical practice. tipsRO, in press.