SGRT DIBH CAT and commissioning

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Abstract

Intrafraction motion is an issue that is becoming increasingly important in the image-guided radiotherapy specifically for thorax and abdomen regions. Intrafraction motion can be caused by the respiratory, skeletal muscular, cardiac, and gastrointestinal systems. There are the technologies supporting motion-encompassing methods, respiratory-gated techniques, breath-hold techniques, forced shallow-breathing methods, and respiration-synchronized techniques to manage respiratory motion during a radiotherapy treatment (see RTP 91 AAPM). The radiotherapy with DIBH is a one of techniques that supports managing a respiratory activity specifically for a treatment to a breast or chest region. Introducing such method supports sparing healthy tissue and OARs (decreasing a risk of complications from side effects) and the balance between complications and cure.

Keywords: radiotherapy, SGRT,DIBH

Introduction

It is important to understand how using DIBH technology affects a treatment procedure and what kind of potential sources of error can introduce in radiotherapy. It is a reason that any new technology applied in the radiotherapy practice must be precisely identified in established radiotherapy pathways and protocols, that advantages and disadvantages, as well limits are very well understood before implementing to the process. It can be done via acceptance tests, commissioning and end-to-end testing.

Respiratory motion management involve the administration of radiation during both imaging and treatment delivery. For DIBH technique, it is realised within a "gate" of breath hold (inhalation) what effectively means a particular range of amplitude of breath cycle. The position (amplitude) of the breath hold gate within a respiratory cycle is determined by monitoring the patient's respiratory motion, using an external respiration surrogate (e.g. skin surface, marker blocks or other external tools positioned on the patient surface – detection of an optical signal reflection). The displacement (amplitude) of the respiration signal identifies relative position between two extremes of breathing motion (inhalation and exhalation) as well as to the reference data (DIBH). The gating system for the DIBH technique based on an amplitude activates radiation beam whenever the inspiration signal is within a pre-set window of relative positions compared to the reference data [1, 2].

The respiratory gating methods for the DIBH technique used during radiotherapy procedures must address two fundamental sources of potential error in dose delivery:

1. Determination of the surface position and relation to the reference data
2. Calibration of the spatial relationship between the tracking coordinate system and the beam-delivery coordinate system. and the beam-delivery coordinate system [1, 2].

Dynamic feedback in gating systems is established by correlating the signal from a respiration monitoring device with the surrogate (skin surface, fiducial markers, etc.). To test these systems, to verify during in vivo dosimetry, to simulate clinical cases and target localization for gating systems, dynamic test phantoms that simulate respiration signal are needed. Such test phantoms can support effective and comprehensive acceptance testing, commissioning, end-to end and routine QA to prove reproducibility, repeatability and efficiency for different clinical scenarios.

There are some factors important to be considered for DIBH testing methods and phantoms:

1) The test phantom should be capable of producing cyclical, irregular motion like human respiration as well as simulate DIBH (inhale and exhale) technique.

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2) The gating feedback mechanism must be able to detect test phantom elements simulating motion.

3) The device should allow position radiation detectors, such as ion chambers, diodes, films, TLDs, etc., to be attached/inserted for dosimetry verification.

4) For SGRT optic systems, the recommendation is to use light-coloured phantoms as they yield the best monitoring results during routine QA, but this is particularly important for institutions where a larger proportion of patients with darker skin tones are treated to assess the effect of surface colour on localisation accuracy. **[3]**

5) The phantom should also be reliable and cost-effective.

Additionally, respiratory gating synchronized procedures must address two fundamental sources of potential error in dose delivery: (1) determination of the surface position as a function of amplitude/position and (2) calibration of the spatial relationship between the SGRT coordinate system and the beam delivery coordinate system [2, 17].

Acceptance tests for gating systems

The acceptance tests should base on the vendor recommendation. Usually, these tests cover checks:

1. criteria of technical specification as well as parameters specified during the tender/purchase process,
2. the DIBH system settings, configuration, integration and synchronisation with CT scanner, Treatment Planning, R&V, Imaging and Radiotherapy Systems,
3. safety aspects of using respiratory systems (especially for systems being used directly with a patient -e.g. active breathing control system with digital spirometer - ABC)
4. coincidence of coordinate systems and isocentres for all components listed above
5. functionalities related to respiratory motion management techniques as: beam delivery, couch movement, DIBH signal detection etc.
6. for an optical gating system - the camera motion position accuracy, which can be tested per procedure provided by the vendor,
7. localization accuracy and reproducibility should be checked following vendor guidelines and reports**,**
8. safe operation and proper functionality of the treatment unit interface,
9. data directory setup for recording breathing curves and patient digital imaging [1, 3, 4, 12].

Commissioning – SGRT respiratory motion management system

For optical SGRT systems, using various technologies to reconstruct 3D surfaces: laser scanning [5], time-off-light [6], stereovision [7], and structured light imaging [8], there should be tested: spatial drift and reproducibility (warm-up and localisation accuracy vs time), static localisation accuracy, dynamic localisation accuracy (4D spatial localisation accuracy, frame rate characterisation, latency), camera system characteristic (camera settings, FOV, occlusion by RT system elements).

Commissioning – SGRT DIBH technique: End-to-end approach

Respiratory motion management is a procedure integrated with a patient radiotherapy treatment pathway. This determines that it can be commissioned via end-to-end tests when a clinical pathway is simulated using different phantoms and software tools (Fig.1) [1, 14].

Motion/dynamic phantom - setting breath patterns: e.g. free breathing, DIBH (INH & EXH), irregular breathing pattern

CT scan (slow CT, inhalation and exhalation breath-hold CT, and four-dimensional or respiration-correlated CT), Defining tracking points/ROIs

TPS (test plans per respiratory motion management technique)
**Outer contour - reference setup surface*
**Outer contour – DIBH*

RT system & gating system:

- *treatment setup and preparation: import, ROIs, threshold protocol, optimise camera setting*
- *plan delivery per respiratory motion management technique – settings, BH gating. surface monitoring, tolerances and beam on-beam off triggers*

Fig. 1 *End-to end pathway for commissioning of respiratory motion techniques*
Source: Own source based on [17].

The phantoms simulating respiratory motion with external and/or internal surrogates should be used in this procedure (Fig.2). Dynamic phantoms simulate human organ and body

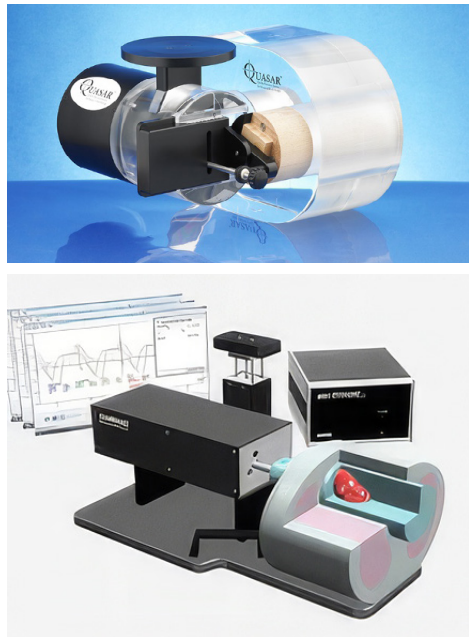

Fig. 2 *Examples of motion phantoms*
Source: Own.

surface motions as-sociated with respiration. The regular motion signals can be used with parameters close to standard breath patterns (phase and amplitude), but for commissioning purposes it would be recommended if these signals could also simulate irregular breath for phase and amplitude as well as breath hold patterns (inhale and exhale) (Fig.3). These phantoms are recommended to test a target/body surface localization and respiratory gated treatment accuracy [9].

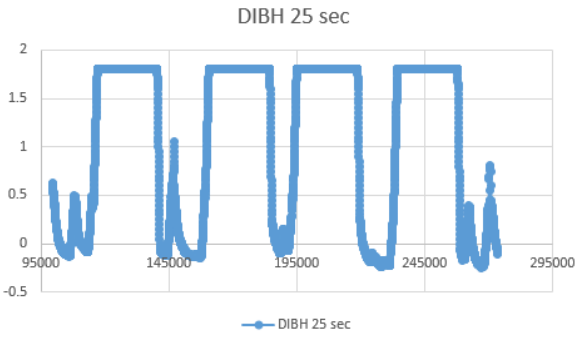

Fig. 3 *Example of DIBH breath pattern to program the motion phantom*
Source: Own.

The motion phantom during commissioning should follow a standard radiotherapy pathway for a DIBH technique.

CT Acquisition – optimisation of low dose scan

The end-to-end test procedure was carried out for clinical implementing a DIBH breast radiation therapy based on SGRT technique (Vision RT).

CT clinical protocols used to support specific respiratory motion management should be optimised during a commissioning process – for example SGRT DIBH: setup/free breathing scan (very low dose to support patient body outlining for radiotherapy planning and treatment purposes) and DIBH scan or 4D CT scanning: pitch values and slice thickness per amplitude, breathing rate, breathing cycle.

A typical setup for a SGRT DIBH technique and monitoring workflow uses one or several reference surfaces for positioning and monitoring the patient during radiotherapy. A reference surface is generated either by extracting the external contour from the DICOM-RT structure and RT plan data set or using the SGRT system itself (at the CT simulator or in the treatment room). For the first solution, two reference surfaces are needed: the first one is for setting the patient up on the treatment position and the second for BH phase detection to trigger beam on (detected patient's surface in the established tolerances) and beam off (detected patient's surface out of the established tolerances) during the radiotherapy session [14].

The CT scan protocol for SGRT DIBH technique required to setup two scans – the first one for the reference surface and the second one for the DIBH surface, also used for RT planning purposes. The main goal of the first scan is providing the imaging data for the patient surface. It could be optimised as a low dose CT scan protocol to obtain a not degraded skin contour for a free breathing phase as a reference scan for the patient setup during RT session. The second scan performed for the DIBH phase provides imaging data for radiotherapy planning as well as a treatment delivery in the restrained breathing phase**.** Optimising the low-dose scan based on the verification of image/skin contour degradation with the reduction of dose-determining parameters (mA, pitch, slice width). The assumption was that reduced CT exposure parameters and dose reduction should not alter the detection of skin surface and skin contour. The Monaco Treatment Planning System (TPS) (volumetric assessment, HU statistics in volume, SSD information) and the SGRT VisionRT system (SSD assessment) were used for verification. The CIRS phantom (simulating the chest) was used for optimising the scan parameters (low-dose scan) (Fig. 4). The contours were made automatically with window and level settings of 1200 and 400 respectively for all acquisitions.

Fig. 4 *Chest CIRS phantom*
Source: IMRT/VMAT Phantoms - Sun Nuclear

The obtained CT scan sets were analysed (Tab. 1) to determine the optimal balance between dose reduction and image quality.

Table 1 *Skin/surface contour parameters for CT scans.*

Scan Ref no	Monaco Study set Naming	CT Acquisition parameters				Patient volume cm3	Heart 2cm VOI (HU/ED)	Scan ref point	No of Images
		pitch	mAs	predicted CTDI mGy	Delivered CTDI mGy				
1	BreastDIBH	1.2	140	11.6	5.85	17584.828	-14/0. 982	Y= -0.05	149
2	Skin	1.2	70	5.76	2.98	17573.254	-14/0.982	Y=-0.05	149
3	BreastDIBH40	1.2	140	11.6	5.89	17586.585	-12/.983	Y= -0.05	149
4	Skin40mAs	1.5	40	3.29	1.81	17575.268	-11/0.992	Y=-0.05	149
5	BreastDIBH30	1.2	140	11.6	5.85	17585.899	-14/0.982	Y=-0.05	149
6	Skin30mAs	1.5	30	2.47	1.35	17578.356	-14/0.982	Y=-0.05	149
7	BreastDIBHBLS	1.2	140	11.6	5.95	20053.725	-15/0.981	Y=-0.05	149
8	Skin30mAsBLS	1.5	30	2.47	1.35	19938.246	-15/0.981	Y=-0.05	149

Source: Own.

Table 2 *SSD results for the obtained CT scans and RT plan*

a) BreastDIBH30 vs. VisionRT

Gantry Angle	BreastDIBH30 (cm)	VisionRT (cm)	Difference (cm)
G0	89.99	90.16	-0.17
G270	85.27	85.16	0.11
G90	84.89	84.76	0.13
G30*	88.22	88.10	0.12
G330	89.42	89.50	-0.08

b) Skin30mAs vs. VisionRT

Gantry Angle	Skin30mAs (cm)	VisionRT (cm)	Difference (cm)
G0	89.99	90.18	-0.19
G270	85.27	85.11	0.16
G90	84.89	84.79	0.10
G30*	88.40	88.29	0.11
G330	89.42	89.46	-0.04

Gantry Angle	Skin30mAs (cm) - BreastDIBH30 (cm)	VisionRT (cm) – Skin 30mAs (cm)	Difference (cm)
G0	90.16	90.18	0.02
G270	85.16	85.11	-0.05
G90	84.76	84.79	0.03
G30*	88.10	88.29	0.19
G330	89.50	89.46	-0.04

Source: Own.

The low-dose scan was implemented to the scanning sequence. CTDI was reduced by approximately 76.9%, while maintaining the surface contouring accuracy and differences between the SSD values determined in Monaco TPS and VisionRT within the acceptable limits of 2 mm.

CT scanning – chest scanning protocol (Fig. 5)

The dynamic CIRS phantom was programmed using a respiratory signal recorded during the 4D CT (free breathing – FB) scan for the clinical case. The original respiratory signal was used for the low-dose CT scan acquisition (FB) and the modified one to acquire the phantom for a generated breath-hold respiratory cycle (Fig. 5). The dynamic phantom with the anthropomorphic phantom placed on the platform, simulating a female-shape body, was scanned using the established CT scanning sequence:

- low-dose scan protocol - respiratory signal simulating FB
- chest scan protocol – DIBH respiratory signal (plato lasting 25sec) (Fig. 5).

The phantoms set was placed on the CT SIM table and aligned with external lasers. Reference marks for the FB and then DIBH setup (Fig.7) were placed on the surface. The phantom was scanned using the low-dose protocol for FB and chest protocol for DIBH (Fig. 8).

The CTDIs were calculated for the breast CT scan (BreastDIBH30) - 5.85 mGy and low-dose CT scan (Skin30mAs) - 1.35 mGy. The total CTDI value for the two scans resulted 7.20 mGy. The RT CT NDRL (UK) for the chest/breast area - 10 mGy [10, 11], was treated as a baseline for the assessment and justification of the introduction of an additional low-dose protocol to the CT imaging sequence for DIBH SGRT breast radiotherapy. The scanning parameters were selected for low dose protocol. They still allowed to maintain the expected quality of image information. SSD verification was then performed using the VisionRT system for BreastDIBH30 and Skin30mAs scans. The check was performed at multiple gantry angles (G0, G270, G90, G30, and G330). The results were compared between the scanning protocols (low-dose and local clinical scanning protocol for breast area scanning) (Tab. 2).

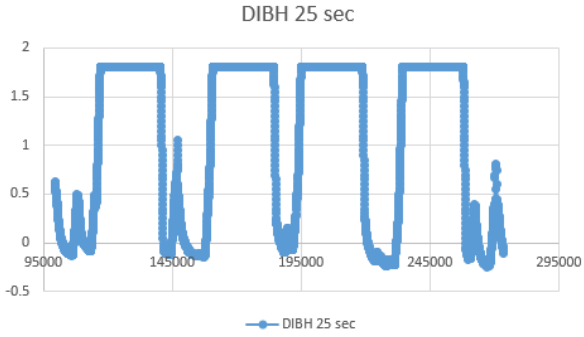

Fig. 5 *DIBH respiratory cycle signal, 25 sek., amplitude 15 mm*
Source: Own.

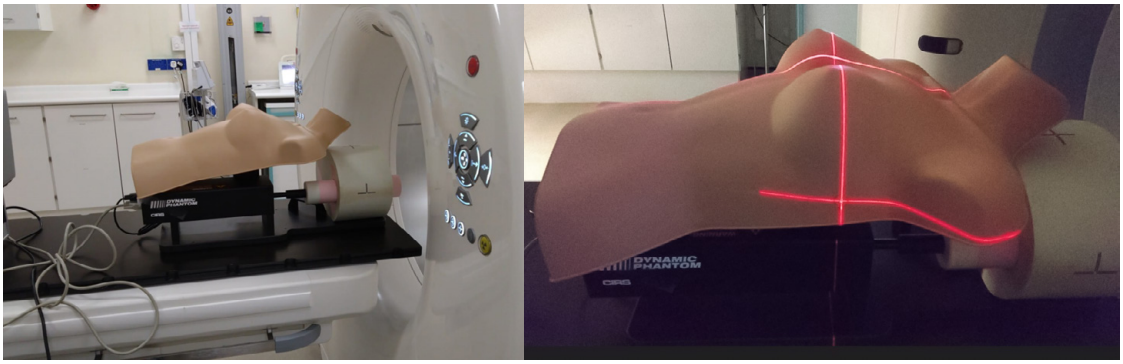

Fig. 6 *Example of the commissioning setup for clinical implementing DIBH system*
Source: Own.

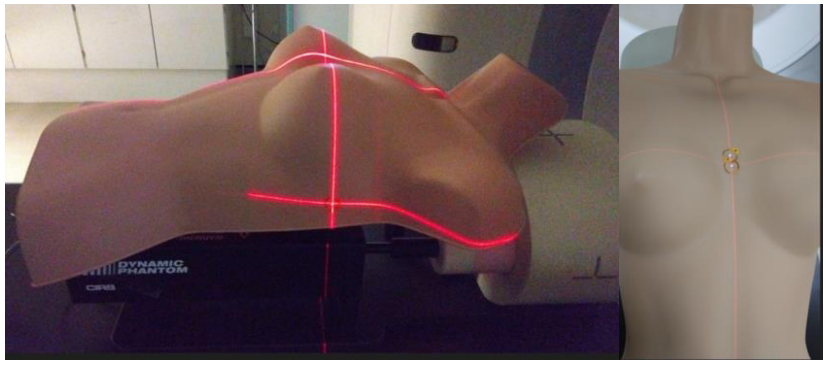

Fig. 7 *The anthropomorphic phantom and reference marks setups for CT scanning*
Source: Own.

Fig. 8 *CT scanning conditions*
Source: Own.

Radiotherapy planning

The CT imaging data (two sets of CT SIM images) was sent to the Monaco TPS. The external structures of the body/patients have been marked up for FB and DIBH scans. The contour of the FB CT body was copied to the DIBH CT set to be used as an "orphan structure" on the Vision RT system. The image registration is not required as both scans were taken under the same geometric conditions and the same coordinate system applied. The "orphan structure" is a reference structure used to setup the patient on the treatment position (FB phase**)** before the RT treatment session. A nomenclature for the reference surface structures was established in the Monaco TPS: FB Body (internal structure) and DIBH: Patient (external structure), since the treatment planning system allows a single external structure to be defined. It allows the structures to be distinguished as representing the reference surfaces for FB and DIBH during a clinical practice.

The additional structures have been drawn (Fig. 9) – simulating a body and PTVs - to allow for the planning of VMAT breast treatment for the left (LT) and right (RT) side. The plans were made with the ISO point at the mid LAT and SUP-INF position and ~10 cm in the POST direction from the ANT REF marker. Also, the RT plans for the ISO points: 7 cm to the RT side and 7 cm to the LT side from the central ISO, were prepared (Fig. 10). The purpose of selecting these ISO points was to simulate the RT treatment arrangements used in a clinical practice. It supported to verify the SGRT system cameras field of view (FOV) restriction when the RT system components (gantry, imaging panels, X-ray tube head) can affect the SGRT system readings by shading/obscuring ROIs in the camera's FOV (Fig. 9).

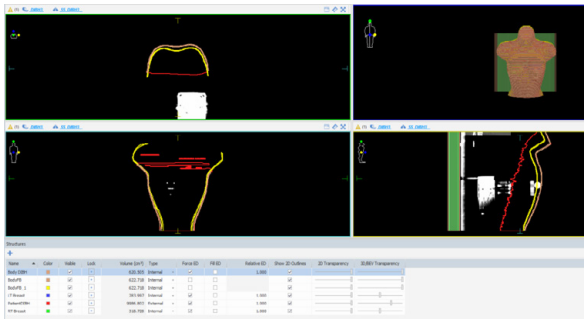

Fig. 9 *Body and patient structures for FB and DIBH scans (FB body structure copied to DIBH scan)*
Source: Own.

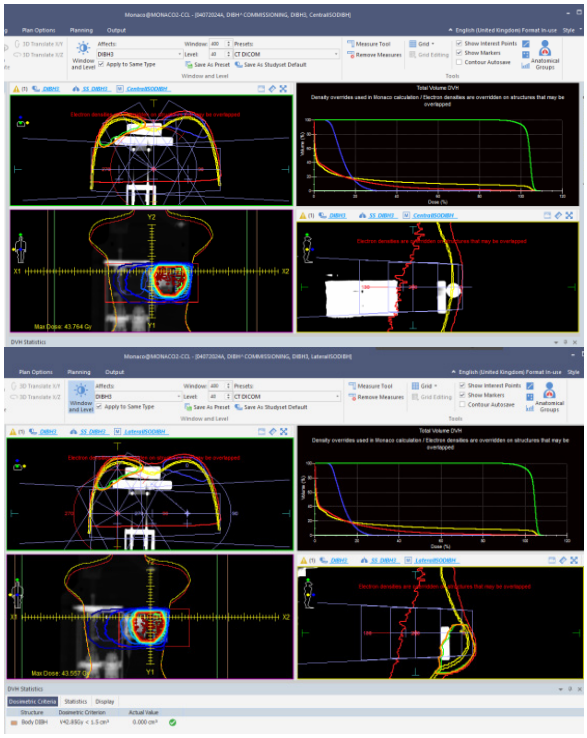

Fig. 10 *RT plans (DIBH) prepared for the anthropomorphic phantom for the Central and Lateral ISO points*
Source: Own.

Radiotherapy treatment delivery

The RT plans were sent to the R&V (Mosaiq) system (RT Plan, RT images, RT structures) and the Vision RT system (RT Plan, RT structures – patient for DIBH, body for FB). Reference data were imported into the Vision RT system – patient structure for DIBH (external) and body structure for FB (orphan structure). ROI was marked according to approved clinical practice (example - Fig. 11) [13-16].

The anthropomorphic phantom and CIRS dynamic phantom set was placed on the treatment table, in a position and configuration consistent with the CT SIM (Fig. 12).

The anthropomorphic phantom was set using SGRT reference data (Vision RT system) for the FB conditions of the (orphan structure). (Fig.11.) The tolerance levels were used according to the approved practice of 3.0 mm for breast cases.

Fig. 11 *Vision RT display– configuration data, reference structure and ROI.*
Source: Own.

Through calculating the deviation between the current (live) and the reference surface, in a region-of-interest (ROI), the SGRT system can support patient-positioning by providing information on the required translations and/or rotations of the treatment couch. The SGRT system can also send the information to the treatment system allowing for automatic couch movement. Depending on the treatment site and workflow an

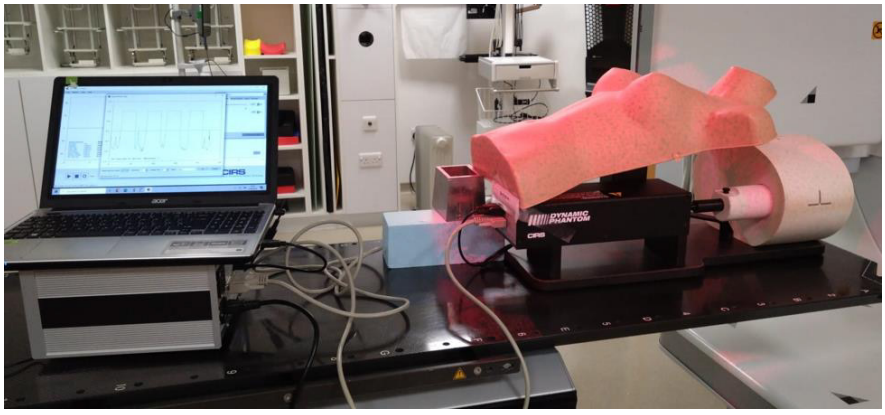

Fig. 12 *The anthropomorphic and dynamic phantom setup on the treatment table.*
Source: Own.

imaging position verification can subsequently be performed. The SGRT system can monitor continuously the position of the defined area of the patient's surface during imaging and treatment (static localisation FOV and localisation accuracy).

Under monitoring SGRT mode the final phantom position between the simulation and treatment setup achieved approximately 1.0 mm. After obtaining the expected phantom position for FB conditions, the DIBH signal was implemented into the dynamic CIRS phantom, and the anthropomorphic phantom position was validated against the DIBH (patient structure) SGRT reference data using the Vision RT system. The achieved position was within 1.0 mm from the position defined by the reference data. The test was also completed for the central and lateral ISO points.

The stability test of the SGRT (Vision RT) system readings was completed for the accelerator gantry (Elekta VHD) with the imaging panels and X-ray tube extended to the operating position was rotated. These components of the radiotherapy system can occlude the SGRT system cameras and ROI, and effect readings. No effect of the override of the SGRT readings was observed due to shading the cameras by the RT system components and limited projection of ROI. It was also identified that ROI extended inferiorly could help avoid the problem of occlusion by RT system components.

Assessing the integrity of the linear accelerator (Elekta VHD) with the SGRT (Vision RT) system was the next step of verification procedure. There was checked the radiation beam delivery under the supervision of the SGRT system (synchronization of the radiation beam with the patient's respiratory cycle). The SGRT (Vision RT) system was connected to the "Response" box. The SGRT system was used to activate and deactivate the radiation beam. The DIBH breath signal (DIBH_25sec_plato, amplitude 15 mm) (Fig. 5) was implemented into a dynamic CIRS phantom to simulate a breath-hold technique using the anthropomorphic phantom. The VMAT breast plans were delivered via Mosaiq R&V system to the linac**.** The plans were delivered under the SGRT (VisionRT) system management triggering the radiation beam activation and deactivation using the DIBH respiratory signal. Radiotherapy systems need time to respond respiratory signals and turn on/off the beam. There was confirmed the SGRT system was stimulating the RT system to deliver and turn off beams accordingly to DIBH signal and set tolerances. The radiation beam was turned on when the breath signal moved to the DIBH phase for the anthropomorphic phantom within the range of applied tolerances and turned off when the breath signal moved to the FB phase and the phantom surface was outside the applied tolerances with respect to the reference data. No runup and time delays were observed between the respiratory signal getting the DIBH phase and the beam activation, which could determine the dosimetry parameters for the treatment.

The VisionRT-guided beam delivery for a DIBH breathing signal with a "leak" was provided and confirmed (Fig. 13) that a scenario in which the patient is unable to maintain stable

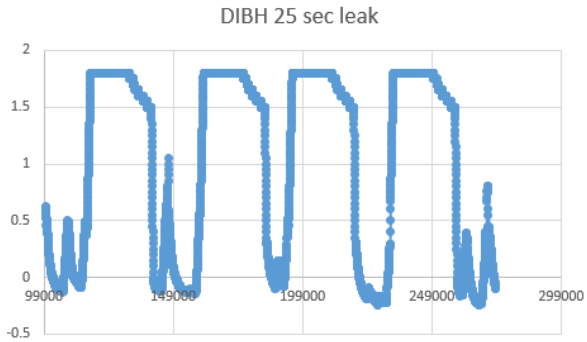

Fig. 1*3 DIBH respiratory signal, 25 sec., amplitude 15 mm with a „signal leak" Source: Own.*

inspiration can still be supported by the SGRT system. The radiation beam was turned on when the respiratory signal moved to the DIBH phase within the range of applied tolerances and turned off when the respiratory signal and the surface of the anthropomorphic phantom, were outside of the applied tolerances for any parameter. No time delays were observed that could determine the dose delivery. The SGRT system supported the DIBH technique, managing the beam delivery as expected.

Conclusions

The CT SIM scanning sequence was established and the SGRT system (Vison RT) was commissioned for the DIBH SGRT technique for breast radiotherapy. The tests were carried out in conditions simulating clinical cases. It was important to confirm the patient's radiotherapy treatment pathway and important aspects of the procedure:

1. positioning the patient before the radiotherapy session (FB reference data) and checking the consistency of the patient's position for the DIBH phase in several breaths, at different isocentres considering occlusion the SGRT system cameras by the radiotherapy system components,

2 checking the patient remains in the correct position and the forced inspiration does not affect the patient position,

3. the tolerances used for the DIBH SGRT technique should be a subject of audit and verification – particularly the MAG parameter, which is the value calculated from 3 parameters of the coordinate system.

The tests carried out to simulate the radiotherapy procedure for the SGRT DIBH breast radiotherapy technique to check the setup process, verify the impact of VisionRT camera occlusion, and verify the integration of the VisionRT system and the linac (Elekta VHD). The tests confirmed that the SGRT (Vision RT) system and radiotherapy system were correctly integrated and the radiation beam on and off was correctly triggered based of the respiratory phase detection (FB and DIBH). The dosimetric verification would be also needed to be performed for this technique to confirm that the times between the triggering (radiation beam rump up), switching off the radiation beam and the SGRT system response to the respiratory phase ensure the

distribution of the delivered dose in the approve tolerances (inc. beam output and dose delivery constancy). The results obtained during commissioning should also provide benchmarks for quality assurance procedures to maintain the tolerance consistent with the spatial uncertainty included in the treatment planning process. The final step is establishing an adequate set of tests specific to this technique.

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