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Guidelines

ESTRO-ACROP guideline on surface guided radiation therapy

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ABSTRACT

Surface guidance systems enable patient positioning and motion monitoring without using ionising radiation. Surface Guided Radiation Therapy (SGRT) has therefore been widely adopted in radiation therapy in recent years, but guidelines on workflows and specific quality assurance (QA) are lacking. This ESTRO-ACROP guideline aims to give recommendations concerning SGRT roles and responsibilities and highlights common challenges and potential errors. Comprehensive guidelines for procurement, acceptance, commissioning, and QA of SGRT systems installed on computed tomography (CT) simulators, C-arm linacs, closed-bore linacs, and particle therapy treatment systems are presented that will help move to a consensus among SGRT users and facilitate a safe and efficient implementation and clinical application of SGRT.

Surface Guided Radiation Therapy (SGRT) is a relatively recent technology that was added to existing image guidance systems. SGRT typically uses visible structured light, stereo-vision systems, time-of-flight systems, or laser scanners to image the surface of a patient with high temporal and spatial resolution without additional radiation dose [1,2].

Generally, the systems employ multiple cameras and through the principle of triangulation, they can reconstruct a three-dimensional representation of the patient's surface (referred to as surface) that is related to the treatment coordinate system and, in some systems, also calculate the treatment isocentre location within that surface. The surface is updated in real-time by the system during patient setup and treatment delivery. For setup this can improve accuracy and workflow. During delivery any inconsistencies between the surface ('live' surface) and the reference surface can be detected in real-time [3]. The reference surface is based on the computed tomography (CT) scan acquired for treatment planning or a surface image obtained earlier with the SGRT system.

The main technical advantages of SGRT systems are that they use non-ionizing radiation and that they offer near real-time monitoring with a large field-of-view (FOV) compared to other in-room imaging systems, with additional possibilities of introducing tattoo-free and open-mask or mask-free workflows. The visual information provided by SGRT is intuitive and may increase patient safety [4]. One limitation of surface-based systems is that they only image the patient's external surface and the correlation to the internal anatomy remains uncertain. Additionally, the patient's skin needs to be exposed, which can provide challenges in terms of privacy and comfort, but also in the presence of fixation devices such as masks.

Abbreviations: 2D, 2-dimensional; 3D, 3-dimensional; 4D, 4-dimensional; 4DCT, respiratory-correlated computed tomography; 6DoF, six degrees of freedom; CBCT, cone beam computed tomography; CT, computed tomography; DIBH, deep inspiration breath hold; FB, free-breathing; FMEA, Failure modes and effects analysis; FOV, field-of-view; IGRT, Image-guided radiotherapy; kV, kilovoltage; MDT, multidisciplinary team; MPE, Medical Physics Expert; MV, megavoltage; OIS, oncology information system; QA, quality assurance; R&V, record and verify; RO, Radiation Oncologist; ROI, region-of-interest; RT, radiation therapy; RTT, radiation therapist; SBRT, stereotactic body radiation therapy; SGRT, Surface Guided Radiation Therapy; SOP, standard operating procedure; SRS, stereotactic radiosurgery.

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SGRT is established in many modern radiation therapy (RT) departments. Several vendors offer SGRT systems for patient setup and monitoring for a wide range of treatment simulation and delivery systems, while some institutions have developed in-house SGRT solutions [5,6]. The European Society for Radiotherapy and Oncology (ESTRO) SGRT working group was initiated at the 3rd ESTRO physics workshop 2019 in Budapest. As confirmed by the survey carried out by this working group in 2020 [7], one major concern shared by many prospective users is the lack of consensus-based clinical guidelines including specific quality assurance (QA) recommendations. This led to the need for a comprehensive up-to-date European consensus on the clinical use and QA of SGRT and prompted the development of these recommendations. Independently, the American Association of Physicists in Medicine (AAPM) published a SGRT-specific task group report (TG 302) [8], building on the TG 147 report which covered QA for non-radiographic localisation and positioning systems [9].

This ESTRO-ACROP guideline is designed to guide current and/or prospective SGRT users through the clinical workflow with specific comments on staff responsibilities, emphasising key points for the optimisation of workflows, and highlighting the most common challenges and potential failure events. It details considerations for acceptance testing and describes important aspects of commissioning and routine QA methods. Many vendors offer additional functionalities as part of their commercial SGRT system, such as patient identification, accessory verification, initial whole-body setup, etc. These additional functionalities are out of the scope of this report as it only considers the SGRT functionality of these systems. The consensus for the guidelines was reached in multiple online discussions of thematic subgroups and approval of the final draft by all group members.

Clinical workflows and responsibilities

Roles, responsibilities and training requirements

SGRT implementation should be led by a core multidisciplinary team (MDT), usually consisting of radiation therapists (RTTs), medical physics experts (MPEs) and radiation oncologists (ROs). Each institution should establish guidelines for staff responsibilities, which may vary between institutions and countries, as national professional training for healthcare staff varies widely from country to country. Frequently, MPEs are involved in commissioning and monthly/yearly QA tests, while RTTs perform daily QA checks, patient treatment preparation, patient positioning and treatment delivery. All team members should principally be familiar with each step of the workflow (see Fig. 1) so that they can intervene in case of unforeseen events or the need for rapid troubleshooting. The core SGRT team, consisting of at least two MPEs and two RTTs, should be endorsed to receive extensive SGRT training.

Workflow optimization

Although a SGRT workflow is vendor- and clinic-specific, some concepts and steps are common in each SGRT application (see Fig. 1).

A typical setup and monitoring workflow uses one or several reference surfaces for positioning and monitoring the patient during RT. A reference surface is generated either using the SGRT system itself (at the CT simulator or in the treatment room) or by extracting the external contour from the DICOM-RT structure data set and the isocentre information from the DICOM-RT plan. Through calculating the deviation between the current (live) and the reference surface, in a region-of-interest (ROI)/point/whole surface, the SGRT system can support patient-positioning by providing information on the required translations and/or rotations of the treatment couch to the RTT on a screen and by other visual means. If so configured, the SGRT system can also send the information to the treatment system allowing for automatic couch movement. Depending on the treatment site and workflow a radiographic position verification can subsequently be performed. The SGRT system can monitor the position of the defined area of the patient's surface during radiographic imaging and treatment. The reference surface used for monitoring is dependent on vendor and/or treatment modality and strategy. Continuous motion monitoring can be carried out throughout the treatment fraction. If the patient moves out of the surface tolerance at any time, the system can stop the treatment, if this function is available and turned on for the combination of SGRT system and linac, or RTTs can interrupt the beam manually.

A generic workflow as described above can be found in more detail in several literature sources, with respective modifications for only-setup [10,11], breath-hold [12], stereotactic radiosurgery (SRS)/stereotactic body radiation therapy (SBRT) [13,14], and for different anatomic sites like head-and-neck, thorax and abdomen [15–17]. To take advantage of SGRT, a well-structured clinical implementation is recommended and therefore, a comprehensive and site-specific workflow should be clearly defined. A common SGRT application is breath-hold monitoring, which is most commonly, but not exclusively, used for left-sided breast cancer treatments. Breath-hold treatments require special workflows often involving multiple reference images in addition to a breathing signal as a surrogate for inspiration level. Table 1 summarises some recommendations for each workflow step aimed to streamline the process, highlighting the essential parameters to be considered/improved, saving resources (time and staff), increasing patient safety and treatment accuracy. A separate column is shown for the particular case of a breath-hold workflow.

The combination of Image-guided RT (IGRT) and SGRT should be considered as standard, however periodicity of radiographic imaging and action levels should be site- and workflow-specific adapted.

Challenges & potential failure events

Potential errors collected by the workgroup when using SGRT are summarised in Appendix I. In many cases, treatment errors can be avoided by commissioning and QA procedures. However, some failure modes and errors are the result of incorrect workflows and/or insufficient training. Common problems include using the wrong reference for treatment and not creating a proper ROI for treatment [18]. The positioning and monitoring parameters, such as a standard ROI for each treatment indication, action levels/tolerances, and acquisition settings, should be defined by the MDT and communicated to all staff involved in the SGRT programme. In general, training and continuous education of SGRT users are essential to prevent errors or non-optimal application of the technology. Regular safety notifications from vendors would be desirable to inform the user community of reported problems. IGRT is a very useful tool to detect SGRT inaccuracies. Therefore, IGRT and SGRT should be used in a complementary manner. Overall SGRT can increase the safety of radiation therapy treatments preventing severe errors but adds (less severe) failure modes [4]. A proper risk analysis [19,20] is an effective measure to minimise the risks of a SGRT workflow.

Procurement, acceptance and commissioning

Procurement and installation of SGRT systems

For this phase, the core multidisciplinary SGRT project team of ROs, MPEs, and RTTs, should be expanded to also include in-house

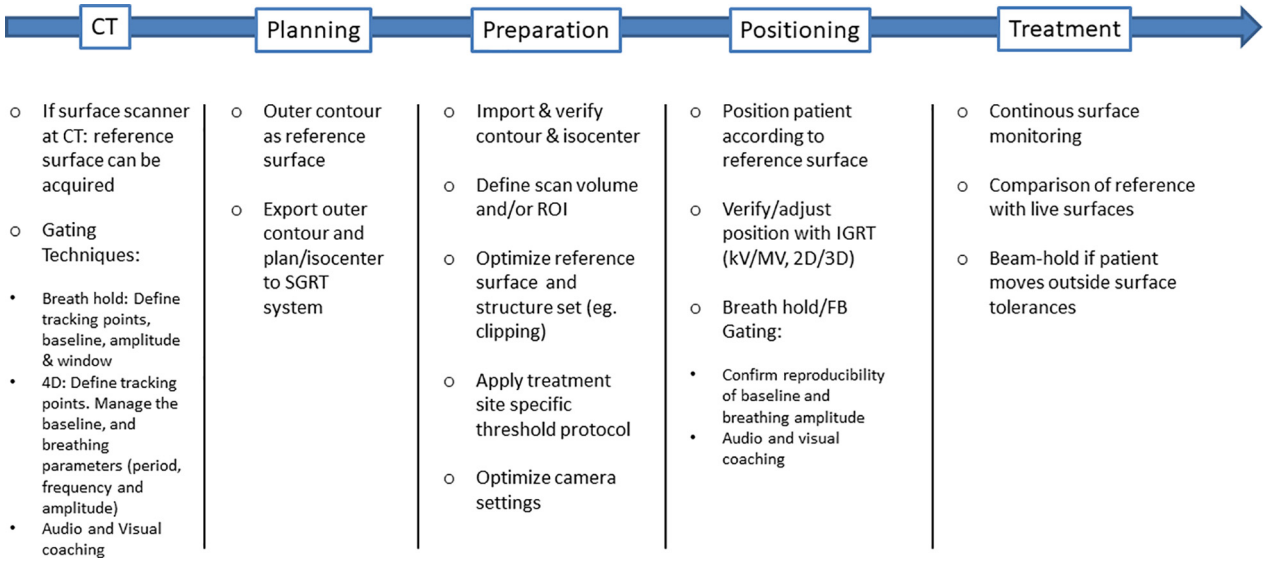

Fig. 1. Diagram of a standard SGRT workflow and the main steps and parameters to be considered.

engineering, IT specialists, facility engineers and hospital management.

First, clinical priorities and indications need to be identified. Then to assess suitability, vendors should be asked to complete a questionnaire that describes the capabilities of their SGRT system concerning the needs of the clinic, considering existing equipment and special circumstances, and outlining installation timescales and conditions as well as staff training opportunities (see Appendix II). Invited vendor presentations can be used for further education on possibilities and options.

The MDT should conduct site visits to clinics with extensive experience with the SGRT system or systems considered for purchase. Ideally, clinics should be chosen that have similar patient management routines and radiation delivery systems. The MDT should consist of at least radiation therapists and MPEs, but preferably also include a radiation oncologist and hospital management. It is useful that the same team visits all clinics with considered SGRT systems, that questions are prepared in advance and that answers are collected at each visit and presented to the team. Vendors should be invited for a site visit and written confirmation of any additional work (costs) required should be obtained before a purchase decision is made.

Considerations include installation requirements like available space at the bunker ceiling, interfacing with linac and record & verify (R&V) system, interference with other systems, including video-surveillance cameras, ventilation vents and patient-support lifts, room lighting, cable channels between bunker and control room, power-supplies, wireless network availability, as well as additional requirements like additional licences needed for the envisioned workflow. For SGRT installations at particle-therapy systems, more considerations about requirements need to be made: the room configuration limits the available camera positions, the possibility of collision/blocking with other objects, and the possibility to pre-align the patient out of the treatment isocentre. A close collaboration between the SGRT and particle therapy vendors is vital to find the best setup.

Based on all this information, the project team should make a recommendation on the purchase options for the clinic's decision makers. It should also perform a risk analysis and develop a realistic time plan for the next steps and an introduction of SGRT to the clinic, down to the changes in standard operating procedures (SOPs).

Systems specifications

The individual specifications of each kind of SGRT system, either simulation room or treatment room, dictate the level of the acceptance and commissioning protocol. Moreover, each system would have different parameters and respective tolerances to be assured.

CT simulators

An SGRT system at the CT simulator can be used for breath-hold monitoring during CT acquisition, for patient coaching and, with some systems, to create a SGRT reference surface. Additionally, some systems offer the possibility to use the respiratory motion signal as a surrogate to reconstruct a respiratory-correlated CT (4DCT) retrospectively or prospectively. Usually only one camera pod is installed in a CT room, resulting in a different FOV compared to a 3-camera pod installation. An interface with the CT simulator might be available with different levels of integration (import/export breathing signal, beam interlock).

Functions and main parameters to test during acceptance include the calibration and accuracy of the SGRT camera(s), tracking of the surface during couch movement, impact of the ROI selection and testing the connections with all integrated systems (see Table 2).

C-arm linacs

The application of SGRT in a C-arm linac setting is the most common [7,21], mainly due to the prevalence of these treatment systems, but also because of their multifaceted uses, ranging from patient setup, monitoring, motion management (free-breathing (FB)-gating, breath-hold to non-coplanar techniques). However, this diversity results in an extensive combination of parameters, tolerances and tests, which users need to adapt to their clinical practices. Issues that most affect the SGRT performance on C-arm linacs are camera pod occlusion (by gantry, imaging detectors or kilovoltage (kV)-source) in combination with the rotational irradiation techniques and reference image calculation for treatments with couch rotations.

Closed-bore linacs

Closed-bore linacs represent several challenges for standard ceiling mounted SGRT systems due to bore occlusions and patient self-occlusions which prevent sufficient surface coverage and six degrees of freedom (6DoF) surface tracking when the patient is

Table 1
List of recommendations for practices/measures at each stage of a SGRT-Workflow.

Stage	General Optimization (Applications: Setup, Surveillance)	Breath-hold-specific optimization *or other breathing techniques Specific optimization for delivery techniques with breath-hold or gating (Application: Breathing gated delivery)
CT	● Define standard SGRT protocols for each indication If reference surface is acquired at CT: consideration of blocking and light/camera settings, consider different FOV due to CT blocking and/or single-camera setting 4D/retrospective method Selection of breathing tracking point/ROI in a stable position on the chest Amplitude and frequency should be within limits, regular and periodic breathing is a prerequisite Observe irregular breathing patterns that lead to incorrect reconstruction and consider re-scanning if artefacts are present	● Enough time for training with the patient should be allocated. Document issues with the patient in the oncology information system (OIS) and/or R&V For 4DCT reconstruction: check the breathing pattern for irregularities in order to reduce artefacts during reconstruction Visual/audio feedback for the patient is advisable. Breath-hold pre-requisites: Minimum breath hold time for CT acquisition, normally 15–20 seconds Minimal amplitude (>1 cm) from breath hold to breathing baseline Technical understanding of the procedure Patient able to communicate and to see and/or hear the instructions throughout the procedure Define a decision-chart to exclude patients with non-reproducible breathing pattern
Contouring & Planning	● Careful and consistent definition of surface contour to be used (e.g. resolution, available FOV, segmentation method, tight to the patient, documentation)	● If different references for setup and breathing are needed, adequate naming and documentation
Treatment Preparation	● The ROI (if needed) should give a good representation of target motion, have unique topographic features and not include immobilisation devices. SRS/SBRT: ROI should consider couch rotation uses, and possible camera blocking-effects Check correct plan, isocentre, couch-rotations, reference-surface and ROI settings. Ensure data consistency with R&V system. Use settings and tolerances template for each treatment site, adapt individually and document. Use of bolus should be carefully considered, bolus material may be "invisible" for the surface scanner	● Check respiration curve and gating window Define site/patient-specific tolerances
1St Treatment	● Check patient identity, plan, reference surface, SGRT settings. Camera light and skin colour settings: should be optimised for each patient if system allows Confirm that none of the SGRT camera pod(s) are blocked by gantry/couch-rotation/panels for reference surface acquisition or during treatment (before the treatment start) and differentiate gantry-blocking variations from patient-variations (checklist to identify the cases, optimise the ROI) At first fraction, SGRT positioning must be verified by independent IGRT (kV and/or megavoltage (MV), 2D or 3D); document the workflow for the following fractions in the R&V system If a new reference surface is acquired, this should be done only with IGRT verification (kV, MV, or cone beam computed tomography (CBCT), according with the site-/application-protocol). In general, the generation of a new reference surface should be carefully considered, with minimal patient rotations (<1°). Ideally IGRT verification should be performed immediately before and/or after capturing the new reference. Use motion monitoring: Treatment should be interrupted if the patient moves out of tolerance, ideally automatically. If a patient does not move back in the original position by themself, repositioning with SGRT/IGRT. -> define a decision-chart including staff roles to help RTTs to select the action to be taken (i.e. for motion during IGRT, motion after imaging, motion during irradiation…); the decision chart should clearly outline staff roles and decision-making authority (or define thresholds for requiring certain staff input, e.g. Notify physics if shifts > X mm) SRS/SBRT: After couch-rotation, establish a decision-process in case of out-of-tolerance SGRT-vectors, e.g. repeat imaging and correct shifts.	● Different reference surfaces for free breathing & inspiration might be used (optimised workflow to avoid selecting wrong reference and to detect incorrect breath-hold). See Latty et al. for recommendations on deep inspiration breath hold (DIBH) verification [27]. Correction of baseline shift should be performed. The baseline shift is dependent on the reference surface of the day and needs to be adapted on a daily basis to account for interfractional changes. Breathing amplitude should remain constant and insufficient inspiration should not be resolved by vertical couch shift When a baseline shift is detected, after a long monitoring time, a new reference should be acquired, verified by radiographic imaging. If frequent baseline shifts are observed, within the treatment time, another respiratory management technique should be considered. Visual and audio guidance and feedback. For further decision making, variations should be recorded and analysed. If a new reference is acquired, confirmation of planned patient position/breathing phase is recommended
Following treatment	● A defined protocol for frequency of SGRT & IGRT combination should be used. In cases without daily IGRT, SGRT should be verified by IGRT at least weekly. Anatomical changes over treatment should be monitored. If changes are	Displacements and variations should be recorded and analysed for further updates: Variation between original baseline and the daily treatment (>5mm), consider IGRT verification for further baseline update.

(*continued on next page*)

Table 1 (*continued*)

Stage	General Optimization (Applications: Setup, Surveillance)	Breath-hold-specific optimization *or other breathing techniques Specific optimization for delivery techniques with breath-hold or gating (Application: Breathing gated delivery)
	observed, these should be investigated before simply acquiring a new reference surface. Document any change in the treatment- parameters (acquisition new reference, change tolerances, change ROI, . . .)	For further decision making, variations should be recorded and analysed. Attention: All types of adjustments and corrections, require previous- and post- IGRT verification.
After treatment	Documentation report of SGRT should be generated and reviewed after the first fraction and at the end of the treatment course. (Report Data: Patient data, site, tolerances, ROIs, responsible staff, linac-interface ON/OFF, and any other workflow-relevant parameter)	Documentation report of SGRT with additional indication of the gating windows and ROI should be produced.

Table 2
Main parameters to include in an acceptance protocol, divided by type of equipment (x – mandatory, o – optional, pass – within Vendor's system specifications). For a full description of each test and respective alternatives consult the test description in Appendix III.

Acceptance			Specification/Tolerance	CT	C-arm linac	Closed-Bore linac	Particle Therapy
Parameter	Label	Test					
Static Accuracy	A1	Isocentre – Agreement between SGRT-isocentre and other isocentric-systems	1 mm/1°	x	x	x	x
	A2	Translational shift – Agreement between introduced and detected shifts in each direction	1 mm (up to 5 cm shifts)/ 2 mm (>5 cm shifts)	-	x	x	x
	A3	Rotational shift – Agreement between introduced and detected rotation in each direction	1°	-	x	x	x
	A4	Impact of camera occlusion – Introduced shifts when one or more camera pods are blocked (for the range of ROI clinically to be used)	1 mm/1°	-	x	x	x
	A5	Couch rotation – Integration & Basic	pass; 1 mm, 0.5°	-	o	-	x
	A6	Setup/loading position – confirm the system calibration at a non-isocentric position (when this option is part of the system)	1 mm/1°	*o*	-	*o*	*o*
Dynamic Accuracy	D1	Beam-Hold performance, AAPM TG 142 [28] – functionality and dosimetric (stationary dose point)	pass/2%	o	x	x	x
	D2	Tracking performance – Ability of the system to correctly measure translations and/or rotations of a moving object	1 mm/1° SRS: 0.5 mm/0.5°	x	*x*	x	x
	D3	Respiratory trace – Detectability of amplitude, frequency, shape variations.	pass	x	o	o	o
	D4	Trigger performance – Phase correct triggering and data reconstruction	pass	x	-	-	-
	D5	Frame-rate impact	pass	x	*x*	*x*	*x*
End-to-End Positioning	E1	End-to-end positioning test – Verify the entire workflow	2 mm-/1°	-	x	x	x
System performance	P1	Thermal drift – Impact of temperature on the camera performance [29]	1 mm/1° (20 min after 20 min in stand-by)	x	x	x	x
	P2	Room-light impact – Influence of the light level on the system accuracy	0.5 mm/1°	x	x	x	x
	P3	Field-of-view -Basic	pass	x	x	x	x
	P4	Quality of acquired surface image	pass	x	x	x	x
	P5	Integration – System interface with all peripheral systems	pass	*x*	x	x	x
	P6	Patient-Interface (Visual or audio)	pass	x	x	x	x
Safety	S1	Interlocks – existence and performance	pass	x	x	x	x
	S2	Data import & export	pass	x	x	x	x
	S3	Database Backups & security	pass	x	x	x	x
	S4	System configuration – Users Right & Pre-sets	pass	o	o	o	o
	S5	Mechanical Integration – Confirm integrity/Collisions	pass	x	x	x	x
Documentation	R1	Export patient- & QA- reports	pass	x	x	x	x
	R2	User manuals	pass	x	x	x	x

at treatment position [22]. Some vendors provide as a solution a hybrid platform where ceiling mounted cameras are used to facilitate patient setup outside the bore and reduce inter-fraction uncertainties. Inside the bore, miniaturised ring-mounted cameras are installed to monitor the patient for intra-fraction motion. This technology is critical for adaptive radiotherapy, breath hold treatments for breast and/or lung and liver SBRT [22,23].

Particle therapy treatment systems

The limited availability of 3D in-room imaging for patient positioning in particle therapy raises the need to improve the patient setup workflow. Therefore, SGRT has a role in clinical practice, both for pre-alignment and for treatment monitoring. The dose delivered by particle therapy is more sensitive to patient misalignment and prone to interplay effects of the scanned beam and respiratory motion, therefore a precise and reactive monitoring system is crucial to ensure the best dosimetric quality of the treatment for free-breathing and breath-hold treatments. The integration of SGRT in the particle therapy clinical workflow demonstrated a reduction in patient positioning times [24] and radiation exposures [25] during the setup phase.

Acceptance & commissioning

Acceptance

The tests performed in the acceptance process (Table 2) should cover the relevant parameters and confirm that the delivered and installed system performs according to the agreed upon specifications. Therefore, the tests should cover the relevant parameters and they should be sensitive enough to confirm performance as specified. A recommended set of tests can be found in Table 2. Special attention should be paid to interconnectivity with other systems and if the installation differs in any way from a standard installation of a system of that type. The acceptance procedure is an integral part of the purchasing process to ensure that all tests required by the clinic are included. While usual system warranties will include performance guarantees, covering the important parameters during acceptance is most efficient. It allows on-the-spot corrections of any deviations found with the installation engineer still onsite.

It is important to schedule sufficient time for the acceptance procedure. Acceptance should be performed by one, or preferably two suitable members of the project team together with the vendor's installation engineer.

Table 3
Suggested parameters to consider during the system commissioning. These can vary with the installation and with the SGRT-applications and product. Some tests might already have been performed during acceptance and are listed here for completeness in italic (#) – include other aspects not evaluated at the acceptance stage (x – mandatory, o – optional, pass – for a specific indication and application the system is accepted for clinical use). Different levels of testing might be required depending on the application (i.e. Basic, Advanced, Radiographic, …) consult the test description in Appendix III for details.

Commissioning Parameter	Label	Test	Specification/ Tolerance	CT	C-arm linac	Closed-Bore linac	Particle Therapy
Static Accuracy	A1	Isocentre – Radiographic	1 mm/1° SRS: 0.5 mm/0.5°	-	x	x	x
	A2	Translational shift – Basic & Advanced	1 mm	x	x	x	x
	A3	*Rotational shift – Agreement between introduced and detected rotation in each direction*	*1°*	-	*x*	*x*	*x*
	A4	*Impact of camera occlusion – Introduced shifts when one or more camera pods are blocked (for the range of ROI clinically to be used)*	*1 mm/1°*	-	*x*	*x*	*x*
	A5	*Couch rotation – Integration & Basic*	*pass; 1 mm, 0.5°*	-	*o*	-	*x*
	A6	*Setup/loading position – confirm the system calibration at a non-isocentric position (when this option is part of the system)*	*1 mm/1°*	*o*	-	*o*	*o*
Dynamic Accuracy	D1	Beam Hold performance – dosimetric	*2% or 2 mm/2% 95% (10% threshold)*	-	x	x	x
	D2	Tracking Performance – FB-Gating Check, Lag Time	*200 ms*	-	o	o	x
	D3	*Respiratory trace – Detectability of amplitude, frequency, shape variations.*	*pass*	*x*	*o*	*o*	*x*
	D4	Trigger performance	pass	o	*o*	*o*	*o*
	D5	Frame-rate impact	pass/application	x	x	x	x
End-to-End Positioning	*E1*	*End-to-end positioning test – Verify the entire workflow*	*2 mm-/1°*	-	*x*	*x*	*x*
Special Techniques	X1	Extension of the FOV	pass	-	o	o	*o*
System performance	*P1*	*Thermal drift – Impact of temperature on the camera performance (tolerance applies for clinical situation, including clinically expected cool down periods)* (29)	*0.5 mm/1°*	*x*	*x*	*x*	*x*
	P2	*Room-light impact – Influence of the light level on the system accuracy*	*1 mm/1°*	*x*	*x*	*x*	*x*
	P3	Field-of-view – Advanced	pass	x	x	x	x
	P4	*Quality of acquired image*	*pass*	*x*	*x*	*x*	*x*
	P5	*Integration – System interface with all peripheral systems*	*pass*	*x*	*x*	*x*	*x*
	P6	*Patient-Interface (Visual or audio)*	*pass*	*x*	*x*	*x*	*x*
	P7	Registration-matrix Quality	pass	-	*o*	*o*	*o*
Safety	*S1*	*Interlocks – existence and performance*	*pass*	*x*	*x*	*x*	*x*
	S2	*Data import & export*	*pass*	*x*	*x*	*x*	*x*
	S3	*Database Backups & security*	*pass*	*x*	*x*	*x*	*x*
	S4	*System configuration – Users Right & Pre-sets*	*pass*	*o*	*o*	*o*	*o*
	S5	*Mechanical Integration – Confirm integrity/Collisions*	*pass*	-	-	-	*x*
Documentation	*R1*	*Export patient- & QA- reports*	*pass*	*x*	*x*	*x*	*x*
	R2	*User manuals*	*pass*	*x*	*x*	*x*	*x*

Commissioning

Commissioning is part of the QA program, and it includes testing the system capabilities and verifying its accuracy/precision in all clinically relevant scenarios. This set of tests (Table 3) should be outlined in a way that can be later reproduced, to assess the consistency of the system performance (e.g. after an upgrade, service-repair, etc.). This phase also includes identifying the system limitations, optimal performance, and documenting the initial system performance. Usually, commissioning is performed by a team of MPEs that consults with vendor representatives in case of inconsistencies or concerns.

One of the important aspects of this process is the end-to-end test, where the entire radiotherapy chain, related to the use of SGRT, should be checked for each unique workflow. This includes for a test phantom, the CT acquisition, import of scan to a treatment planning system (TPS), contouring, definition of the treatment plan, export to the SGRT system, import of plan to an R&V system, SGRT configuration, phantom setup using SGRT and relevant imaging and irradiation techniques (if applicable, breath-hold techniques). Depending on the clinical usage of SGRT, additional tests have to be performed as indicated in Tables 2 and 3. The tolerances in Tables 2 and 3 have been adapted based on AAPM TG 147 [9] and AAPM TG 302 [8] for the tests described. Some tolerance values were tightened, and new tests were introduced based on the availability of new technologies and updated clinical needs.

Quality assurance

Quality assurance checks on SGRT should be performed at regular intervals which are generally annually, monthly, weekly, and daily with the understanding that daily means days on which the SGRT system is used. Additionally, SGRT QA needs to be performed following repairs and regular maintenance of the SGRT system or other peripheral systems that influence the SGRT system, which should be at least in an annual frequency.

For clinics new to SGRT or to the specific SGRT system it is reasonable to start with a higher frequency of tests, as well as with a larger number of tests and reduce either or both once the team is more comfortable with the equipment and based on test outcomes preferably including a failure modes and effects analysis (FMEA) specific to the clinic.

The recommended QA tests will generally be independent of the specific SGRT system, although most systems are technically integrated in either the CT, linac or particle-based systems which may require some slightly adapted dedicated test procedures.

Table 4 lists the minimum recommended tests, which should be adapted and expanded on for newer installations and for specific treatment techniques requiring higher accuracies. Descriptions of the tests are provided in Appendix III and an overview of phantoms for the tests is provided in Appendix IV.

All tests using an anthropomorphic phantom should be performed as close to the clinical application as reasonable. This

Table 4
Quality Assurance tests categorised by daily, weekly, monthly or annually periodicity. A – annually, M – monthly, W – weekly, D – daily, R – following repair or maintenance, O – optional.

Quality assurance			Frequency/Specification				
Parameter	Label	Specification	Recommended tolerance	CT simulator	C-arm linac	Closed-Bore linac	Particle Therapy
Static Accuracy	A1	Isocentre	1 mm/1° SRS: 0.5 mm/0.5°	D	D – Laser M- Radiographic	D	D
	A2	Translational shifts	2 mm	-	M	M	M
	A3	Rotational shifts	1°	-	M	M	M
	A4	Impact of camera occlusion	*1 mm/1°*		A\R	A\R	A/R
	A5	Couch rotation	1 mm/1° SRS: 0.5 mm/0.5°	-	M- Basic A – Radiographic	-	A/R
	A6	Setup/loading position	1 mm/1°	-	-	D	M
End to end positioning test	E1	End to end test	2 mm/1°	A/R	A/R	A/R	A/R
Dynamic Accuracy	D1	Beam hold performance	2% or 2 mm/2% γ = 95% (10% threshold)	-	A	A	A
	D2	Tracking performance – translations & Rotation & Couch-motion	1 mm	-	M/A	A	A
	D2	Tracking performance – rotations	1°	-	M/A	A	A
	D2	Tracking performance – with couch motion	1°, 1 mm	A	-	A	A
	D3	Respiratory trace	pass	D/M	D /M		D/M
	D4	Trigger performance	pass	A	-	-	-
System Performance	P1	Thermal Drift (clinical)	0.5 mm	A	A	A	A
	P3	Field of view – Basic/Advanced	pass*	A	A	A	A
	P4	Quality of acquired image	pass*	A\R	A\R	A\R	A\R
	P5	Integration – System interface with all peripheral systems	pass	-	-	-	-
	P6	Patient Interface	pass	D	D	D	D
Safety	S1	Interlocks	pass	M/A (If available)	M/A	M/A	M/A
	S3	Database backup & security	pass	A	A	A	A
	S4	System Configuration	pass	A	A	A	A
	S5	Mechanical Integrity	pass	D	D	D	D
Documentation	R3	QA-Documentation	pass	M/A	M/A	M/A	M/A

(*) when only visual inspection is possible, the comparison with the acceptance-reference should be done based on clinical criteria).

means a relevant phantom should be used and the ROI of the SGRT system should be set as it would be in the clinical scenario. If there are multiple distinctly different scenarios (e.g., very large and very small ROIs), the tests should be done for each scenario separately. Additional detail can be found in [26].

Conclusion

This document presents the first European comprehensive guidelines on the commissioning, QA, and clinical use of SGRT systems. Its application will contribute to a consistent, safe, and efficient implementation and use of SGRT in clinics. The additional workload for training, implementation and QA that comes with SGRT should be reflected in hospital staffing and funding levels. SGRT and IGRT are complementary technologies and combined SGRT-IGRT workflows should be developed. The technology of SGRT is evolving rapidly and the current guidelines may need to be adapted to future SGRT solutions.

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Conflict of interest

PF has received speaker honoraria from C-Rad AB and Brainlab AG, is currently employed by Brainlab AG; However, at the time of the conception and the implementation of the guideline, PF was not employed by Brainlab AG. PF declares that his employment had no influence on the guideline design, the collection and the analysis of data, on the writing of the manuscript or the decision to submit the guideline for publication. MS and VB have received speaker honoraria from VisionRT Ltd. SC has received research grants and speaker honoraria/travel support from Elekta AB, ViewRay technologies, Inc. and Brainlab AG. MO has received speaker honoraria from C-RAD AB. All other authors have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radonc.2022.05.026.

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