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# Quality assurance of gantry-mounted image-guided radiotherapy systems

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## Recommendations No. 16

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# Contents

# 1 Introduction

These recommendations describe the quality assurance (QA) of gantry-mounted image-guided radiotherapy (IGRT) systems using either the MV treatment beam or an extra gantry-mounted X-ray system (radiography, fluoroscopy and kV cone beam CT (CBCT)). IGRT performed with room-mounted systems (rail-track or ceiling/floor mounted), image-guided robotic systems, tomotherapy units or non-ionizing radiation, is not covered by this document.

It is assumed that the standard procedures for linear accelerator QA, as described in the SSRMP recommendations No. 11: "Quality Control of Medical Electron Accelerators" [1] are applied. Only the additional procedures necessary for gantry-mounted IGRT or those which require stricter QA than for the conventional use of linacs are described here. The components of kV gantry-mounted IGRT systems are similar to those used for diagnostic imaging, but in IGRT they are used for patient repositioning, organ movement detection, and adaptive therapy. SSRMP recommendation No. 5 "Qualitätsprüfungen in der Röntgendiagnostik" [2], the Swiss ordinance on medical X-Ray equipment 814.542.1 [3], the BAG directives R-08-06 for the QA of digital imaging systems [4] and R-08-08 for the QA of CTs [5] have been issued for diagnostic purposes. This recommendation applies only to imaging systems used exclusively for image guidance in radiation therapy. CT simulators are not included, but should also be checked on a regular basis [6]. The tolerance values stated in this recommendation correspond to conventional use of gantry-mounted IGRT systems. They may have to be narrowed for specific applications such as stereotactic treatments. The frequency of the tests aimed at checking image quality has been chosen assuming that image degradation will be detected visually during clinical use and reported immediately to the certified medical physicist[1].

The radiation protection shielding requirements for gantry-mounted IGRT systems are usually fulfilled by the existing shielding in treatment rooms for the use of linear accelerators. It is the responsibility of the certified medical physicist to verify that no additional shielding is required.

The use of gantry-mounted IGRT systems leads to extra radiation dose to the patient. The imaging parameters and procedures shall be optimized, taking into account the image quality requirements and the imaging goal for IGRT. However, it is outside the scope of this document to give recommendations for optimizing the IGRT process or for managing the additional patient dose due to imaging (for a complete survey, the reader is referred to the report of the AAPM Task group 75 [7]). Baseline dose values should be measured and monitored with a QA program. This is described in Chapter 4.

The QA tests of this document are grouped according to subject: Chapter 2 deals with safety, Chapter 3 with geometric accuracy, Chapter 4 with image performance and Chapter 5 with data handling. Finally, Chapter 6 gives a summary of the different QA tests that should be performed as well as tolerance values and suggested frequencies. Baseline values must be established during the acceptance and commissioning process for all the recommended tests. For the annual tests, it is recommended to perform them more frequently in the period following acceptance in order to check the reproducibility of the measurements and to obtain an average baseline value.

In many cases, the details of the QA tests to be performed and their respective frequencies and tolerances will depend upon the department's technical equipment and its clinical use. Consequently, it remains the responsibility of the certified medical physicist to apply these

[1] A medical physicist with SSRMP certification in medical radiophysics.

recommendations as appropriate in the clinic. It is also the responsibility of the medical physicist to ensure that the necessary personnel has sufficient training on the clinical and other operating modes of the installed gantry-mounted IGRT system.

# 2 Safety

## 2.1 Security systems

The security tests specific to gantry-mounted IGRT systems should be considered an integral part of the linac safety tests proposed in ref [1]. It is advised to perform these tests during the routine linac QA.

### *2.1.1 Interlocks*

Aim:

To check that all manual ways of terminating the imaging beam and motions are functional. These include:

1. the fluoroscopic dead-man switch
2. the interrupt button
3. the entrance door opening

Frequency and tolerance:

Daily Functional

### *2.1.2 Beam on indicators*

Aim:

To check that the “beam on” indicator lights during imaging irradiation.

All combinations of operations of X-ray sources i.e.: MV only, kV only, and kV+MV should be tested if used clinically.

Frequency and tolerance:

Weekly Functional

### *2.1.3 Anti-collision systems*

Aim:

To check that the anti-collision systems are functional.

Check that all motions are stopped when an anti-collision system is activated. Including:

1. the MV detector panel
2. the kV detector panel
3. the X-ray tube

Frequency and tolerance:

Weekly Functional

# 3 Geometric accuracy

QA of geometric parameters is the most crucial part of the QA of gantry-mounted IGRT systems since one of the primary tasks performed with these systems consists in determining if the treatment position of the patient/target corresponds to the one used in planning and, if not, allows correct repositioning.

## 3.1 kV imaging field collimation

Collimation of the imaging field serves to limit the irradiation to the detector panel size, to improve the image quality by reducing scattered radiation and to decrease the effective dose to the patient.

Aim:

To check that the imaging field size agrees with the indicators.

Representative field sizes from the protocols in clinical use should be measured with the panel in the required position. If coded manual collimators are used, check that interlocks prevent the operator from using the wrong collimator.

Frequency and tolerance:

| | |
|---|---|
| Annually | 2 mm |

## 3.2 Isocenter

In standard practice, the patient is initially positioned for treatment using wall-mounted orthogonal lasers, which should coincide with the position of the treatment isocenter. The accuracy of gantry-mounted IGRT systems depends on the ability to localize the treatment isocenter.

The treatment isocenter is defined here as the centroid of the intersections of the beam axes when rotating the collimator, gantry and table.

Aim:

To check that the isocenter indicated by the IGRT system corresponds to the treatment isocenter.

Frequency and tolerance:

| | | |
|---|---|---|
| Daily | Quick check based on the laser isocenter | 2 mm |
| Monthly | Full check with determination of the treatment isocenter | 2 mm |

## 3.3 Beam and panel alignment

The beam and the detector should be aligned in order to avoid image distortion or artifacts.

Aim:

To check that the beam axis of the imaging system is perpendicular to the detector plane.

Frequency and tolerance:

| | |
|---|---|
| Annually | 1° compared to baseline |

### 3.4 Image registration and couch correction accuracy

When image registration is performed, the software calculates a couch correction (translation, rotation) that, if applied, will reposition the patient correctly.

Aim:

To check the image-based geometric position of an object and the mechanical couch correction accuracy for the image registration applications provided by the IGRT software: 2D/2D and 3D/3D registration.

Frequency and tolerance:

Weekly 2 mm and 1° if table rotation corrections are applied

## 4 Image performance

Since image performance is strongly dependent on generator performance, the X-ray generator stability should be checked annually. This could be performed by the manufacturer as part of the linear accelerator maintenance. For systems where the MV imaging beam does not have the same dosimetric characteristics as the therapeutic beam (output, dose per pulse etc), the beam output should be checked as for a therapeutic beam, with adapted tolerances and frequencies.

Note that some of the tests can be performed by visual inspection, but this is subjective. When establishing baseline values and analysing images, the same individual(s) should perform the image evaluation in order to minimize inter-observer variability.

For tests requiring visual inspection, it is also important to assess the display performance [4, 8].

Additionally, the relationship between X-ray exposure and image quality should be established during acceptance and/or commissioning.

### 4.1 Planar imaging

Most flat-panel systems must be calibrated to compensate for signal offsets and defective pixels. Periodic recalibration of the flat panel is necessary and routine QA procedures can be used either to trigger this recalibration or to ensure image quality consistency after such a recalibration.

The following tests should be performed for each imaging configuration used clinically.

#### *4.1.1 Spatial accuracy*

In order to match the planar images with simulator images (DRRs), they must be scaled and calibrated at the nominal distance of the treatment isocenter. This scaling should be checked in two orthogonal directions for a representative set of source to detector distances and gantry angles.

Aim: To check the scale of the planar images

Frequency and tolerance:

Annually 2 mm

### *4.1.2 Spatial resolution*

Aim: To check the spatial resolution of the imaging system.

Frequency and tolerance:

Annually 1.6 line pairs per mm (lp/mm) for kV images

0.6 lp/mm for MV images.

### *4.1.3 Contrast resolution*

Aim: To check the contrast resolution.

Frequency and tolerance:

Annually 3 % contrast for a 8 mm diameter object (kV images)

1.2 % contrast for a 7 mm diameter object (MV images)

Comments:

For MV imaging, this test could be replaced by a measurement of contrast-to-noise ratio

### *4.1.4 Noise/ Contrast-to-noise ratio*

Aim: To check the image noise.

Frequency and tolerance: 10 % baseline

Annually

### *4.1.5 Image Uniformity*

Aim: To check the image uniformity.

Frequency and tolerance:

Annually 10 % of the baseline value

### *4.1.6 kV imaging dosimetry*

Dose measurements for radiographic and fluoroscopic 2D projection imaging shall be performed during acceptance and commissioning of the gantry-mounted IGRT system. The X-ray output shall be quantified in terms of a reference dose rate in mGy/mAs in air at the isocenter for a representative field size. The linearity of output as a function of the total mAs setting, using various combinations of current (mA) and exposure time (ms) shall also be assessed during acceptance and commissioning of the imaging system.

For fluoroscopic imaging modes it is recommended to specify the dose rate in mGy/min using the measurements for single exposures (frames) and factoring in the fluoroscopic imaging acquisition technique (mAs, number of frames per second).

Aim:

To monitor the X-ray generator output and to establish reference dose values. It is recommended to cross check at least a representative sample of the acceptance and commissioning dose values.

Frequency and tolerance:

Annually 20 % of the baseline value

Comments:

Due to the low doses measured for clinical protocols, measurements could be made using an increased mAs setting for higher accuracy.

## 4.2 CBCT imaging

CBCT image quality is highly susceptible to mechanical sag of the X-ray source and the imager resulting from gantry rotation. This mechanical sag should be minimized if not eliminated by the hardware and shall be reproducible. The adverse effect of the mechanical sag on image quality is corrected for by software prior to 3D image reconstruction. However, a reproducible sag of both X-ray source and imager ensures that the scale of the images and the location of the imaging isocenter with respect to the 3D image coordinates are known and accurate enough to be used for patient repositioning. The measurement of sag maps for different gantry angles is typically done during the geometric calibration of the CBCT imaging system. The results of these measurements are then used in a pre-processing step for CBCT image reconstruction. However, these parameters need to be constant over time to give consistent CBCT image quality.

For the tests, it is recommended to evaluate the same slice within the phantom that was used for establishing the baseline values in order to limit the influence of cone beam image artifacts.

Similarly, the same scan length and phantom position should be used as for the baseline scan in order to eliminate the influence of scatter artifacts.

Some of the tests could be performed with higher exposure settings compared to the clinical settings if baseline values have been measured for the higher settings.

### *4.2.1 Spatial accuracy*

Aim: To check the geometric scale and distortion of reconstructed images.

Frequency:

Annually 2 mm

### *4.2.2 High contrast / spatial resolution*

Aim: To check the spatial resolution of the reconstructed images.

Frequency and tolerance:

Annually 0.1 lp/mm

Comments:

For kV systems at least 0.6 to 0.7 lp/mm should be visible [10].

A software image analysis could also be performed to calculate the modulation transfer function (MTF) which represents the high contrast spatial resolution.

The amount of scatter will influence the results; therefore the test should be performed under the same conditions as the baseline measurement.

### *4.2.3 Contrast / Low contrast visibility*

Aim: To check the image contrast of the reconstructed images.

Frequency and tolerance:

Annually 10 % of the baseline value

Comments:

This test should be based on a statistical analysis of images or performed visually by more than one person since it is particularly dependent on observer and reading conditions.

This test could be replaced by a measurement of contrast-to-noise ratio.

### *4.2.4 Noise*

Aim: To check the image noise.

Frequency and tolerance:

Annually 10 % of the baseline value

This test could be replaced by a measurement of contrast to noise ratio.

### *4.2.5 Uniformity*

Aim: To check the image uniformity.

Frequency and tolerance:

Annually smaller than twice the baseline value

### *4.2.6 Sensitometry*

Aim: To check the linearity of the reconstructed CT numbers

Frequency and tolerance:

Annually (if not used for re-planning) not worse than the baseline value

Comments:

Since the results of sensitometry are highly dependent on cupping correction, the image uniformity should be checked during the same image acquisition.

This test should be performed for a set a materials which covers the whole range of anatomical densities (typically from 0 to 1.5 $g/cm^3$) and for at least one imaging configuration. If CBCT images are used for re-planning, all the clinically used configurations should be checked. In this case, it is recommended to carefully consider whether the test should be performed more frequently than stated above.

#### *4.2.7 Slice thickness*

Aim: To check the CBCT slice thickness.

Frequency and tolerance:

Annually The measured slice thickness should be within 50 % of the nominal value.

#### *4.2.8 Artifacts*

Aim: To check that there are no additional artifacts in CBCT images

Frequency and tolerance:

Annually Absence of additional artifacts

Comments:

Image artifacts in CBCT imaging are mainly cupping or capping artifacts, beam hardening artifacts, ring artifacts and metal artifacts. Check that the acquired images are free from additional artifacts compared to the baseline scans.

#### *4.2.9 Imaging dosimetry*

Reference values of the dose delivered to the patient shall be acquired during the commissioning of the gantry-mounted IGRT system for all protocols in clinical use and at each modification of these protocols. These reference dose values are usually recorded as nominal values in the patient treatment chart for assessing the effective dose received from imaging.

Aim: To check the constancy of the dose delivered by the CBCT.

It is recommended to cross-check at least a representative sample of the acceptance and commissioning dose values using the same type of measurement technique.

Frequency and tolerance:

Annually 20 % of the baseline value

# 5 Data handling

Gantry-mounted IGRT systems generate a substantial volume of data which contains specific information about the geometric uncertainties of the treatment setup, the amount of organ motion and the anatomical evolution of the patient during the course of treatment. It is crucial to guarantee that this information is accessible and kept available in a secure manner.

## 5.1 Integrity

In order to use gantry-mounted IGRT systems for image guidance, the data have to be processed and mixed with reference data coming from other sources such as the planning system or previous imaging studies. Tests should be performed to check that the transfer from these other sources is functional and accurate. Integrity can be tested by re-analyzing the data used for commissioning and looking for any deviations or abnormalities. This test has to be performed after upgrade of any part of the hardware or software of the gantry-mounted IGRT system, virtual simulation, or planning system.

Aim of the test:

To ensure that the functionality of the gantry-mounted IGRT system is consistent over time, i.e., present analyses return results that are consistent with previous analyses.

Frequency and tolerance:

Annually functional

## 5.2 Archiving and retrieving

As required by Swiss regulation [11], data related to patient treatments have to be kept for 20 years. This implies that all or parts of the data produced by gantry-mounted IGRT systems must be adequately archived. It is up to the clinic to decide the amount and type of data archived, but the medical physicist is responsible to set up an adequate procedure describing the archiving process and to guarantee its application for all patients. Data archived could include all or only part of the raw projections, the reconstructed slices and the positioning shifts, but they should be comprehensive enough to have a record of the history of the patient position during the course of treatment.

Aim of the test:

In the case of electronic archiving, check that the present functionality of IGRT software is able to retrieve the correct information.

Frequency and tolerance:

Annually functional

# 6 Summary of the tests to be performed

QA tests are summarized in the table below. These tests should also be performed after maintenance or repair of the system.

| Chapter | Test | Frequency | Tolerance |
|---|---|---|---|
| 2 | **Safety** | | |
| 2.1.1 | Interlocks | d | functional |
| 2.1.2 | Beam on indicators | w | functional |
| 2.1.3 | Anti-collision system | w | functional |
| 3 | **Geometric accuracy** | | |
| 3.1 | kV Imaging field collimation | a | 2 mm |
| 3.2 | Isocenter Quick check<br>Full check: | d<br>m | 2 mm<br>2 mm |
| 3.3 | Beam and panel alignment | a | 1 ° |
| 3.4 | Image registration and couch correction accuracy: | w | 2 mm /1° |
| **4** | **Image performance** | | |
| **4.1** | **Planar imaging** | | |
| 4.1.1 | Spatial accuracy: | a | 2 mm |
| 4.1.2 | Spatial resolution | a | kV: 1.6 lp/mm<br>MV: 0.6 lp/mm |
| 4.1.3 | Contrast | a | kV: 3 % 8 mm Ø<br>MV: 1.2 % 7 mm Ø |
| 4.1.4 | Noise /contrast-to-noise ratio | a | 10 % baseline |
| 4.1.5 | Uniformity | a | 10 % baseline |
| 4.1.6 | kV imaging dosimetry | a | 20 % baseline |
| **4.2** | **CBCT imaging** | | |
| 4.2.1 | Spatial accuracy: | a | 2 mm |
| 4.2.2 | High contrast / spatial resolution | a | 0.1 lp/mm |
| 4.2.3 | Contrast / Low contrast visibility | a | 10 % baseline |
| 4.2.4 | Noise | a | 10 % baseline |
| 4.2.5 | Uniformity | a | < 2x baseline value |

| | | | |
|---|---|---|---|
| 4.2.6 | Sensitometry | a | Baseline |
| 4.2.7 | Slice thickness | a | 50 % nominal |
| 4.2.8 | Artifacts | a | Absence |
| 4.2.9 | Imaging dosimetry | a | 20 % baseline |
| **5** | **Data handling** | | |
| 5.1 | Integrity | a | functional |
| 5.2 | Archiving and retrieving | a | functional |

Abbreviations: Baseline (measured data are consistent with or better than the data acquired during acceptance and commissioning measurements [9]), d: daily, w: weekly; m: monthly, a: annually

# 7 References


[1] Quality Control of Medical Electrons Accelerators, SSRPM Recommendation No.11 (2003), ISBN 3 908 125 34-0, http://www.sgsmp.ch/r11qca-e.pdf (9.6.2010)

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[3] Swiss ordinance no. 814.542.1 on medical X-ray equipment (1998)

[4] BAG directives R-08-06 for the QA of digital imaging systems (2004)

[5] BAG directives R-08-08 for the QA of CTs (2004)

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[10] The Role of In-Room kV X-Ray Imaging for patient Setup and Target Localization: Report of the AAPM Task Group (2009), http://www.aapm.org/pubs/reports/RPT_104.pdf (9.6.2010)

[11] Swiss ordinance no. 814.501.513 on electron accelerators (2004)

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