CRCPD Publication #E-11-3

Technical White Paper: An Educational Report On Helical IMRT

Developed by CRCPD's
H-34 Task Force for Helical IMRT

April 2011

EXECUTIVE SUMMARY

Helical IMRT (Intensity Modulated Radiation Therapy) is an external radiation therapy technique to deliver therapeutic doses of radiation to a tumor or cancer inside the body. This technology is called Helical or Spiral Tomotherapy and is different from the earlier tomotherapy device called NOMOS Peacock, which was a sequential or serial tomotherapy modality.

The term helical is used to indicate the fact that both the gantry and the couch move during helical tomotherapy, while standard external beam from a linear accelerator involves only the movement of the gantry, not the couch during treatment. The radiation is delivered slice-by-slice (tomo), in a helical or spiral fashion. The intensity of the beam is modulated to deliver high dose to the target while sparing healthy adjacent tissues and structures.

This machine and technique was developed by Professor Thomas Rockwell Mackie, Ph.D. and used to treat the first patient in 2002 at the University of Wisconsin in Madison, Wisconsin. This machine has the ability to provide 360 degree coverage around the target (tumor plus an appropriate margin), while the beam intensity is modulated to conform to the shape of the target so as to minimize dose to surrounding healthy tissue.

This machine and technique represent an improvement in dose delivery while reducing radiation to normal tissue. An additional feature of this device is that the treatment setup (patient's position) is verified prior to each treatment session via the gantry mounted imaging device. Therefore, this is an IGRT (Image Guided Radiation Therapy) treatment along with IMRT modality.

This White Paper describes Helical IMRT, discusses shielding considerations and quality assurance requirements/frequencies and provides a checklist for inspectors.

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INTRODUCTION

The main considerations in the use of Helical IMRT are machine calibration and performance, treatment planning and QA, and operator training. Therapists need vendor-provided training in daily QA, patient set up and treatment, and emergency response for both patient and machine failures. Physicists and dosimetrists need training in calibration and QA procedures, and treatment planning methods, in addition to the emergency response procedures. Calibration of the beam output is different from the AAPM TG51 protocol. However, independent verification of the calibration is available through the Radiological Physics Center (RPC) and should be obtained.

Regulatory oversight should include a review of the shielding design and calculations, area and personnel monitoring and the quality assurance program. An inspection should include a review of staff training documents, acceptance testing and service records, and daily, monthly and annual QA records. Patient chart review should include QA of individual patient treatment plans prior to start of treatment and after any revisions to the plans, and double checks of the same.

GENERAL OPERATION PRINCIPLES

Helical IMRT or Hi Art Tomotherapy looks like a CT scanner because it is a CT scanner, with a 6 MV linear accelerator mounted on the ring gantry. The system allows 360 degree fan beam delivery of IMRT and daily image guidance with the CT. It is a fully rotational dynamic IMRT delivery modality that uses a binary multi leaf collimators (MLC) (64 leaves) to modulate the intensity of a narrow fan beam. The treatment is delivered helically, with the gantry rotating while the couch (and the patient) moves longitudinally through the fan beam.

Most treatments are preceded by the acquisition of a diagnostic quality megavoltage CT image. This image guidance assures positional accuracy for every treatment session. The design and the dynamic nature of treatment delivery pose new requirements for QA. The beam stopper with 5 inches of lead ensures that the primary beam is shielded. The maximum field size ranges from 5mm X 40 cm to 5 cm X 40 cm and the diameter of the gantry bore is 85 cm. The source to axis distance (SAD) is therefore 85 cm as opposed to the 100 cm SAD in a conventional linear accelerator (linac). Another difference from a conventional medical linac is the absence of a flattening filter. These conditions are inconsistent with the reference conditions for the AAPM TG 51 calibration protocol. However, the RPC does provide for calibration checks of TG 51 noncompliant beams from machines such as Tomotherapy, Cyberknife, the Gamma knife and proton beams. The RPC accepts that a Qualified Medical Physicist (QMP) may use alternate techniques and methods for producing TG51 equivalent beams that, in turn can be used to implement QA guidelines. Research has shown the effect of geometrical limitations and spectrum changes from the standard configuration is small. The literature and company documentation can offer guidance on TG51 calibration modifications.

The QMP should establish QA procedures to be carried out daily, weekly, monthly and annually. Measurement methods and tolerances, and response and corrective actions when the tolerance is exceeded, should be specified, using AAPM and the manufacturer guidelines. Because target change may take place in less than a year, full calibration may be needed more often than annually.

SHIELDING CONSIDERATIONS

Shielding aspects are a combination of those of linacs and helical CT scanners. With beam energy similar to that of a 6 MV x-ray beam, there is no need to consider neutron production. The binary MLCs are 64 in number and project to 6.25 mm at the reference distance of 85 cm.

Shielding may be calculated as for a standard 6 MV accelerator with a beam stopper.

Beam stopper is 13 cm thick lead. Primary beam attenuation as measured by the manufacturer, Tomotherapy is 4.1×10^{-3}. This compares reasonably well with expected attenuation, using 5.7 cm TVL from NCRP 151. $10^{(-13/5.7)} = 5.2 \times 10^{-3}$.

For >90 degree scattering, lead disks provide shielding. At smaller divergent angles, tungsten fixture provided the shielding.

Maximum leakage is seen at 90/270 degrees (0/180 degrees is the longitudinal or couch IN/OUT direction).

Shielding for 0.1% of leakage is adequate for both leakage and primary beam contributions.

Scatter is greatest at 0 & 180 degrees.

Recommended workload of 700,000 mu per week is consistent with 30 patients per day and with a mix of clinical cases. This can increase to 840,000 mu or more for 35 patients per day or certain mu intensive procedures.

Use a margin of a factor of 2 for barriers adjacent to the gantry, account for variation in construction material density.

No margin needed for couch movement in the IN/OUT direction.

Follow vendor guidance and supplement with calculations and document with area monitors.

CHECKLIST FOR INSPECTORS

1. A comprehensive QA manual

   This manual should list policies and procedures that address QA tests, frequencies, tolerance, and corrective actions when tolerances are exceeded.

   The manual should also list policies and procedures on treatment planning procedures, double checks, weekly and post treatment completion physics checks, etc.

2. Initial acceptance testing and commissioning measurements data

   Including independent verification of calibration (Radiological Physics Center or other means), training documents for staff (qualified medical physicists [QMPs], dosimetrists and therapists), including emergency response training.

3. Shielding evaluation and monitoring documents

   Including calculations, thermoluminescent dosimeters (TLDs), personnel badge monitoring records, area dosimetry monitors etc).

   Inspectors can spot check exposure levels in adjacent areas including upstairs and downstairs (if applicable), for regulatory compliance. If the unit is in a vault that housed a high energy linac previously, may want to check the secondary barriers because the scatter pattern is different from conventional linacs.

   Review patient workload and if increased since initial evaluation, then the exposures listed in the initial document need to be scaled up correspondingly.

4. Service/repair log and subsequent QA documents. Major service such as target or magnetron change has to be followed by full calibration.

5. Staff level, training and performance:

   Recommend two therapists per machine.

   Check therapists' license and registration status for compliance with state regulations

   Review documents for training to operate tomotherapy unit.

Checklist for inspectors *[Continued]*

Observe workflow in terms of how therapists address patients and escort them into the treatment room and how they select and retrieve patient treatment records.

Ask them to explain how they monitor patients for movements while under treatment and what they do if there is an emergency, either with the machine or the patient.

Interviewing therapists should be carried out only while they are not actively engaged in patient treatment.

6. Safety signs and postings and features

Audiovisual communication devices, Radiation Warning Signs and Beam On lights, Emergency Off switches

Are there instructions posted for emergency response, including names and contact information for physicists and service engineers?

QUALITY ASSURANCE REQUIREMENTS/FREQUENCIES

DAILY

Test parameter/function	Tolerance
LASERS	
GREEN	
Stationary alignment	
Vertical	Home position +/- 1 mm.
Lateral	Home position +/- 1 mm
RED	
Moveable lasers	Home Position +/- 1 mm
(to coincide with the stationary lasers)	
Alignment (adjustment requires tomotherapy field service support)	
Overhead sagittal laser moves laterally +2 cm	+/- 2 mm
Overhead transverse laser moves longitudinally +8 cm	+/- 2 mm
Side coronal lasers move vertically +4 cm	+/- 2 mm
Output Consistency with TPS	3.0%
At 1.5 cm depth (rotational or static, could alternate weekly)	
(Note: TG 148 does not specify the dose rate explicitly, only consistency with the treatment planning system)	
At 1.5 cm depth (rotational or static, could alternate weekly)	
Energy	
Ratio 10cm/1.5cm 0.61	+/- 0.02 (3.3%)
or	
TPR 5/20	+/- 2%
Image	
Image/laser coordinate coincidence	+/- 2 mm, +/- 1 mm (non SRS/SBRT, SRS/SBRT)
or	
Image registration/ Alignment (phantom image)	+/- 1mm
Couch Movement	+/- 1mm
(Distance traveled from reference lasers)	
Safety Checks	Door interlocks and audiovisual monitors

MONTHLY
TO BE DONE BY THE QMP USING PHYSICIST'S DOSIMETRY SYSTEM AND QA TOOLS

Test parameter/function	Tolerance
Isocenter	
Distance between virtual isocenter, defined by lasers and radiation isocenter	70 mm +/- 1 mm
All lasers	Same as daily checks
MLC, Gantry and Couch performance	
MLC and gantry isocenter alignment	+/- 1mm
Gantry rotation and MLC synchronicity	
Gantry angle accuracy and consistency	+/- 1 degree
Couch speed uniformity	Non uniformity +/- 2% of dose
Couch translation per gantry rotation (synchrony)	1 mm per 5 cm
Couch movement digital vs. actual	+/- 1mm
Couch level	0.5 degree
Couch longitudinal motion alignment	+/- 1mm
Couch sag	+/- 5mm
Output	
Static consistency	+/- 2%
Rotational consistency with treatment planning system	+/-2%
Amplitude of variation	+/-2%
(Tomotherapy dose rate interlock is set at +/- 7%. Therapists may be instructed to watch it for smaller variations.)	
Energy or Beam Quality	
Consistency with baseline	+/-1% of PDD at 10 cm or TMR ratio 10 cm to 20 cm
Beam Profiles	
Transverse profile vs. baseline	1% average difference in field core
Longitudinal profile vs. baseline for each slice width	1% of slice width at FWHM

Monthly, to be done by the QMP *[Continued]*

Treatment Interruption

Interrupted and completed vs. uninterrupted procedure (standard IMRT procedure)	+/- 3 %

Monitor chambers

MU constancy between the 2 monitor chambers	+/-2%

Output Ramp Up (The leaves can be set to close until the output ramps up. This should be monitored by the physicist and service engineer.)	<10 seconds, nominal

MVCT IMAGE

Geometric distortion	+/-2 mm or +/- 1mm (SRS/SBRT)
Noise	Consistent with baseline
Uniformity	Consistent with baseline
Contrast	Consistent with baseline
Resolution	1.6 mm object, high contrast
Dose	Consistent with baseline. May drift due to target wear

If MVCT is used in dose calculation

Uniformity	25 HU
HU (water/lung/bone test plugs)	+/- 30 HU/, +/- 50 HU, +/-50 HU

ANNUALLY OR AFTER MAJOR SERVICE
SUCH AS TARGET OR MAGNETRON REPLACEMENT
TO BE DONE BY THE QMP, USING WATER TANK
(In addition to monthly checks)

Test parameter/function	Tolerance
MECHANICAL ALIGNMENTS:	
Y jaw centering (source to y jaw alignment)	0.3mm@ source
X alignment of source (source to MLC alignment)	0.24mm@source
Y jaw divergence/beam centering (Source alignment with axis of rotation)	0.5 mm @isocenter
Y jaw gantry rotation plane alignment (Y jaw alignment with axis of rotation)	0.5 degree
Treatment beam field centering	0.5mm @ isocenter
MLC lateral offset	1.50mm@isocenter
MLC twist (alignment with beam plane)	0.5
MLC leaf latency	Compare to baseline data obtained at the time of time of installation. May need service engineer's help.
BEAM PARAMETERS:	
Beam output calibration (TG 51) vs. baseline For each slice width	+/-1%
Beam quality, agreement with model	+/-1% PDD or TMR Ratio 10 cm to 20 cm
Transverse profiles	+/-1% average difference in field core
Longitudinal profiles	+/-1% of slice width at FWHM
GREEN LASERS	
Axial laser (distance to isocenter and twist)	+/-1mm/0.3degree
Sagittal/coronal (alignment with axis of rotation)	+/- 1 mm
MVCT	
Coincidence if imaging/treatment/laser coordinates	2 mm or 1 mm (non SRS/SBRT, SRS/SBRT)
TREATMENT PLANNING SYSTEM	
CT Data import	
Dimension of object in TPS vs. physical	1 kVCT voxel

Annually, or after major service *[Continued]*

CT voxel dimensions	Pass
CT orientation	Pass
CT gray scale values	Pass
Text data on CT images	Pass
Structure set import (agreement with contouring software)	
Dimension	1 kVCT voxel
Location	Pass
Orientation	Pass
Dosimetric verification (agreement with TPS)	
Point dose in low gradient area	+/-3%
Point dose in high gradient	+/-3%/3mm

(Please note that TG148 lists quarterly checks and that additional and/or more frequent tests/checks may be required if the unit is upgraded by the manufacturer or if any test parameters indicate drift or potential for failure or new treatment protocols are introduced in the clinic.)

DEFINITIONS

Field Size — The size of the radiation field, defined at a reference distance SAD (source to axis difference), 85 cm for Helical Tomotherapy

IGRT — Image Guided Radiation Therapy - Every treatment session starts with acquisition of a mega voltage computed tomography (MVCT) image of the patient anatomy in the treatment position and compared to a stored image, prior to delivery of the therapeutic dose of radiation. This position verification allows precision delivery of high doses with tight margins.

IMRT — Intensity Modulated Radiation Therapy - Using the multi leaf collimators (MLCs) in a dynamic fashion to conform to the shape of the target, the intensity of the beam is modulated to deliver high dose to the target while sparing healthy adjacent tissue and structures.

Isocenter — The point in space that is the center of rotation of the gantry. On conventional linacs, this point coincides with the centers of rotation of the couch and the collimators. Tomotherapy unit has a virtual isocenter and a radiation isocenter. The virtual isocenter is the real isocenter translated out of the bore 70-cm. It allows for more convenient patient setup outside of the bore.

LINAC Linear Accelerator

MVCT Mega Voltage Computed Tomography, the high energy therapy x-ray beam used in acquiring images, as opposed to x-ray beam quality in conventional computed tomography.

MLC Multi Leaf Collimator

PDD Percent Depth Dose, The ratio of the absorbed dose at any depth to the absorbed dose at the fixed reference depth, using a constant source to surface distance specified as a percentage**.**

QMP Qualified Medical Physicist. Comply with the state's regulations to practice as a radiation therapy physicist (may need a license to practice as a therapy physicist in the state and certification by American Board of Radiology or equivalent board) and, in addition, trained in calibration, treatment planning and all safety aspects in the use of tomotherapy by the manufacturer.

RPC Radiological Physics Center http://rpc.mdanderson.org/RPC/

SAD Source to Axis Distance (Distance from the x-ray target to the isocenter, 85 cm)

SRS/SBRT Stereotactic Radio Surgery (brain lesions)/Stereotactic Body Radio Therapy (extracranial lesions)

SSD Source to Surface Distance - The distance from the radiation source (x-ray target) to the surface of the phantom or the patient.

Synchronicity During the helical delivery, the couch travels at a constant speed through a continuously rotating gantry, while the multi leaf collimator (MLC) leaves open and close on a subsecond timescale, programmed according to the patient's treatment plan. The QA process must ensure synchronicity between the couch, gantry, and MLC and accelerator pulsing, as well as check their mechanical precision.

TPR Tissue Phantom Ratio - The ratio of absorbed dose at a given point to the dose at a fixed reference depth using a constant source to detector distance. The reference distance for a Tomotherapy Helical Hi Art system is 1.5 cm.

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