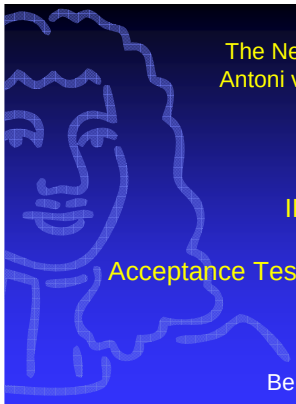


The Netherlands Cancer Institute
Antoni van Leeuwenhoek Hospital

IMRT QA

Acceptance Testing and Systematic QA

Ben Mijnheer

AAPM 2003 Summer School Proceedings
Colorado Springs, Colorado
June 22-26, 2003

Intensity-Modulated Radiation Therapy

The State of the Art

Jatinder R. Palta
T. Rockwell Mackie
Editors

AAPM
Medical Physics Monograph No. 29

2

Which aspects of IMRT need special attention with respect to acceptance testing and systematic QA ?

Planning

- Inverse treatment planning system
- Sequencer
- Dose calculation

Delivery

- MLC leaf position
- Data transfer from TPS to linac
- Dose delivery

3

Reports on commissioning and QA of a TPS

- Fraass B, Doppke K, Hunt M, Kutcher G, Starkschall G, Stern R, Van Dyk J. American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: Quality assurance for clinical radiotherapy treatment planning. Med. Phys.25: 1773-1829, 1998.
- Mayles, W.P.M., Lake, R., McKenzie, A., Macauly, E.M., Morgan, H.M., Jordan, T.J., Powley, S.K. Physics aspects of quality control in radiotherapy. The Institute of Physics and Engineering in Medicine, pp. 60-95, 1999.
- IAEA TRS 430, Commissioning and Quality Assurance of Computerized Treatment Planning Systems for Radiation Treatment of Cancer. International Atomic Energy Agency, Vienna, 2004.
- Netherlands Commission on Radiation Dosimetry. Quality Assurance of 3-D Treatment Planning Systems, 2005.

ESTRO

EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

- Ben Mijnheer
- Agnieszka Olszewska
- Claudio Fiorino
- Guenther Hartmann
- Tommy Knöös
- Jean-Claude Rosenwald
- Hans Welleweerd

Sponsored by "Europe against Cancer"

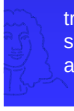
QUALITY ASSURANCE OF TREATMENT PLANNING SYSTEMS - PRACTICAL EXAMPLES FOR NON-IMRT PHOTON BEAMS

PHYSICS FOR CLINICAL RADIOTHERAPY
ESTRO Booklet No. 7

5

Acceptance testing and QA of a treatment planning system

- Many tests are described in a number of reports.
- These tests are very useful in appreciating the possibilities and limitations of the system and understanding the models and algorithms.
- Only in the ESTRO booklet a separation has been made between tests to be performed by the vendor (acceptance tests) and by the user (commissioning and periodic quality control tests) for non-IMRT beams.
- No guidelines for acceptance testing of inverse treatment planning systems, including the MLC sequencer and specific dose calculations, are currently available.



6

What are the main differences in sources of uncertainty between IMRT and other 3DCRT techniques ?

Planning

- Inverse treatment planning system
- Sequencer
- Dose calculation

Delivery

- MLC leaf position
- Data transfer from TPS to linac
- Dose delivery

7

Inverse planning

- A number of aspects are the same for acceptance testing and systematic QA of planning of IMRT and 3DCRT techniques.
- IMRT imposes, however, more stringent requirements on the accuracy of volume determinations, beam modelling and dose-volume histograms, including the effect of dose grid on these parameters.
- Tests for these issues are given in existing QA reports.

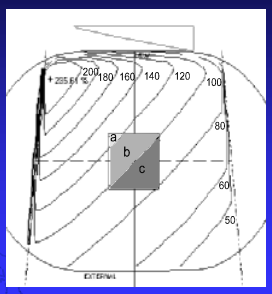
TG 53 Dosimetric QA Recommendations

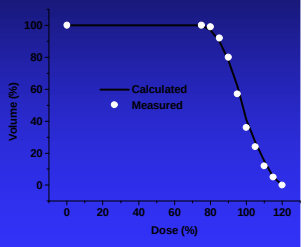
- A comprehensive series of test cases must be planned, measured, calculated, compared, analyzed and evaluated before any dose calculations are used clinically.
- The particular test cases designed depend on the RTP system, on the way the system is used clinically and on other factors.
- Optimizing the test procedure for each clinic is essential if the QA program is to be effective yet achievable.

(From Dick Fraass)

9

Dose-volume histogram test





(Craig, Brochu and Van Dyk, IJROBP, 1999)

10

Test 5.3.2 Dose-Volume Histogram

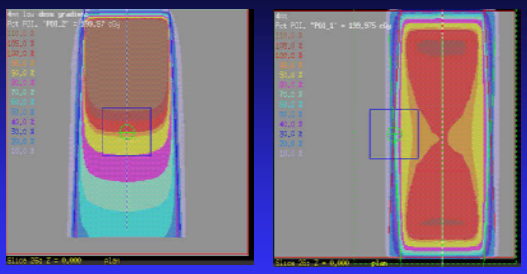


Figure 7.17 Virtual phantom, internal structure and beam setting defined in the system for the DVH test; (a) low dose gradient area test; (b) high dose gradient area test.

11

Test 5.3.2 Dose-Volume Histogram
High dose gradient area

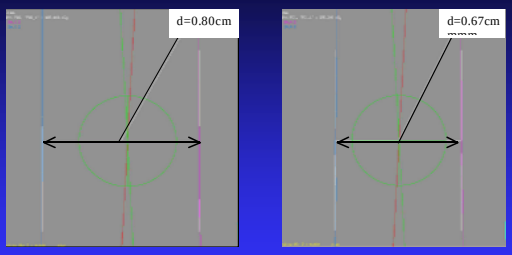


Figure 7.22 Measurements of the distance d between the 20% (blue) and 80% (pink) isodose lines; (a) 4mm dose grid size; (b) 2mm dose grid size. The two lines in the centre of the figure represent the beam edges.

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Table 7.16 Results of the volume calculation between the 20% and 80% isodose surfaces.

Dose grid size [mm]	$V_{80\%}$ [cm^3]	$V_{20\%}$ [cm^3]	$V_{20\%} - V_{80\%}$ [cm^3]	d [cm]	30 x d [cm^3]	Difference between $V_{20\%} - V_{80\%}$ and direct volume calculation [%]
4	64.53	88.53	24.09	0.80	24.00	0.4
2	66.05	86.03	19.98	0.67	20.10	0.6
Difference between dose grids [%]			20.6		19.4	

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Inverse planning

- The objective / cost functions implemented in inverse treatment planning algorithms are still under development. For instance, biological models are only recently implemented in optimisation software.
- Generally only the dose distribution in the main organs at risk is considered; volumes with low dose values (*e.g.*, total body dose) are often not part of the optimisation process.
- For these and other reasons inverse planning systems can be expected to be subject to many changes in the future.

Which aspects of IMRT need special attention with respect to acceptance testing and systematic QA ?

Planning

- Inverse treatment planning system
- Sequencer
- Dose calculation

Delivery

- MLC leaf position
- Data transfer from TPS to linac
- Dose delivery

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Sequencer

- Leaf motion calculators, which translate the optimal intensity distribution from inverse planning calculations into physically realisable segments, will be adapted regularly to make them more efficient or less degrading.
- The new combination of field shapes and beam intensities will result in a different sequence of smaller radiation fields having different interplay between the accuracy of penumbra, leakage and tongue-and-groove effect.
- Commissioning of all IMRT techniques has therefore to be repeated after the introduction of a new sequencer in the planning system.

Which aspects of IMRT need special attention with respect to acceptance testing and systematic QA ?

Planning

- Inverse treatment planning system
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Delivery

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- Dose delivery

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Tolerances for the accuracy of photon beam dose calculations

- What should be done if in a few points the difference between the calculated and measured dose exceeds the criterion for acceptability?
- Should criteria for acceptability of dose calculations be based on a percentage of the local dose value or relative to a normalized dose value?
- Should criteria for the acceptability of dose calculations be dependent on the complexity of the treatment?

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Confidence limit

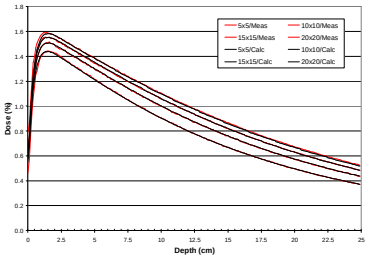
The confidence limit is based on the determination of the mean deviation between calculation and measurement for a number of data points for comparable situations, and the standard deviation (1 SD) of the difference, and is defined as:

$$\Delta = |\text{mean deviation}| + 1.5 \times SD$$

(A multiplicative factor of 1.96 instead of 1.5 has been proposed by Palta *et al.*, for IMRT planning systems)

(Venselaar *et al.*, Radiother. Oncol. 60, 191–201, 2001)

19



Depth dose curves of a 6 MV beam for four field sizes, obtained by scanning in a water tank, normalized to the output (measured with an ionization chamber) at 10 cm depth of the 10cm x 10cm field. Red lines are measured data and black lines calculations performed by a TPS.

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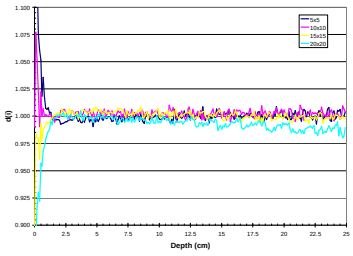
Open square fields (PDD)



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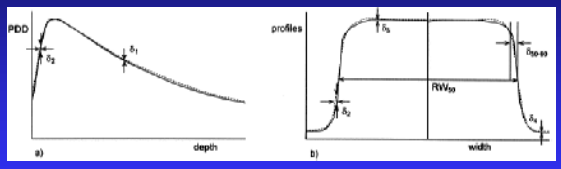
Evaluation of PDDs

Build-up region (0-2 cm)	Field size	Field size	Field size	Field size
	5x5 cm^2	10x10 cm^2	15x15 cm^2	20x20 cm^2
Average deviation (%)	3.7	0.7	- 1.3	- 3.7
Standard deviation (%)	6.2	2.1	2.4	5.1
Confidence limit (%)	**13.0**	3.9	5.0	**11.3**
Remaining curve (2-25 cm)				
	5x5 cm^2	10x10 cm^2	15x15 cm^2	20x20 cm^2
Average deviation (%)	- 0.1	0.2	0.1	- 0.6
Standard deviation (%)	0.3	0.3	0.3	0.5
Confidence limit (%)	0.5	0.7	0.6	1.4

Statistical evaluation of the deviations between calculated and measured data of the four 6 MV depth dose curves. Note that the confidence limits for the 5x5 cm^2 and 20x20 cm^2 do not fulfil the recommended 10% accuracy requirement of dose calculations of a TPS in the build-up region as presented in Table 2.1

Regions of the criteria for acceptability of dose calculations



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Criteria for acceptability of dose calculations

Proposed values of the tolerances for δ for application in different test configurations

Tolerance	(1) Homogeneous, simple geometry	(2) Complex geometry (wedge, inhomogeneity, asymmetry)	(3) More complex geometries, i.e. combinations of (2)
δ_1 (central beam axis data) high dose, small dose gradient	2%	3%	4%
δ_2[4] (build-up region of central beam axis, penumbra region of the profiles) high dose, large dose gradient	2 mm or 10%	3 mm or 15%	3 mm or 15%
δ_3 (outside central beam axis region) high dose, small dose gradient	3%	3%	4%
δ_4 (outside beam edges) low dose, small dose gradient	3%[5] (30%)	4%[5] (40%)	5%[5] (50%)
RW_{50}[5] (radiological width)	2 mm or 1%	2 mm or 1%	2 mm or 1%
$\delta_{50,50}$ (beam fringe)	2 mm	3 mm	3 mm

(Venselaar *et al.* Radiother. Oncol. 60,191–201,

24

Criteria for acceptability of dose calculations for IMRT planning

Table 2. Proposed values of the confidence limits and action levels for IMRT planning

Region	Confidence limit ($P \geq 0.05$)	Action level
Δ_1 (high dose, small dose gradient)	3%	5%
Δ_2 (high dose, large dose gradient	2 mm DTA or 10%	3 mm DTA or 15%
Δ_3 (low dose, small dose gradient	4%	7%
$\Delta_{FO/O}$ (dose fall off)	2 mm DTA	3 mm DTA

(Palta *et al*., AAPM Medical Physics Monograph 29, pp. 593-612, 2003)

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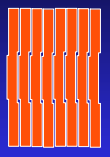
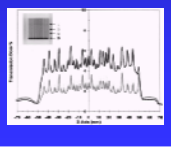
Refinement of dose calculations are needed to take into account:

- Dose calculation grid size
- MLC round leaf end –none divergent
- MLC leaf-side/leaf-end modeling
- Collimator/leaf transmission
- Penumbra modeling; collimator jaws/MLC
- Output factor for small field size
- PDD at off-axis points
- ????????





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Acceptance testing of the dose calculation of the TPS

- Don't perform (extensive) testing of the algorithms in the TPS.
- Information about the possibilities and limitations of the algorithms in the TPS should be provided by the vendor.
- Contact other users or a user group for the results of dose verification tests.
- Verification of the (3D) dose distribution should still be performed for each treatment technique in each institution.

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Which aspects of IMRT need special attention with respect to acceptance testing and systematic QA ?

Planning

- Inverse treatment planning system
- Sequencer
- Dose calculation

Delivery

- MLC leaf position
- Data transfer from TPS to linac
- Dose delivery

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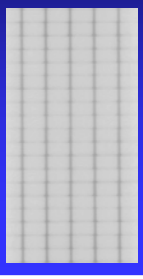
Systematic QA

• Verification of leaf position (film, linear array, EPID)

Garden fence test*

* Modified Test 5
Chui et al., MedPhys 23, 1996

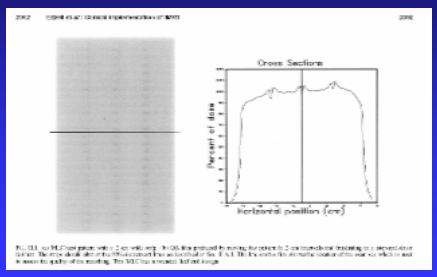
- Moving leaf pairs, 1mm gap
- Every 2 cm: short stop
- Measured with film
- Sensitivity: ± 0.5 mm



29

Systematic QA

- Verification of leaf position (film, linear array, EPID)

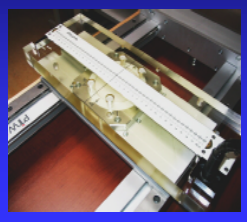


30

Systematic QA

- Verification of leaf position (film, linear array, EPID)

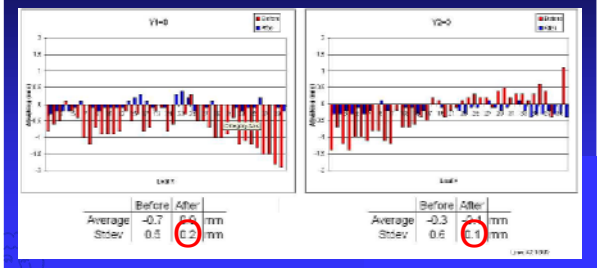
- Linear array of 47 ionisation chambers
  - Size 4mm x 4mm
  - Distance 8mm
  - Min step size 0.1mm
  - Moves in 2 directions
- At SSD 80cm
  - Leaf width 8mm
  - Each leaf matches one detector
  - Penumbra scan
  - 50% value is leaf position



(from Thijs Perik, NKI-AVL)

31

Leaf positions after acceptance of MLC and after adjustment for IMRT



(from Thijs Perik, NKI-AVL)

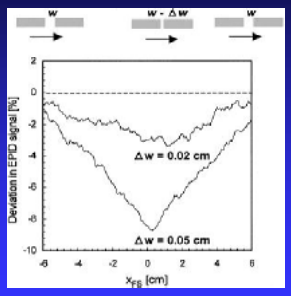
32

Systematic QA

- Verification of leaf position (film, linear array, EPID)

33

Relative differences between gray scale profiles *with* and *without* introduced errors in the 0.5 cm leaf gap width, *w*.

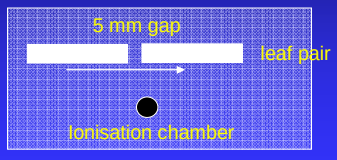


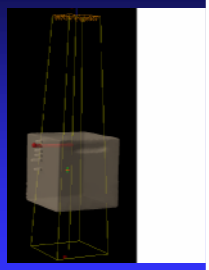
(Vieira *et al.*, Med. Phys. 29, 2034 –2040, 2002)

34

QA DMLC delivery

- Absolute dosimetry test
- Integrated in weekly check of the linac



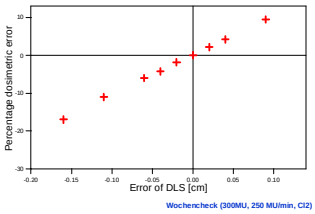


(from Ines Eichwurzel) CHARITÉ CAMPUS MITTE

35

QA DMLC delivery

- Absolute dosimetry test
- Integrated in weekly check of the linac



(from Ines Eichwurzel) CHARITÉ CAMPUS MITTE

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Which aspects of IMRT need special attention with respect to acceptance testing and systematic QA ?

Planning

- Inverse treatment planning system
- Sequencer
- Dose calculation

Delivery

- MLC leaf position
- Data transfer from TPS to linac
- Dose delivery

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Systematic QA

Verification of data transfer from TPS to linac

- Generally no separate check is made if a dosimetric verification is performed.
- If no dosimetric verification is applied (*e.g.*, when using only an independent MU computation), a visual check that plan data have been properly transferred from the planning system to the delivery system should be made for each patient.

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Which aspects of IMRT need special attention with respect to acceptance testing and systematic QA ?

Planning

- Inverse treatment planning system
- Sequencer
- Dose calculation

Delivery

- MLC leaf position
- Data transfer from TPS to linac
- Dose delivery

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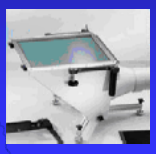
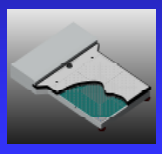
Systematic QA

Verification of dose calculation and dose delivery

- Film or matrix device for 2-D dose verification

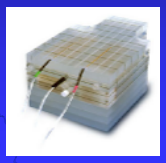




40

Systematic QA

Verification of dose calculation and dose delivery

- Ionisation chamber measurement for absolute dose verification

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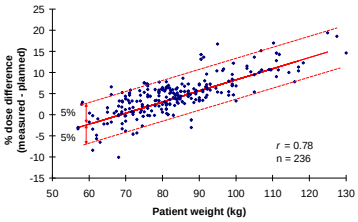
Systematic QA

Verification of dose calculation and dose delivery

Ionisation chamber measurements in a simple phantom for the same number of MUs as applied for prostate IMRT treatments



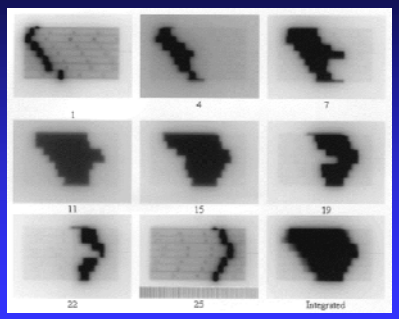
(From Carlos De Wagter)

42

Amorphous silicon (a-Si) EPID

43

Pre-treatment verification of an IMRT beam for prostate treatment using the sliding window technique at Memorial Sloan-Kettering Cancer Center.



(Chang *et al.*, Int J Radiat Oncol Biol Phys 47, 231 – 240, 2000)

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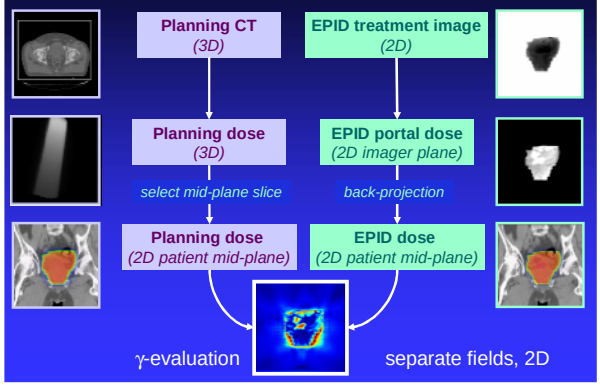
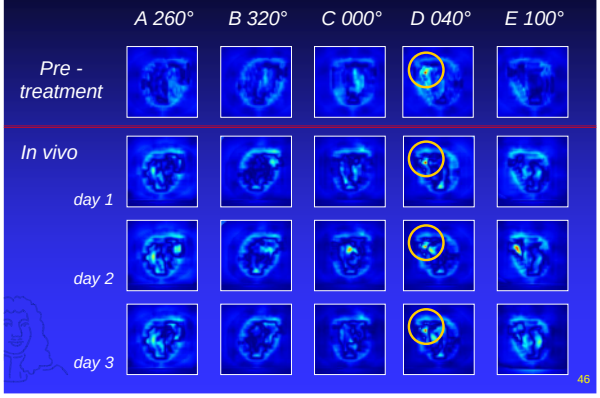
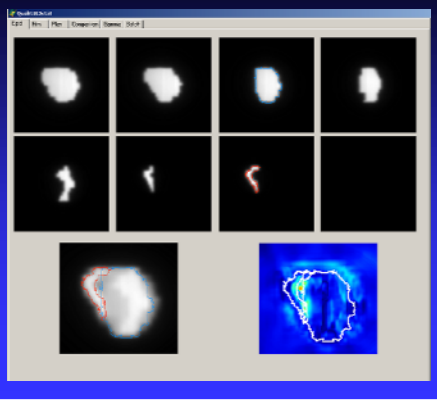
EPID *in vivo* dosimetry at NKI-AVL



Prostate IMRT treatment verification using EPID dosimetry



Cold spot: overlapping segments



IMRT QA in Europe

- Contrary to the situation in the US, IMRT in Europe was until recently only applied in a relatively small number of, mainly academic, institutions.
- The reason for this difference in widespread implementation was that in Europe IMRT was considered more as an experimental type of treatment technique requiring considerable resources (which were only partly reimbursed).
- In recent years both the hard-and software became more mature, while also more experience with respect to IMRT QA became available. As a consequence many more institutions, also smaller and busy clinics, started in Europe with IMRT.

IMRT QA in Europe

- Italy: A working group of the Italian Medical Physicist Association is drafting a document on commissioning and QA of IMRT.
- UK: IPEM is drafting a document on the guidance for the clinical implementation of IMRT, which includes also staffing requirements.
- France: A document has been drafted by physicists of the (GORTEC) group giving recommendations for a head and neck IMRT quality assurance protocol.
- Spain: Both physical and clinical aspects of QA of IMRT are included in a document that describes in detail, for example, also criteria for patients to be admitted to an IMRT protocol and margin recipes of volumes of interest.

Contents of ESTRO report on guidelines for the verification of IMRT

- Approaches for IMRT verification and the methods of data analysis.
- QA tests for accelerator and MLC performance.
- Comparison of the various techniques for dosimetric verification.
- Independent dose calculations.
- Patient specific QA procedures.
- Recommendations concerning type, frequency and tolerances of tests to be performed for IMRT verification in relation to the required accuracy.

IMRT QA in Europe

- Verification of leaf position:
  Weekly to twice a year (depending on experience, major maintenance, stability of accelerator : KNOW YOUR LINAC!)
- Verification of data transfer from TPS to linac:
  All patients if no dosimetric check is performed, for instance if an independent MU calculation is made.
- Verification of dose calculation and/or dose delivery:
  All patients, total plan or separate fields, depending on experience and measuring device.

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How much differs IMRT QA now from when you introduced IMRT in the clinic?

- Film and 2-D detector array measurements of single fields are less applied; particularly film dosimetry is becoming less popular (many departments are becoming film-less).
- More institutions are relying now on independent MU calculations or a single ionisation chamber measurement of the total plan, in combination with a stringent leaf position verification QA programme.
- The emphasis is shifting from intensive patient specific QA to commissioning of the IMRT process, including a better understanding of the models and algorithms in the planning system.

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Intensity-Modulated Radiation Therapy

The State of the Art

Jatinder R. Palta
T. Rockwell Mackie
Editors

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Many thanks for your attention!

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Geographical Centre of Europe

There is an ongoing debate as to where the Geographic Centre of Europe really lies. The differing opinions are based on different measurements, and different ways of calculating the final result.

Among locations currently claiming to be the centre of Europe are:

- Torun in northern Poland
- Rakhiv in western Ukraine
- Bernotai in Lithuania

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Geographical Center of the US

Lebanon, Kansas

Geographic Center of the 48 States

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