TG114: Verification of Monitor Unit Calculations for Non-IMRT Clinical Radiotherapy

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Conflict of Interest

- None

Outline/Overview

- Task Group charges
- Why MU verification is needed
- Objective and limitations of the MU verification
- Aspects of the MU verification program
- Methods of MU verification
- Action level guidelines
- Remedial actions

Background

- Pre ~1980s
  - Primary MU calculations were manual, based on parameterized look-up tables
  - Lots of errors and potential for error
    - e.g. look up wrong value, math error, transcription error
- 1980's
  - Computerized TPS introduced
    - Simple algorithms, usually computerized version of look-up table parameterization
  - Verification done using a manual calculation

Background

- 1990's
  - TPS algorithms become more sophisticated
  - CT-based heterogeneity correction introduced
  - Computerized MU verification programs introduced
- 2000's
  - Sophisticated algorithms and CT-based heterogeneity correction become widespread
  - Computerized MU verification programs nearly universal

Background

- Now
  - Errors that were thought of as the reasons for verification are now basically gone
  - Must get some of the data for verification from the TPS (e.g. radiological depth; depth for oblique fields) so not really independent
  - TPS is more sophisticated than verification system, so expect a difference. How to interpret results?

Background

- So why do a verification calculation anymore?
- Am I doing anything other than checking if the computer has correctly done what it can do better than I can?
- Am I wasting my time?

John Kovalic – Dork Tower

TG114

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TG114 Charges

- Re-evaluate the purpose and methods of the “independent second check” for MU calculations in the modern clinic
- Present recommendations on how to perform such verifications.
- Provide recommendations on establishing action levels for agreement between primary and verification calculations and provide guidance in addressing discrepancies.

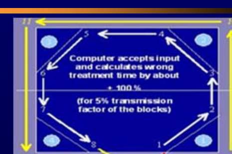
TG114 Charges

- **TG114 does not apply to IMRT**
- For IMRT guidance, look for the following reports to be published:
  - TG218: Tolerance levels and methodologies for IMRT verification QA
  - TG219: Independent dose and MU verification for IMRT patient specific QA

Is an MU check still useful?

Panama 2000-2001

- Blocked/unblocked areas were “reversed”
- MU not verified
- 28 patients overdosed; at least 17 deaths



- IAEA conclusion: “*Results provided by the TPS need to be checked, and this should include verification by manual calculation of the treatment time and dose to the selected point. This verification should be part of the QA programme*.” (IAEA, “Investigation of an Accidental Exposure of Radiotherapy Patients in Panama”, 2001)

Epinal, France 2004-5

- Dynamic wedges introduced, but some plans/MU mistakenly calculated using hard wedges
- MU verification program and diodes "unusable" because not updated for dynamic wedge
- 24 patients overdosed
- "… the error could have been corrected if the independent calculation of the number of monitor units (MU) and in vivo dosimetry… had been maintained." (Summary of Summary of ASN report n° 2006 ENSTR 019 - IGAS n° RM 2007-015P)

Glasgow 2006

- Change in method of calculating/normalizing MU
  - Old: MU calced for 1 Gy then rescaled
  - New: MU calced for actual fx dose
- Adopted for all except some "complex" procedures, including CNS.
- MU erroneously calced in TPS for fx dose of 1.75 Gy (new procedure), then was rescaled (old procedure).
- 1 young adult patient overdosed

WHO Review

- World Health Organization (WHO) reviewed incidents reports from 1976 – 2007
  - Total of 3125 adverse events, 4616 near misses
  - Reviewed sources of errors
  - Gave recommendations to mitigate errors

Modern Radiotherapy Adverse Events

WHO: Radiotherapy Risk Profile, 2008, figure 4

WHO Report – Mitigating Risks

6. Planning

Risks	Potential impact	Solutions
Incorrect calibration or incorrect output data generation	High	Equipment quality assurance External independent dosimetry comparison audits Protocols and sign-off procedures and audits
Incorrect physical data such as decay curves and tables of constants	High	Independent checks Planning protocols In vivo dosimetry
Faulty planning software Incorrectly commissioned planning software	High High	Commissioning Quality Assurance Sign-off procedures In vivo dosimetry
Misuse of planning software Erroneous monitor unit calculation	High High	Competency certification Manual check by independent professional In vivo dosimetry

Recent "near-miss"

URGENT MEDICAL DEVICE CORRECTION
URGENT FIELD SAFETY NOTICE

Subject:	Treatment field calculated with an energy other than that selected
Commercial Name of Affected Product:	
Reference / FSCA Identifier:	CP-05308
Date of Notification:	***2011-06-30***
Type of Action:	Notification
Details on Affected Devices:	Refer to appendix page.

Description of Problem:

This letter is to advise you of an anomaly in Treatment Planning System version 10. The issue is that the treatment field energy may change from the current selection to a previous selection without user intervention and without invalidating the MU or calculated dose distribution.

Support for Verification

- IAEA 2000: "…having a second person check data and repeat calculations or measurements is an important way of finding mistakes before they result in incorrect doses to patients."
- ICRP 2009: "*A simple secondary MU calculation, independent from the TPS, has proven for many years to be an efficient tool for prevention of major errors in dose delivery.*"
- ACR-ASTRO Practice Guideline 2011: "Verify that the results of an independent check on monitor units are within established departmental guidelines"

Objectives of the MU Verification

- "The goal of the MU verification is to ensure that the primary monitor unit calculation is sufficiently accurate for the safe and effective treatment of the patient." – TG114 report
- Serve as part of the quality assurance process to prevent errors in treatment.
- Find (gross) errors in the MU calculation.

Limitations of the MU Verification

- **NOT** a check of the overall accuracy of the primary TPS
- **NOT** a substitute for thorough TPS commissioning
- **NOT** a substitute for continual/periodic QA of the TPS
- **NOT** a check of the overall accuracy of the entire calculated dose distribution
- **NOT** a complete QA plan review

Errors

- Errors are classed into two broad categories: random and systematic
- Which category an error belongs to can depend on circumstances
- MU verification is effective at reducing random errors; less so for systematic errors
- Level of connectivity between TPS and R&V system influences frequency and category of errors that are likely to occur

Likelihood of Errors in a Clinic

- Table 1 lists potential errors and their relative likelihood under 3 data transfer scenarios:
  - **Manual** – Everything entered by hand
  - **Partial automation** – Some or most parameters are transferred electronically, some manual entry/edit still required
  - **Full Automation** – All parameters transferred electronically to the R&V system
- Potential for errors happening classified High, Medium, or Low

Likelihood of Errors in a Clinic

Potential error condition	Degree of automation: Manual	Partial	Full
(1) Tray factors			
(a) Leaving out tray	H[a]	M[a]	L[a]
(b) Using wrong tray	H	H	L
(2) Wedge factors			
(a) Leaving out wedge	H	M	L
(b) Wrong wedge	H	L	L
(c) Wrong wedge direction (for enhanced dynamic wedge or for off-axis calculations)	H	L	L
(d) Off-axis in wrong direction (e.g., along instead of perpendicular to wedge gradient)	H	L	L
(3) Not planning according to Rx			
(a) Wrong energy	H	L	L
(b) Wrong field size	H	M	L
(c) Wrong beam weights	H	L	L
(d) Wrong prescription dose	H	L	L

Essential Aspects

- Part of complete plan review
  - TG recommends performing prior to first treatment
- Thorough commissioning and QA of MU verification system
  - Must have the same level of care in implementation and maintenance as the primary TPS
- Independence

Independence

- Independence of MU verification system
  - Different calculation method and/or program
  - Separate and independent beam data files
    - May be based on same measured data
  - Download of patient-specific parameters from TPS to verification system allowed and encouraged, but must be confirmed
- Independence of verifier
  - Performed (preferably) or supervised by qualified physicist not involved in primary calculation

Methods of Verification

- Calculational
  - Point comparison
    - By far most common
    - MU or Dose
  - Planar dose comparison
  - Volumetric dose comparison
- Measurement

Comparison Point Selection

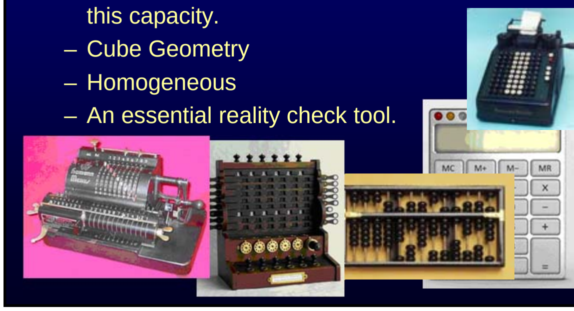
- Location, Location, Location
- Point should be 2 cm from beam/block edge
  - Avoid penumbra effects
- Point should be at least 1 cm downstream and lateral to large heterogeneities
  - Avoid disequilibrium effects
- Single point common to all fields in a plan is preferred but not required.
- Plan normalization point (ICRU point) preferred but not required.

Calculational Methods

- Manual
  - Point
- Commercial or home-grown computerized MU verification systems
  - Point
  - Planar
- Independent treatment planning systems
  - Planar
  - 3D

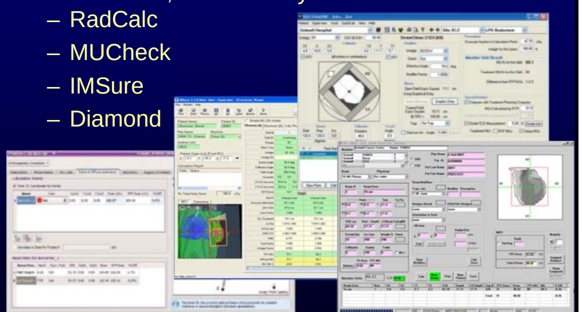
Calculational Methods

- Manual
  - Tried and true, all clinics should maintain this capacity.
  - Cube Geometry
  - Homogeneous
  - An essential reality check tool.



Calculational Methods

- Commercial, dedicated systems
  - RadCalc
  - MUCheck
  - IMSure
  - Diamond



Calculational Methods

- Independent TPS
  - The most accurate option
  - The most thorough option
  - The most expensive option
  - The most cumbersome option

Verification Methods

- Potentially advantageous to check a complex system with a simple system
  - Effects of scatter, missing tissue, inhomogeneity can be separately assessed
  - Better intuitive understanding of how these effects influence calculation
  - Aids in investigation of discrepancies by measurement
  - Can use additional correction factors/methods if needed

Measurement

- Dose Measurement
  - Usually a last resort
    - IMRT is the exception
  - For simple geometry it is generally unnecessary
  - For complicated geometry it is generally inadequate or at least rather difficult
    - Requires anthropomorphic, heterogeneous (custom?) phantoms and high resolution dosimeters

Action Levels (aka Tolerances)

- What is the acceptable difference between the primary and verification MUs?
- No one-size-fits-all
- Agreement depends on:
  - Calculation algorithms
  - Modeling of patient geometry
  - Heterogeneity correction methods
- The greater the difference in calculation methodology, the larger the acceptable difference in results

Action Level Guidelines

- Values determined by consensus of TG members
  - Consistent with published values
- Guidelines apply for all non-IMRT photon beams as well as electron beams.
- Tables are **guidelines only**. Each facility must determine appropriate levels for itself.
  - Ideally determined during commissioning.

Action Level Guidelines

Table II. Homogeneous primary calculation

Primary Calculation Geometry	Similar Calculation Algorithms			Different Calculation Algorithms		
	Same patient geometry	Approx. patient geometry	Uniform cube phantom approx.	Same patient geometry	Approx. patient geometry	Uniform cube phantom approx.
Minimal field shaping	2 %	2.5 %	3 %	2.5 %	3 %	3 %
Substantial field shaping &/or contour change	2.5 %	3 %	4 %	3 %	3.5 %	4 %
Wedged field, off-axis	2 %	2.5 %	3 %	3.5 %	4 %	5 %

Action Level Guidelines

Table II. Homogeneous primary calculation

Primary Calculation Geometry	Different Calculation Algorithms		
	Same patient geometry	Approx. patient geometry	Uniform cube phantom approx.
Minimal field shaping	**2.5 %**	**3 %**	**3 %**
Substantial field shaping &/or contour change	**3 %**	**3.5 %**	**4 %**
Wedged field, off-axis	**3.5 %**	**4 %**	**5 %**

Action Level Guidelines

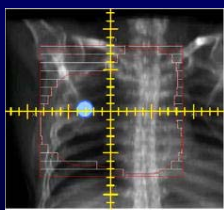
Table III. Heterogeneity-corrected primary calculation

Primary Calculation Geometry	Similar Calculation Algorithms		Different Calculation Algorithms	
	Same patient geometry	Approx. patient geometry	Same patient geometry	Approx. patient geometry
Large field	**2 %**	**3 %**	**2.5 %**	**3.5 %**
Wedged field, off-axis	**2%**	**3%**	**3.5%**	**4.5%**
Small field low density heterogeneity	**3 %**	**3.5 %**	**4 %**	**5 %**

Resolving Discrepancies

- Review and compare calculation parameters
  - Correct parameters used for both
  - All accessories, etc. accounted for
- Check the comparison point location
  - Especially with respect to heterogeneities
- Apply corrections to the verification calc
- Check for incorrect data or improper modeling within either of the systems
- Clinical judgment

Example: Large Field Lung Case



- 4-field technique; AP field
- 6 MV
- 60° motorized wedge
- Calc point 3 cm off-axis
- Primary calculation uses superposition/convolution with heterogeneity corrections
- Verification uses TPR
- Compare dose at calculation point

Homogeneous Verification Calc

- Physical depth = 11.8 cm
- Verification dose = 37.6 cGy
- TPS dose = 41.9 cGy

} Difference = -10.3%

Table II. Homogeneous primary calculation

Primary Calculation Geometry	Different Calculation Algorithms		
	Same patient geometry	Approx. patient geometry	Uniform cube phantom approx.
Wedged field, off-axis	3.5 %	4 %	5 %

Heterogeneous Verification Calc

- Radiological depth = 7.7 cm
- Verification dose = 43.1 cGy
- TPS dose = 41.9 cGy

} Difference = 2.9%

Table III. Heterogeneity-corrected primary calculation

Primary Calculation Geometry	Similar Calculation Algorithms		Different Calculation Algorithms	
	Same patient geometry	Approx. patient geometry	Same patient geometry	Approx. patient geometry
Wedged field, off-axis	2%	3%	3.5%	4.5%

Summary

- Monitor Unit Verification is an important safety tool
  - Part of the pre-treatment plan review
- The verification should be independent
  - Separate calculation program, separate data files, separate physicist
- Many verification systems are currently available
  - Most based on traditional parameter calculations
  - Thorough commissioning and on-going QA are essential

Summary

- Action levels must be established by each facility
  - TG report tables are guidelines only
  - Depend on calc model, patient geometry, field shape/size, heterogeneity correction
  - Requires a thorough knowledge of accuracy and limitations of both primary and verification systems
  - Part of the commissioning process
- Action levels should be documented in a written policy

Thank you!

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