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TG219: IT'S USE, STRENGTHS AND WEAKNESSES

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CONFLICT OF INTEREST

- None

ROSTER

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STATEMENT OF THE PROBLEM

- To review and evaluate the algorithms of "independent/second check" of monitor unit calculations for IMRT.
- The TG will make recommendations
  - On the clinical implementation of calculation programs
  - On commissioning and benchmark QA of 2nd MU calculation programs,
  - Propose additional measurements, if necessary.
  - On clinical testing and periodic quality assurance of 2nd MU calculation programs and
  - On test tolerances

- The report is intended to apply to the verification of MU for the continuum of IMRT delivery techniques such as static gantry IMRT (SG-IMRT), volumetric modulated radiation therapy (VMAT), CyberKnife, and TomoTherapy.

SURVEY FINDINGS SUMMARY (2012)

- A dose/MU verification program is generally used for the majority of IMRT/VMAT treatment plans although approximately 31% of responders **do not use dose/MU verification software for VMAT treatment plans.**
- RadCalc is the most common.
- Eclipse is the most common treatment planning system.
- The most common passing rate criteria for dose/MU verification software is 5% for IMRT (51%) and none for VMAT (34%), although 30% of VMAT responders also use 5% as passing rate.
- More than 50% of users use a single point for their calculations and
- Only 6% use 3D volumetric dose.
- Using the same beam data as the TPS but a different dose calculation algorithm is believed to be necessary to ensure independence of the IMRT dose/MU verification software.
- Additional measurements (usually MLC leaf gap test) are also required during commissioning.
- The most common IMRT dose/MU verification calculation algorithm represented by software(s) in use is the "factor-based calculation algorithm".

SURVEY

Do you use the MU second verification program?		
Answer	Count	Percent
Yes	322	78.73%
No	87	21.27%
Did you use the same data or algorithms obtained from your treatment planning system for the IMRT MU calculation verification program?		
Yes	196	39.84%
No	296	60.16%
What is your primary treatment planning system?		
a) Eclipse	378	48.21%
b) Pinnacle	260	33.16%
c) CMS	63	8.04%
d) Oncentra	14	1.79%
e) Hi-Art	32	4.08%
f) Research/home grown	4	0.51%
Other, please specify	33	4.21%
How frequently do you use an IMRT/VMAT MU calculation verification program?		
a) For every IMRT treatment	581	90.78%
b) For selected IMRT treatment	21	3.28%
c) Other, please specify	38	5.94%

SURVEY

Which MU calculation verification program do you currently use for IMRT? (select all that apply)

IMRT			VMAT		
Answer	Count	Percent	Answer	Count	Percent
a) RadCalc	381	52.48%	a) RadCalc	220	32.07%
b) IMSure	70	9.64%	b) IMSure	31	4.52%
c) MUcheck	133	18.32%	c) MUcheck	71	10.35%
d) Diamond	26	3.58%	d) Diamond	18	2.62%
e) Dosimetry Check	27	3.72%	e) Dosimetry Check	21	3.06%
f) Mobius 3D	0	0%	f) Mobius 3D	0	0%
g) 2nd TPS	8	1.10%	g) 2nd TPS	6	0.87%
h) None	25	3.44%	h) None	213	31.05%
i) Other, please specify	56	7.71%	i) Other, please specify	106	15.45%

What is the MU calculation verification program's passing rate you are currently using for MU ratio?

Answer	Count	Percent	Answer	Count	Percent
a) 3%	204	31.87%	a) 3%	103	16.09%
b) 5%	328	51.25%	b) 5%	192	30%
c) 7%	25	3.91%	c) 7%	28	4.38%
d) 10%	13	2.03%	d) 10%	10	1.56%
e) None	26	4.06%	e) None	220	34.38%
f) Other	44	6.88%	f) Other	87	13.59%

REVIEW OF THE PROBLEM

- IMRT/VMAT in a radiotherapy department increase the workload⇨the potential danger for serious errors in the planning and delivery of radiotherapy.
- The goal of a routine pre-treatment verification procedure is to catch errors before the actual treatment begins.
- The aim for the current report is:
  - to define and describe the role of independent IMRT dose and MU verification,
  - to provide an overview of existing approaches including commercially available software, and
  - to give recommendations for implementation and use of software for independent IMRT dose and MU verification.

REVIEW OF THE PROBLEM

- This report is NOTmeant as a comprehensive summary of what needs to be done to ensure safe and accurate delivery of IMRT or VMAT.
- This report does NOT address periodic machine or MLC specific quality assurance procedures, commissioning of the whole IMRT/VMAT planning and delivery chain, or dosimetric means for patient specific IMRT/VMAT quality assurance.

PLANNING AND DOSE DELIVERY ERRORS

- IMRT planning and delivery is a more complex process
- End-to-end QA verification tests for the IMRT treatment planning system and IMRT delivery equipment, along with patient specific verification QA are required to ensure the accuracy of the radiation delivery to patients.
- Errors and/or uncertainties in the planning and delivery process can result in erroneous dose distributions delivered to the patient

12 IMRT ACCURACY

- Linac output variations,
- MLC leaf position accuracy,
- MLC leaf failure,
- Leaf-end design,
- field output variations for small static step-and-shoot field segments and/or narrow sliding-window shapes with low MUs,
- Leaf position and leaf gap reproducibility,
- Inter- and intra-leaf transmission,
- Leaf acceleration/de-acceleration speed,
- Tongue-and-groove effect, and
- MLC system sag with gantry rotation

SOURCES OF ERRORS FOR THE SECOND MU CALCULATION PROGRAM

		Probability of error			
Common sources of error		(Algorithm "dimensions")			
Data related		1D	2D	3D	Comment
	Scp	L	L	L	Errors are more likely for small fields
	PDD	L	L	L	
	TMR	M	M	M	Usually calculated from PDD
	Fit	-	-	M	1D and 2D algorithms do not usually use a fit to the data
User related					
	Wrong plan	M	M	L	
	Wrong points	M	M	M	
	Wrong Rx	L	L	L	High if manually input
	Wrong images	M	M	M	
Plan related					
	Low dose region	H	M	M	
	High gradient region	H	H	H	
	Small field	M	M	M	
	Small MU	L	L	L	
	Dynamic beams	H	M	M	
	Split fields (large angle scattering)	M	M	M	
	Lateral electron disequilibrium	H	M	M	

IMRT COMPLEXITY

- Step and Shoot
- Sliding Window
- VMAT
- TomoTherapy
- CyberKnife

LIMITATIONS OF DOSE/MU VERIFICATION SW

- Usually single point, not 3D
  - Semi-infinite slab geometry
  - No patient information
  - Treatment specific factors are verified
  - Inhomogeneities
- Data directly from the treatment planning system or the database of the record and verify system
  - does not provide a check of the correct file transfer from the treatment planning system to the treatment delivery console,
  - or a verification of the multileaf collimator performance for IMRT delivery.
    - Cannot replace IMRT measurements

LIMITATIONS OF DOSE/MU VERIFICATION SW

- Tools for independent IMRT dose and MU calculation **CANNOT** replace measurements for commissioning IMRT equipment.
- Independent MU calculation tools for IMRT require verification of the software and must be commissioned prior to their clinical use.
- It is recommended that independent patient specific measurements of the delivered fluence or of dose planes in phantom should be used to verify that the correct MLC and gantry-collimator parameters have been transferred to the treatment console.

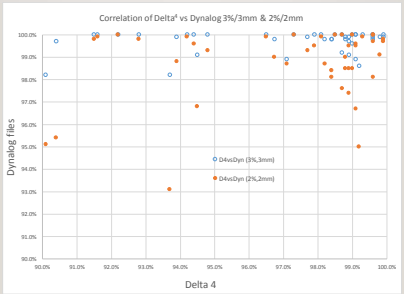
HOW DOSE/MU VERIFICATION PROGRAMS COMPLEMENT MEASUREMENTS FOR IMRT QA

- Experimental verification has become the preferred method for IMRT commissioning as well as for patient specific QA
  - Workload considerations
  - Verification measurements are usually not performed in patient geometry
- Advantage of an independent dose calculation method for IMRT include:
  - far less time consuming than experimental methods for patient specific QA
  - Calculational procedures do not require machine time.
- The goal of MU calculation in IMRT is to streamline QA procedures in such a way that the frequency of direct dose measurements is limited or optimized.
  - This can lead to an increase in the frequency of IMRT use in the clinic

HOW DOSE/MU VERIFICATION PROGRAMS COMPLEMENT MEASUREMENTS FOR IMRT QA

- Use linac log files for many quality assurance procedures in radiation oncology
- Measured fluences with an EPID or a transmission detector can be used as input data for independent dose calculation
- The clinical use of independent dose or monitor unit calculation system for IMRT can have educational aspects. Implementing such a system will require commissioning, testing, and definition of acceptance and tolerance levels for decision making, etc., which in turn requires understanding of the underlying dose calculation algorithm

HOW DOSE/MU VERIFICATION PROGRAMS COMPLEMENT MEASUREMENTS FOR IMRT QA



HOW MEASUREMENTS COMPLEMENT DOSE/MU VERIFICATION PROGRAMS

- Assumption:
  - IF (MU and dose verification by software agree),
  - THEN (dose delivery is acceptable)
- But, sources of error not detected include:
  - Leaf calibration
  - Patient setup
  - Organ motion
  - Beam calibration
  - Limitations of dose calculation in TPS

ALGORITHMS FOR MU CALCULATION VERIFICATION

Table 3a: 2D algorithms and evaluation methods available in various second dose/MU calculation system and the specifics of various algorithm types.

Alg. Types	Hetero. Corr. Methods	Head Scatter Models	Pat. Geom.	# Calc. points	Eval. Method
1.Factor based	A. RTAR	A. HS central axis meas.	2D contour/CT	A. one point	A. % err.
2.Model based	B. Batho power	B. HS off-axis meas		B. 2 - 10 points	B. Gamma Index (or DTA)
3. Monte Carlo (MC)	C. ETAR	C. model: flattening filter		C. planar dose	C. DVH
4 Deterministic (GBBS)	D. FFF	D. model: ff+cs+ps			
	F. material Z				

ALGORITHMS FOR MU CALCULATION VERIFICATION

Table 3b: 3D algorithms and evaluation methods available in various second MU calculation system and the specifics of various algorithm types.

Alg. Types	Hetero. Corr. Methods	Head Scatter Models	Pat. Geom.	# Calc. points	Eval. Method
1. Factor based	A. FFF	A. HS off-axis meas	3D contour/CT	B. 2 - 10 points	A. % err.
2. Model based	B. Collapsed cone	B. model: flattening filter		C. planar dose	B. Gamma Index (or DTA)
3. Monte Carlo (MC)	C. material Z	C. model: ff+cs+ps		D. 3D dose cloud	C. DVH
4. Deterministic (GBBS)	D. Secondary electron transport	D. model: source obscuring			
		E. model: monitor backscattering			

HETEROGENEITY CORRECTIONS

Table 4: Relationship between accuracy and calculation algorithms of the second MU calculation program, see section 3.4 for details.

	Typical error range (local % difference from measurement or MC)				
	Center of lung tumor	in or downstream of lung	In bone	At surface	High Z (e.g., dental)
Factor-based	4.9	3-10	3-10	>40	20-40
AAA	3.7	2-5	2-3	20	10-15
Collapsed cone (C/S)	3.7	2-5	1-2	20	10-15
Deterministic (GBBS)	1.5	1-2	<1	-	5
MC	<1	-	-	-	5

ACCEPTANCE

- The physicist should consult the manufacturers of the respective software to obtain detailed instructions.

COMMISSIONING

- The commissioning requirements for dose/MU verification software will depend on the type of algorithm in use.
- Measurement errors in acquired beam data will propagate as systematic uncertainties in the QA procedure
- The measured data (e.g., *PDD* curves, *OAR* (i.e. *OCR*) curves, and output factors) that are used for the modeling process of the primary TPS will typically be the same data that is entered into secondary dose/MU verification software.

COMMISSIONING

- As with any system used in the clinical treatment of patients, the secondary dose/MU verification system requires commissioning and ongoing quality control monitoring to ensure the accuracy, safety, and efficacy of the system as recommended by AAPM TG 53 and AAPM MPPG 5A
- Full documentation of the commissioning tests and results should be kept in place at the institution and serve as the guidelines for the ongoing QA program
- Non-dosimetric functions of the secondary dose/MU verification should also be commissioned.

COMMISSIONING

Tasks	Test required
Open beam Homogenous phantom	SSD setup, various Jaw size and depth SAD setup, various Jaw size and depth SAD setup, various Off axis point with representative jaw size and depth
Static field Homogenous phantom	Blocked field (Block/MLC) Compensator field Wedge field (CAX and Off axis) Field edge Skin Flash Surface slope
Dynamic field Homogenous phantom	Dynamic wedge (CAX and Off axis) Step and shoot Sliding window VMAT
Heterogeneous Phantom	Different density tissue internal (lung/bone, etc) Different density tissues interface Different density field edge
Real patient plan	Statistic evaluation between real patient plans and MU calculation program results.
Criteria	Percentage, Gamma index or DVH(based on plan type, site, etc.)

COMMISSIONING VALIDATION/BENCHMARKING

- Specific guidance for treatment planning system benchmark can be found in AAPM TG-53
- After commissioning of the secondary MU software per the recommendation of AAPM Task Group Report 114 and AAPM MPPG 5A

COMMISSIONING VALIDATION/BENCHMARKING

Tasks	Data required
Linac physics Model	Energy, SAD, Dmax, size/angle range (Jaw, gantry, collimator, couch)
Linac Dosimetry Model	PDD/TMR(open, wedge), Profile(open, wedge), Output Factor (open Sc/Sp, wedge), transmission factors (Jaw, block tray, comp tray, couch, immobilization, etc), reference MU definition
MLC physics Model	MLC type, leaf number, size, etc
MLC Dosimetry Model	attenuation(inter and intra leave), dosimetric leaf gap, etc

"INDEPENDENCE" OF THE VERIFICATION SOFTWARE

- For an independent dose calculation of individual IMRT beams or a composite IMRT treatment plan, in principle, a completely independent commercial or in-house developed software solution is desirable
- to avoid introducing systematic errors in both systems, it is highly recommended to use two different sets of experimentally determined beam data

WHAT IS CHECKED

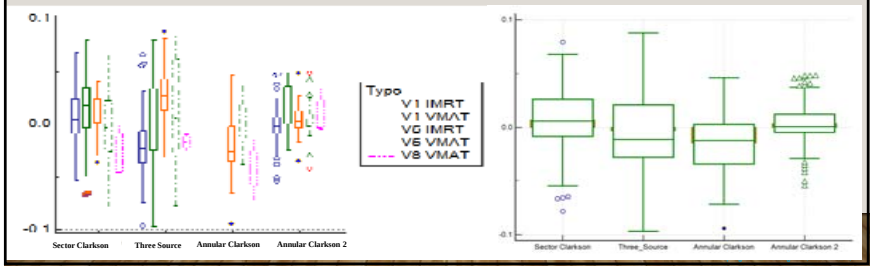
- Dose/MU
  - the independent secondary dose/MU verification system should be able to calculate the MU required for the delivery of the prescribed dose, or confirm the resultant dose from a given MU value.
- Patient Geometry
  - Patient geometry (e.g., entry point, SSD, depth, heterogeneity) will have a large effect on dose per MU. The secondary dose/MU verification will perform the calculation based on the data received from the TPS.
- Dose Volume constraints
  - DVH metrics have been shown to be more sensitive to critical dose errors than single point dose verification or gamma passing rates.

HOW MANY POINTS

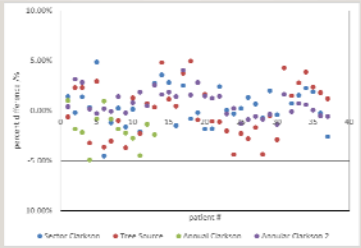
- The number of points varies depending on the vendor, and or clinical practice
- If only one point checked, it is critical that the chosen point is in a low dose gradient region so that comparison is meaningful.
- Some commercial secondary dose/MU verification have implemented 2D calculations to one plane or 3D calculations to the entire volume and additionally provide gamma maps for dose evaluation.

COMPARISON BETWEEN TPS AND DOSE/MU VERIFICATION SOFTWARE

- Acceptable difference criteria
  - They recommend tolerance limits of 3% for ion chamber measurement in target areas and action limits of 5% for point dose verification



ACCEPTABLE DIFFERENCE CRITERIA



ACTION LEVELS FOR UNACCEPTABLE DIFFERENCES

Table 6: Action levels of the second MU calculation compared to TP calculations for various clinical situations for a single point. All percentage differences are defined as local relative difference. Note, the action level is larger than the tolerance level as described in AAPM TG218. For 2D or 3D action level, use specification as described in AAPM TG218

	Homogeneous		Heterogeneous	
	Single beam	Composite plan	Single beam	Composite plan
High Dose/Low Gradient	5%	3%	7%	5%
Low Dose/Low Gradient	7%	5%	10%	7%

FOLLOW UP FOR CASES WITH POOR AGREEMENT

- In cases where there is poor agreement between the primary TPS and the secondary MU verification system, it is important to examine the case to understand the nature of the disagreement
- While this possibility should be examined, moving the point routinely for numerous patients or repeatedly for a given patient to ensure acceptability is not an appropriate solution

BENCHMARK CASES

- After commissioning of the second dose/MU verification system, it is imperative to verify to accuracy of this system
- the process is similar to the one outlined in TG-53 and MPPG-5A for the verification and QA of treatment planning systems
- they should cover the range of plans encountered clinically, including both routine cases (e.g., head and neck), as well as a range from small field, such as radiosurgery, to large field, such as mesothelioma
- should also be designed with the different techniques used clinically: step-and-shoot, dynamic MLC, and/or VMAT

BENCHMARK CASES

- Failure to achieve this level of agreement should be result in either
  1. improved commissioning of the second calculation system such that appropriate agreement is achieved, or
  2. identification of the limitations and establishment of alternate criteria for treatment plans of a similar nature.
- is important to establish a baseline for the performance of the system to specific test cases
- Benchmark plans used for periodic QA of the second MU system can reasonably be a trimmed version of the set used for commissioning, including only a few cases.
- QA of the second dose/MU verification system is also warranted when the TPS is updated.

RECOMMENDATIONS

- The goal of independent dose/MU calculation in IMRT is to streamline QA procedures in such a way that the frequency of direct dose measurements may be limited or optimized (Section 2.3).
- Independent dose and MU calculation can be only part of a more comprehensive QA program for IMRT in a department because of the limitations of secondary dose/MU software. Such software currently cannot detect errors in dose calibration, MLC errors, collimator or gantry discrepancies or patient setup inaccuracies (Section 2.2 and 2.4).

RECOMMENDATIONS

- "Independence" for secondary dose/MU software follows the same definition as outlined in TG114, i.e. it can be comprised of independent algorithms and/or independent beam data. It is acceptable to use the same beam data used for the TPS commissioning provided the algorithm for dose calculation is different, but ideally both the algorithm and beam data will be independent (Section 5.1).
- Commissioning of the secondary dose/MU software should be performed based on the recommendations of AAPM report 53 and MPPG 5A(Section 4.2)

RECOMMENDATIONS

- Ongoing QA for the secondary dose/MU software should be carried out annually and anytime a TPS or secondary dose/MU software upgrade occurs, consistent with MPPG 5A (Section 4.3).
- The software validation and benchmarking should be done following the recommendations of AAPM Task Group 119
- For each individual IMRT/VMAT field, the agreement between TPS and secondary dose/MU verification should be within the recommended action levels shown in Table 6. Plan acceptability should be based on the composite plan. Single beam agreement should be used to help further the understanding of the plan quality (Section 5.4).

RECOMMENDATIONS

- Plan failing to meet acceptability criteria should be evaluated seriously to understand the case of the disagreement and manage it appropriately. Routine disagreement between the secondary dose/MU verification system and the primary TPS should prompt thorough review of the commissioning and QA of the secondary system (Section 5.4.3).
- Vendors should move away from systems that offer only a single comparison point and should develop second dose/MU verification systems that compute the dose distribution throughout the high dose volume (Section 5.3)

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