Moving from a simple Type A independent dose calculation to a Type B or Type C based independent dose calculation

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- Ownership of Clearsight RT LLC (unrelated to this topic)

Background

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Report & Task Group Details:

AAPM TG-40: Recommended independent check (of MU calculation) within 48 hours
"This review should occur prior to treatment; where this is not possible (e.g., emergency treatment), then it should be done before the third fraction or before 10% of the dose has been delivered, whichever occurs first"

AAPM TG-114: Recommendations on independent calc software commissioning, & calc details, timing, & tolerances

AAPM TG-71: Codified a formalism for hand calculations

ICRU Report 24: "Dosimetry systems must be capable of delivering dose to an accuracy of 5%"
This guidance is echoed in subsequent reports

AAPM IMRT Subcommittee Report: "Direct measurements will be necessary until independent dose calculation methods are developed and validated."

AAPM TG-219: Report approved by TPC and final version submitted to SC on 6/3/2020.
Some details provided in 2017 AAPM presentation

Dose Calculation Algorithm Classification

- **Type A:** Models that do not consider the changes in electron transport
- **Type B:** Models that in an approximate way consider changes in lateral electron transport
- **Type C:** Algorithms in which the physics generating the dose absorption process is accounted for

Fogliata, Antonella, and Luca Cozzi. *Physica Medica* 44 (2017): 157-162.

Choice of 2nd Calculation Algorithm

Type A (simple hand calc)

Advantage: effects of scatter, missing tissue, and tissue heterogeneity are separated and can be independently assessed

Disadvantage: Simple calc is limited for complex calculations involving small fields and/or heterogeneity corrections.

Type B or C (sophisticated calc)

Advantages:

- Improved dosimetric accuracy especially in the presence of scatter disequilibrium and tissue heterogeneities
- Ability to assess dosimetric uncertainties on the patient DVH

Disadvantage: Black box… (difficulty to assess sources of uncertainties)

TG-219 recommendation to transition from single point comparisons to a system that computes dose distribution throughout the high dose volume

Stern, Robin L., et al. *Medical physics* 38.1 (2011): 504-530.
AAPM 2017 Presentation: TG219: IT'S USE, STRENGTHS AND WEAKNESSES

Why Transition to a Type B or C Independent Dose Calc Algorithm?

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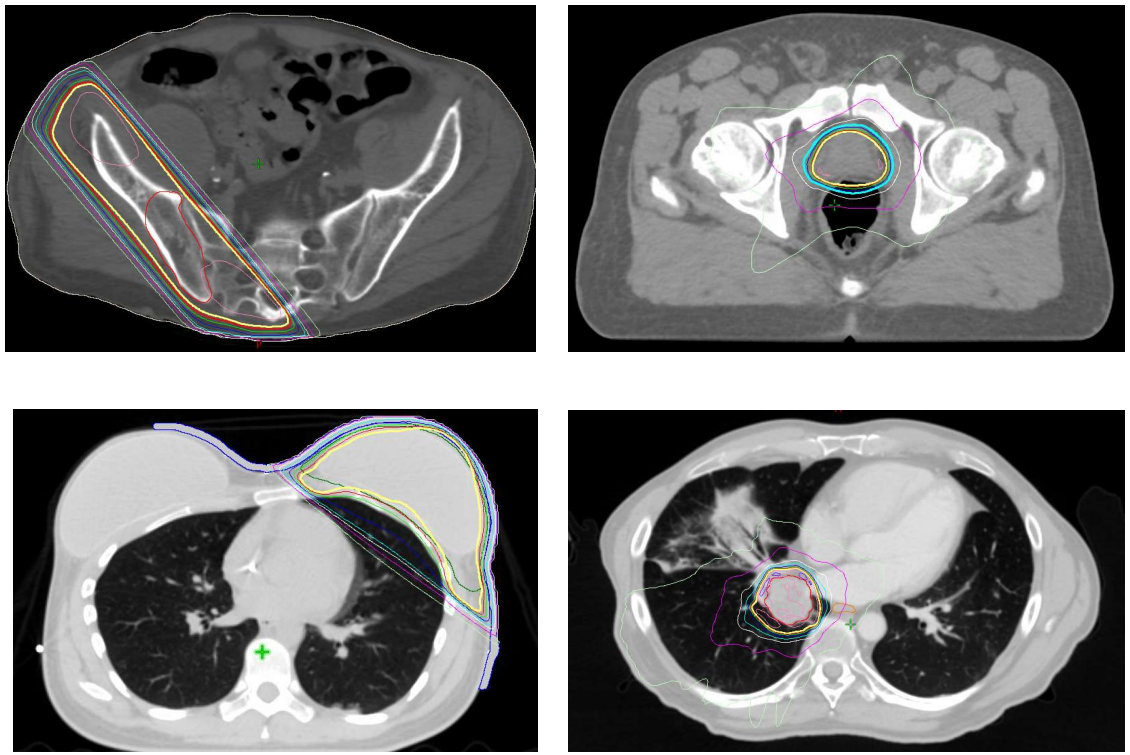
Appropriate Geometry for Simple (Type A) Calc



- Points within 2 cm of a field edge may experience disequilibrium effects arising from lack of lateral scatter.
- Points should be located, if possible, in soft tissue and positioned at least 1.0 cm downstream and 1.0 cm lateral to heterogeneous tissue interfaces to avoid large disequilibrium effects

Stern, Robin L., et al. *Medical physics* 38.1 (2011): 504-530.

TG-114 recommended action levels

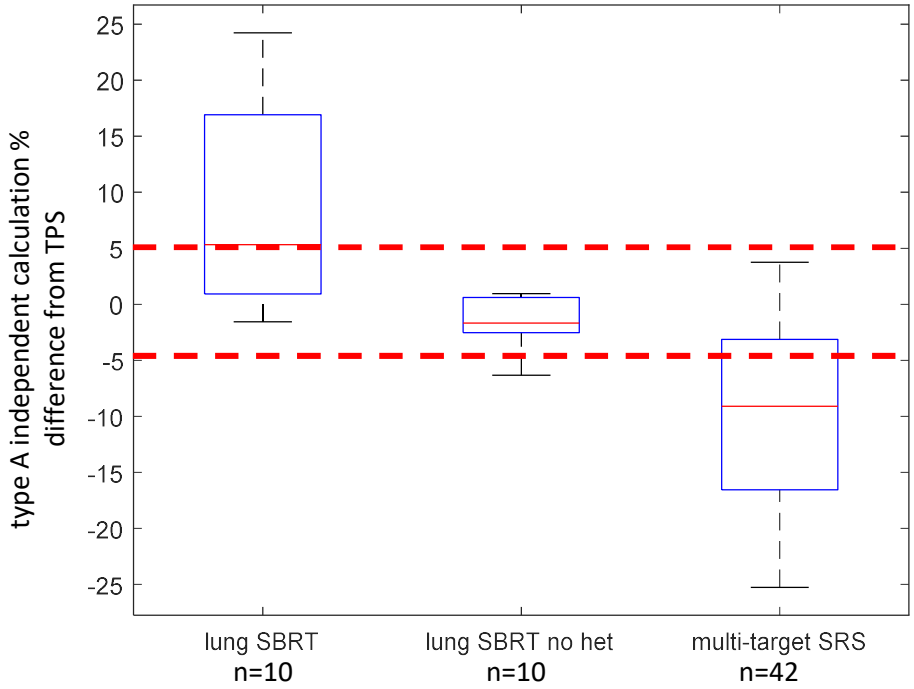
TABLE III. Guidelines for action levels for disagreement between verification and primary calculations with heterogeneity corrections.

	Similar calculation algorithms		Different calculation algorithms	
Primary calculation geometry	Same patient geometry (%)	Approx. patient geometry (%)	Same patient geometry (%)	Approx. patient geometry (%)
Large field	2	3	2.5	3.5
Wedged fields, off-axis	2	3	3.5	4.5
Small field and/or low-density heterogeneity	3	3.5	4	5

TG-219 may provide updated action levels for IMRT 2nd calculations.

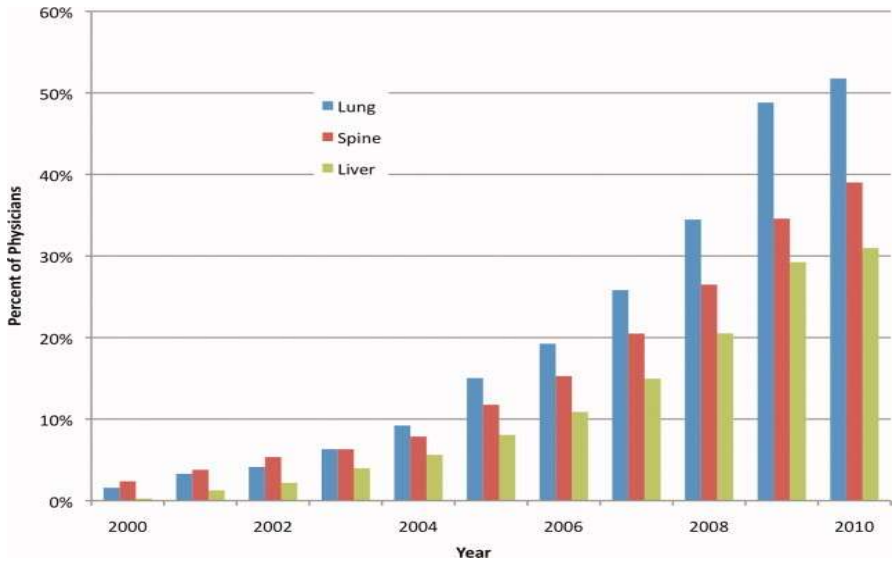
Stern, Robin L., et al. *Medical physics* 38.1 (2011): 504-530.

Type A Calc. Accuracy for Complicated Cases



Use of SBRT over time

Increasing incidence of cases for which scatter equilibrium, inhomogeneity, etc. for which a type A calculation is inadequate



Cancer, Volume: 117, Issue: 19, Pages: 4566-4572, First published: 15 March 2011, DOI: (10.1002/cncr.26067)

Independent recalculation outperforms traditional measurement-based IMRT QA methods in detecting unacceptable plans

Purpose: To evaluate the performance of an independent recalculation and compare it against current measurement-based patient specific intensity-modulated radiation therapy (IMRT) quality assurance (QA) in predicting unacceptable phantom results as measured by the Imaging and Radiation Oncology Core (IROC).

Methods: When institutions irradiate the IROC head and neck IMRT phantom, they are also asked to submit their internal IMRT QA results. Separately from this, IROC has previously created reference beam models on the Mobius3D platform to independently recalculate phantom results based on the institution's DICOM plan data. The ability of the institutions' IMRT QA to predict the IROC phantom result was compared against the independent recalculation for 339 phantom results collected since 2012. This was done to determine the ability of these systems to detect failing phantom results (i.e., large errors) as well as poor phantom results (i.e., modest errors). Sensitivity and specificity were evaluated using common clinical thresholds, and receiver operator characteristic (ROC) curves were used to compare across different thresholds.

Results: Overall, based on common clinical criteria, the independent recalculation was 12 times more sensitive at detecting unacceptable (failing) IROC phantom results than clinical measurement-based IMRT QA. The recalculation was superior, in head-to-head comparison, to the EPID, ArcCheck, and MapCheck devices. The superiority of the recalculation vs these array-based measurements persisted under ROC analysis as the recalculation curve had a greater area under it and was always above that for these measurement devices. For detecting modest errors (poor phantom results rather than failing phantom results), neither the recalculation nor measurement-based IMRT QA performed well.

Conclusions: A simple recalculation outperformed current measurement-based IMRT QA methods at detecting unacceptable plans. These findings highlight the value of an independent recalculation, and raise further questions about the current standard of measurement-based IMRT QA. © *2019 American Association of Physicists in Medicine* [https://doi.org/10.1002/mp.13638]

Kry *et al.*: Medical Physics, 46 (8), August 2019

Implementation

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Commercial software with Type B or C independent dose calculations

- Dose calculation details:
  - Algorithms:
    - Collapsed Cone Convolution Superposition
    - Monte Carlo
  - Volumetric dose calculation
  - Beam model:
    - Standardized per linac model
    - Customized / tuned to individual linac
- Analysis details:
  - DVH based comparisons
    - Comparison to dose limits & constraints
    - Comparison to value(s) from TPS
  - Gamma analysis
- Ancillary Options
  - Treatment delivery simulation, plan detail checks, etc.
  - Log file analysis (pre-treatment or daily monitoring)
  - Incorporation of EPID / Pre-Treatment QA into model
  - Incorporation of daily CBCT for dosimetric analysis

Independence of 2nd Calculation

- **Independence** = using a **different methodology** and/or **different program** than that used for the primary calculation
- **Independence cannot be obtained using same program as primary calculation.** Even if TPS has more than one calculation model implemented, use of a separate program is strongly recommended because many of the potentially errant parameters would be common to both calculation models
- When beam and patient models are similar, the **algorithmic implementations should be different**.
- **Files** containing **beam data** and parameters should be **separate** and **independent**

Stern, Robin L., et al. *Medical physics* 38.1 (2011): 504-530.

Commissioning

- From TG-114 (2011)
  - Performance of **independent calc should be compared to measurements** (not just to the TPS), and compared, if possible, with the results of other established calculation systems of known accuracy
  - Commissioning tests should include **clinically relevant geometries** that verify the accuracy of shaped field calculations and calculations in heterogeneous media
  - Commissioning should establish the accuracy of system in different clinical situations, and this should be used to **establish action levels**
- From TG-219 (2017 AAPM Presentation)
  - Commissioning of the secondary dose/MU software should be performed based on the recommendations of AAPM report 53 and MPPG 5A. 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. The software validation and benchmarking should be done following the recommendations of AAPM Task Group 119

Stern, Robin L., et al. *Medical physics* 38.1 (2011): 504-530.

Commissioning Examples From Literature

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 15, NUMBER 5, 2014

Commissioning results of an automated treatment planning verification system

Christopher L. Nelson,[a] Bryan E. Mason, Ronald C. Robinson, Kelly D. Kisling, Steven M. Kirsner

- Customized the independent calc model
  - Extracted beam data from standardized model
    - field sizes 1x1cm^2 to 40x40cm^2
    - PDDs
    - Profiles (in field, penumbra, tail)
  - Compared to TPS beam data when customizing beam model
    - Inputs:
      - PDD values at three depths, & three field sizes
      - output factors for six different field sizes
      - off-axis ratios for a 40×40cm^2 at six locations
- Dose comparison for 40 clinical treatment plans
  - Solid water phantom
  - CC04 Ion chamber (% difference)
  - Kodak EDR2 film (3% / 3mm Gamma)

J Appl Clin Med Phys 2020; **21**:**11**:304–311

Commissioning and clinical implementation of the first commercial independent Monte Carlo 3D dose calculation to replace CyberKnife M6™ patient-specific QA measurements

Maaike T. W. Milder[1] | Markus Alber[2,3] | Matthias Söhn[3] | Mischa S. Hoogeman[1]

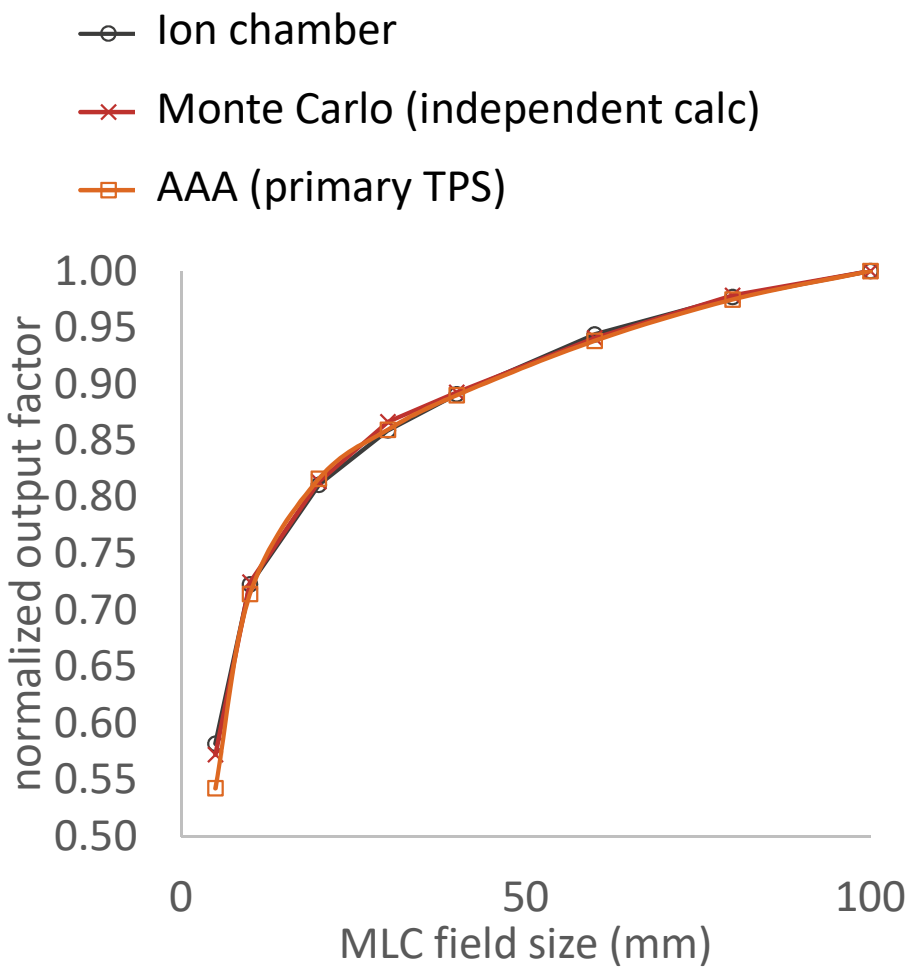
- Beam Model Validation
  - Comparison of calculated values with measurement for PDDs, Output factors, Off axis ratios
- Independent dose calculation of clinical plans
  - Retrospectively re-calculated 84 clinical treatment plans
  - Range of treatment sites (n=5) & PTV sizes (30-300cc).
  - 3D Gamma Index Comparison (2% ,1mm, global, 10% cutoff)
- Establishing action levels
  - Action criteria set using control charts for Gamma Index agreement, as described in the paper & in TG-218

Our experience

- Monte Carlo Independent Dose Calculation Software (SciMoCa)
- Data for beam modeling
  - PDDs
  - Profiles
  - Output factor tables
  - Leaf gap -> need method, & detector for Monte Carlo modeling
- Acceptance & software functionality
- Commissioning:
  - Comparison with measurement data in water
    - Point dose spot checks (profiles & PDDs for geometry not included in beam modeling data)
    - Profiles & Penumbra
    - Output factors
    - Static MLC fields
- Commissioning (continued)
  - Heterogeneity & HU to Density Calculation
    - HU calibration verification
    - Density override function
    - Heterogeneity correction verification
  - Comparison with measurements in clinical plans
    - Ion chamber measurements
  - Comparison with TPS for clinical plans
    - Multiple treatment sites & geometries
  - Workflow & action criteria
    - DVH analysis
    - Dose to water or dose to medium?
    - Handling of body contour, couch structures
    - immobilization device, bolus, etc.
- SRS specific commissioning

Spot Check Ion chamber Measurements

Linac	Energy	n	Ion Chamber vs. Independent calc (Monte Carlo)	Ion Chamber vs. primary TPS (AAA)
TB	6X	40	-0.07% ± 0.54% [-1.29%, 1.18%]	-0.28% ± 0.39% [-1.54%, 0.53%]
STX	6X	40	0.04% ± 0.59% [-0.98%, 1.52%]	-0.21% ± 0.32% [-1.13%, 0.45%]
TB	6XFFF	40	-0.52% ± 0.60% [-1.79%, 0.98%]	0.33% ± 0.40% [-0.67%, 1.27%]
STX	6XFFF	40	-0.55% ± 0.66% [-1.72%, 1.04%]	0.17% ± 0.36% [-0.67%, 0.99%]
TB	10X	40	-0.43% ± 0.88% [-1.99%, 2.26%]	0.08% ± 0.30% [-0.72%, 1.06%]
STX	10X	40	-0.49% ± 0.58% [-1.54%, 0.92%]	0.13% ± 0.22% [-0.38%, 0.54%]
TB	10XFFF	40	-1.03% ± 0.73% [-2.76%, 0.83%]	0.19% ± 1.29% [-0.91%, 8.14%]
STX	10XFFF	40	-0.85% ± 0.84% [-2.18%, 1.71%]	-0.09% ± 0.21% [-0.58%, 0.40%]
TB	15X	40	-0.47% ± 0.71% [-2.04%, 0.94%]	-0.04% ± 0.30% [-0.65%, 0.99%]
STX	15X	40	-0.45% ± 0.48% [-1.43%, 0.67%]	0.19% ± 0.49% [-0.38%, 2.42%]



Agreement of AAA (primary TPS) and Monte Carlo (independent calc) with ion chamber point dose measurement for clinical IMRT and VMAT plans

	IMRT (various sites)		VMAT (various sites)	
	AAA	Monte Carlo	AAA	Monte Carlo
6X	2.9%	3.9%	3.0%	1.9%
6XFFF	3.9%	3.0%	1.3%	1.3%
10X	-0.7%	1.2%	0.9%	3.3%
10XFFF	-0.1%	-0.7%	-2.5%	-2.5%
15X	1.5%	1.1%	1.6%	1.6%

Dose to Medium vs. Dose to Water

Primary TPS:

- AAA-> Dose to water
- AXB-> Dose to medium

Independent calc algorithm:

- Monte Carlo-> dose to medium

*our current procedure is for the independent calc to always match the TPS

AAPM Task Group 329: Reference dose specification for dose calculations: Dose-to-water or dose-to-muscle?

Linac calibration is done in water, but patients are comprised primarily of soft tissue. Conceptually, and specified in NRG/RTOG trials, dose should be reported as dose-to-muscle to describe the dose to the patient. Historically, the dose-to-water of the linac calibration was often converted to dose-to-muscle for patient calculations through manual application of a 0.99 dose-to-water to dose-to-muscle correction factor, applied during the linac clinic
planning system (TPS) dose calculation al
making application of a manual scaling unn
scaling factor is appropriate, resulting in hig
nity. In this report we provide guidance on t
water calibration to dose-to-muscle in pati
does not account for the difference betwee
dose scaling is warranted. We have tabulatec
imate dose-to-muscle or calculate dose-to-
report dose-to-muscle directly from the TPS
the applicable correction required for speci
and should remain attentive to possible cha
2019 American Association of Physicists in
Key words: calibration, medium, muscle, r

6. RECOMMENDATIONS

Based on the above, this group makes the following recommendations pertaining to calculation and reporting of dose in patients.

1. Linear accelerator clinical reference calibration should always be conducted in water and reported as dose-to-water (and not dose-to-tissue), following the current protocols for clinical reference dosimetry (e.g., TG-51).
2. Manual modification from dose-to-water to dose-to-tissue should be done on an algorithm-by-algorithm basis through the TPS reference dose specification (e.g., "Reference dose at calibration depth").
3. A qualified medical physicist should identify the appropriate correction from Table I ("Correction applied to TPS reference compared to calibration in water") and define the TPS reference dose (e.g., "Reference dose at calibration depth") by multiplying this correction factor and the measured dose-in-water.

Dose Agreement Criteria Options

- TG-219:
  - Plan acceptability should be based on the composite plan.
  - Single beam agreement should be used to help further the understanding of the plan quality
- Analysis options:
  - DVH based comparisons
    - Organ specific dose limits & constraints
    - Organ specific comparison to value(s) from TPS
  - Gamma analysis

Comparison criteria: organ specific dose limits & constraints

- Advantages:
  - Adds an automated layer into the check
  - Ability to verify important dose constraints on a 2nd algorithm
- Disadvantages:
  - Lots to configure upfront
  - Challenging for situations where a single criteria per organ is not applicable (multiple physicians with specific constraints, varying treatment regimes, etc.)
  - Ancillary to the focus of the independent dose calculation algorithm (checks appropriateness of organ doses, rather than accuracy of dose calculation)

Comparison criteria: Organ specific comparison to value(s) from TPS

- We use mean PTV dose within ±5%
  - Could also add other constraints for PTV ($D_{95\%}$, $D_{99\%}$, $D_{1\%}$, etc.)
  - Could also add similar OAR constraints
- Advantages:
  - Corollary of traditional 2nd calculation point dose comparison vs. volume dose comparison
  - PTV constraints focused on high dose volume
- Disadvantages:
  - Does not inherently verify whether the organ dose is appropriate

Plan Report Status: Pending

Patient Name: Grey_SIMT1_smallgrid
Patient DOB:
Patient ID: cJGZWggvwFjckL8CcWcy7Lp7b
Institution: Unknown
Last Updated: May 25, 2021

Plan Name: 1SRS_Brain
Prescription: 20 Gy
Fraction(s): 1
Delivery Type: VMAT
Template: Mean Dose Comparison

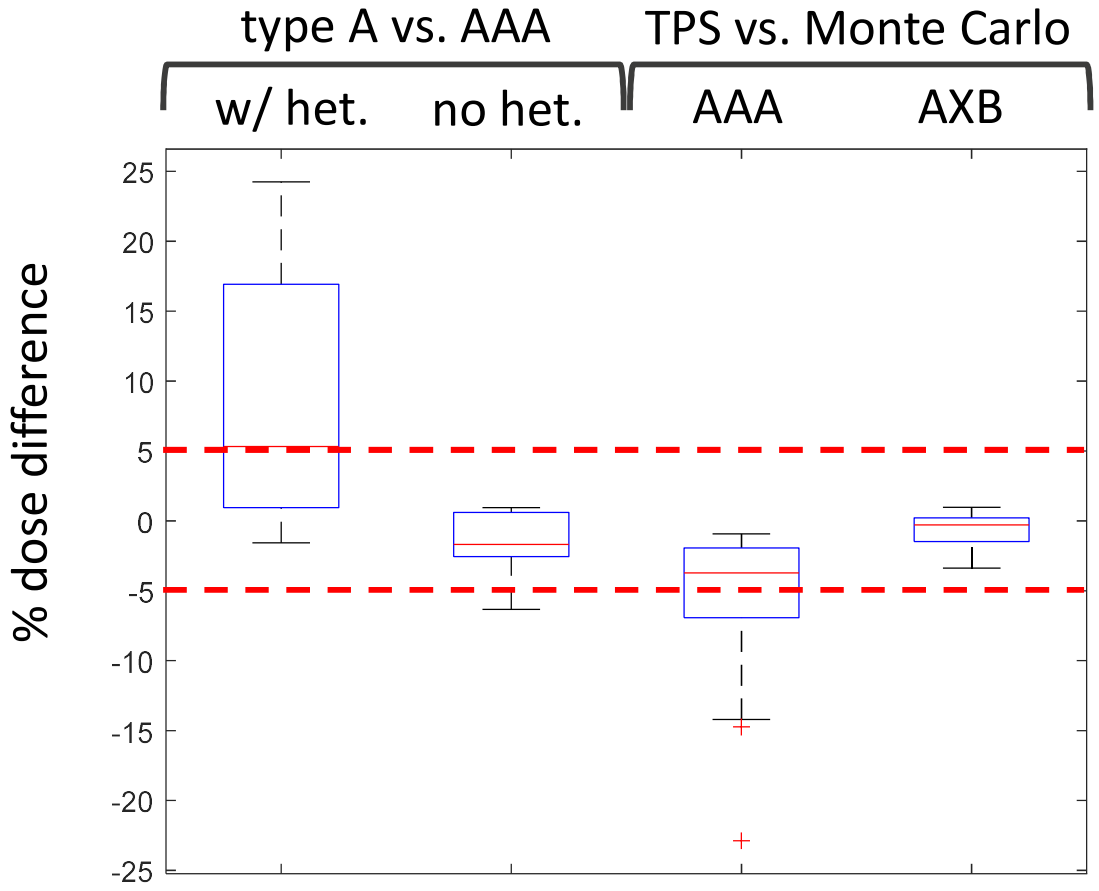
Metric Values

		TPS	SMC	% Difference
ExpLtLatCerMet (PTV_1) 0.34 cc / 95.62 %				
DMean (> 1.00 % Rx)		103.83 % Rx	104.09 % Rx	-0.26 %
ExpLtMedCerMet (PTV_2) 0.42 cc / 96.57 %				
DMean (> 1.00 % Rx)		104.01 % Rx	105.05 % Rx	-1.04 %
ExpRtLatCerMet (PTV_3) 0.22 cc / 97.46 %				
DMean (> 1.00 % Rx)		103.98 % Rx	104.92 % Rx	-0.94 %
ExpRtMedCerMet (PTV_4) 0.43 cc / 99.11 %				
DMean (> 1.00 % Rx)		80.31 % Rx	80.86 % Rx	-0.54 %
ExpRtTempMet (PTV_5) 0.42 cc / 99.35 %				
DMean (> 1.00 % Rx)		95.67 % Rx	95.58 % Rx	0.09 %

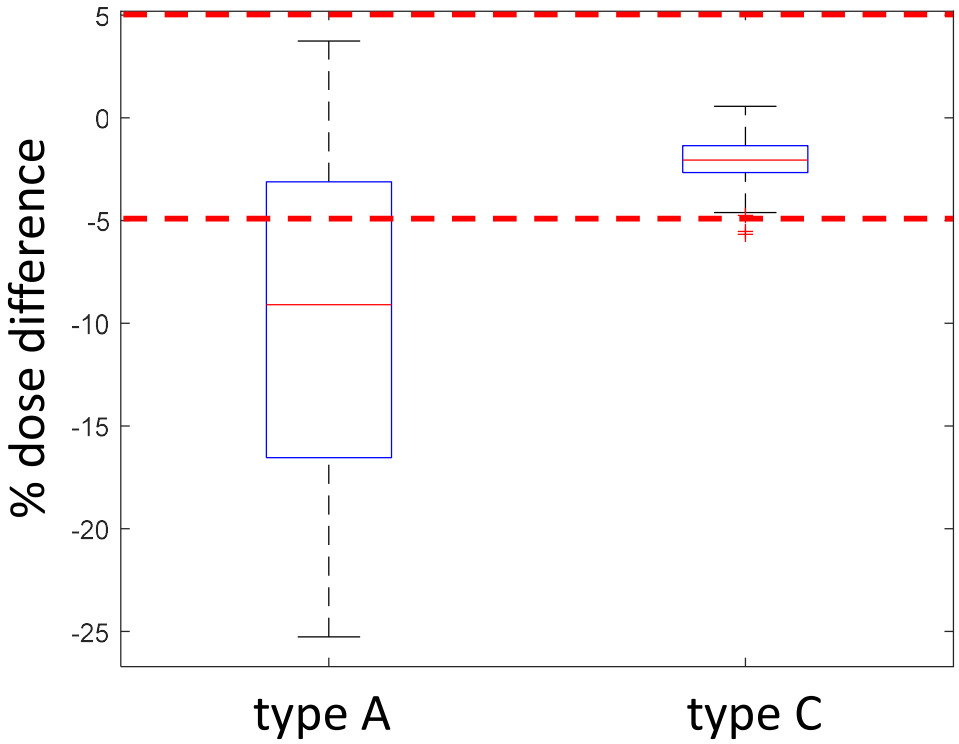
Comparison Criteria: 3D Gamma Index

- We use 3% / 1mm, global, 15% threshold
  85-90% action level
- Advantages:
  - Analysis is comprehensive (uses full dose matrix)
- Disadvantages:
  - Does not account for spatial clinical relevance (PTVs / OAR)
  - Can mask errors when improper comparative measures are used, or if the volume of dose discrepancy is small

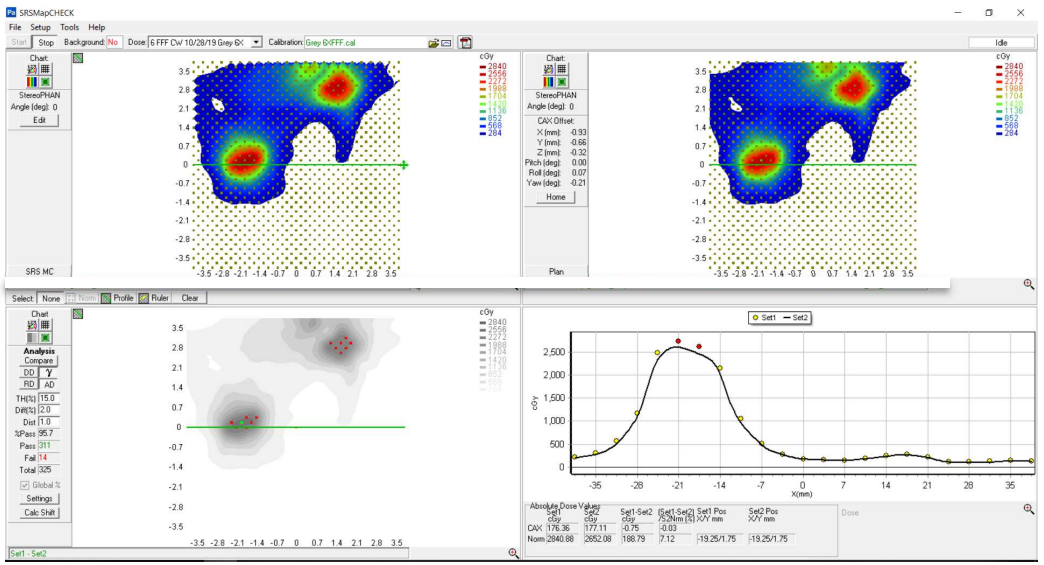
Independent Calc. for Lung SBRT



Independent Calc for Multi-Target SRS



- Pre-treatment QA: Difficult / tedious to verify all PTVs
- Independent Monte Carlo calc is comprehensive & thus serves as an excellent complement to pre-treatment QA



Thank you!

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