An automated Monte Carlo QA system for volumetric modulated arc therapy: possibilities and challenges

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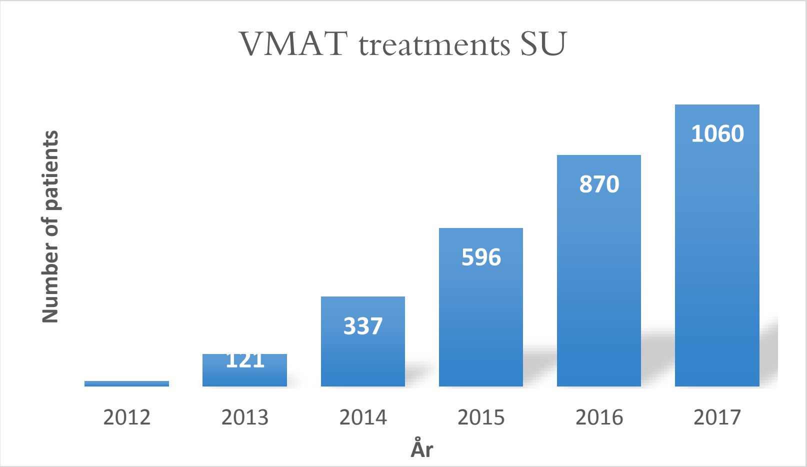
Background

- *Increased clinical use of volumetric modulated arc therapy*

- *Need for comprehensive Quality Assurance procedures*



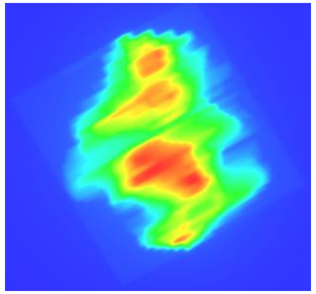
~~Field concept~~
~~MU verification~~
~~In-vivo diod measurements~~

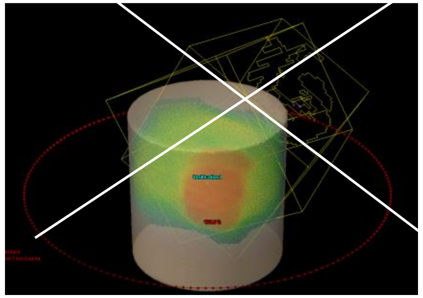
No longer valid

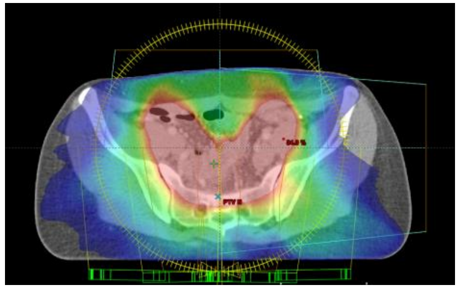
New pre-treatment aspects

- Can accelerator deliver the plan (Machine QA)

- Is the TPS calculated dose distribution correct







Monte Carlo dose distribution in patient geometry

From MC simulations to MC QA system

From research tool to routine clinical tool

Both

✓Basis: 4D Monte Carlo simulations

Dose distributions due continuously-variable beam configurations

EGSnrc software with DOSXYZnrc modifications [Popescu and Lobo]

✓Validated accelerator head model; patient tissue segmentation model

MC QA

- Automated work-flow
- From dose comparison to decision oriented evaluation
- Other aspects, e.g. storage of the results

Objectives

To develop and implement a MC system for patient specific QA of VMAT

- performing calculations in patient geometry
- generating treatment planning system compliant DICOM objects
- including a stand-alone module for 3D analysis of dose deviations based on the normalized dose difference (NDD) method

Method & materials: MC QA system: prerequisites

Accelerator models: Clinac iX, TrueBeam

✓ Validated against measured PDD, lateral profiles, output factors

✓ MLC validation (SYNCVMLC and SYNCHDMLC modules). Determination of:

- *MLC bank offset (physical position of the first MLC leaf pair)*
- *Density (Clinac iX) and thickness (TrueBeam, HDMLC)*
- *Position along beam axis (SCD)*

Patient model: CTC_auto, based on CTC_ask*

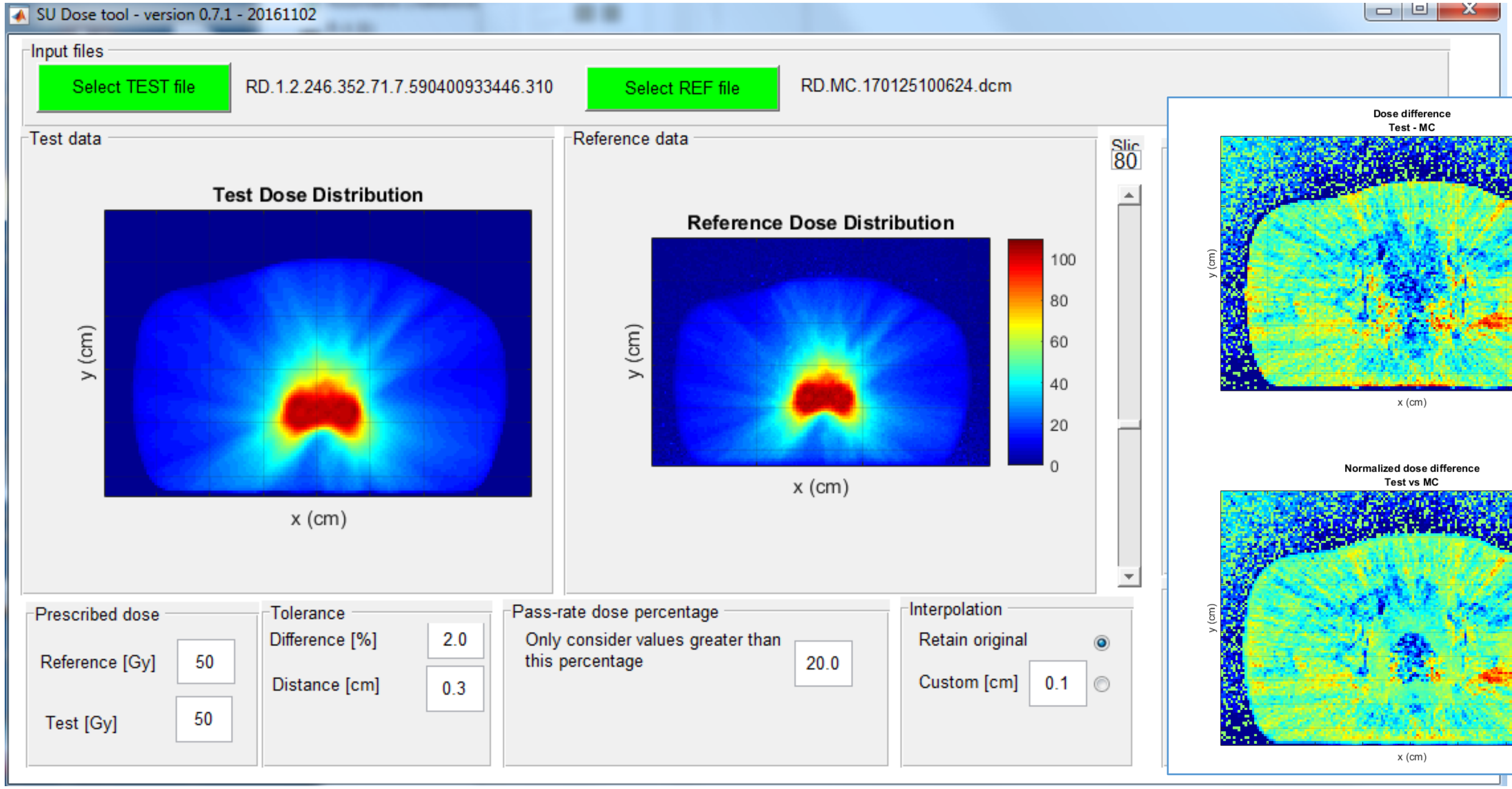
*Ottosson, R O, Behrens C F. Phys Med Biol. 2011; 56 (22): N263–274

- Voxel phantom based on CT data and DICOM RT Struct
- User defined structure specific tissue segmentation
- Treatment couch included if defined as a structure
- Phantom resolution as defined in DICOM RT Dose
- Patient orientation as defined in DICOM RT Plan
- Written in python, automated

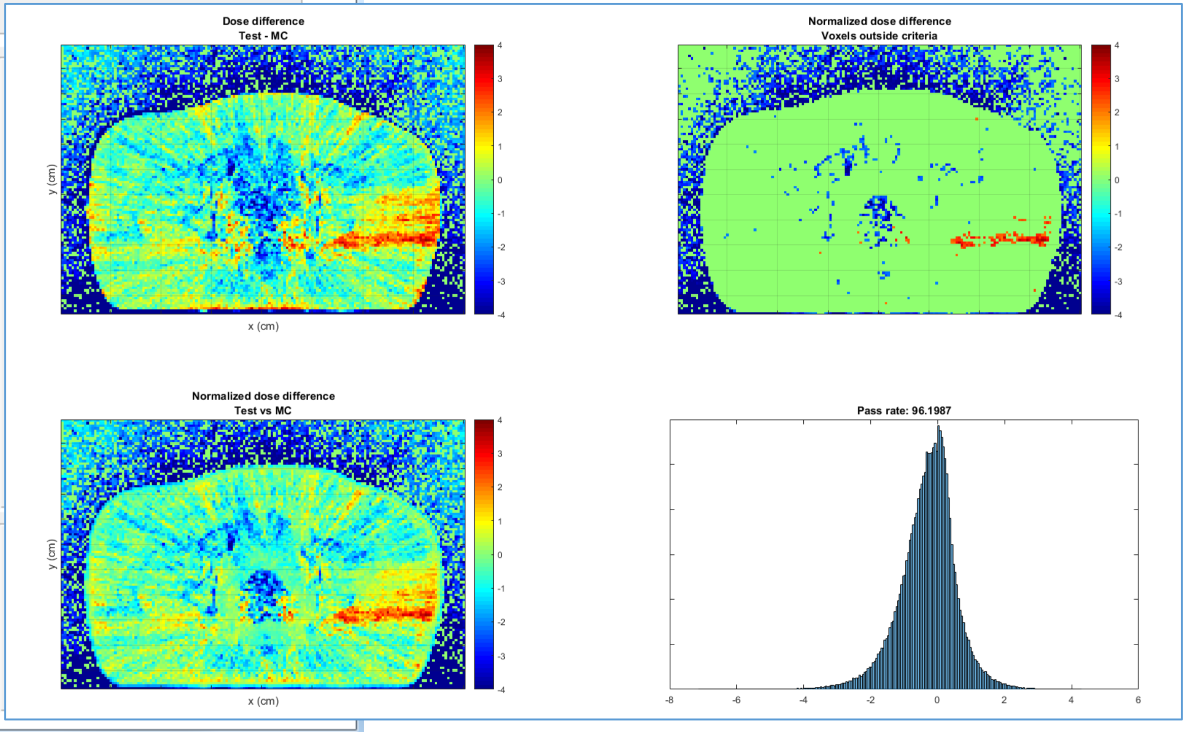
Method & materials: Stand alone analysis module

NDD algorithm for 3D quantitative dose distributions comparison

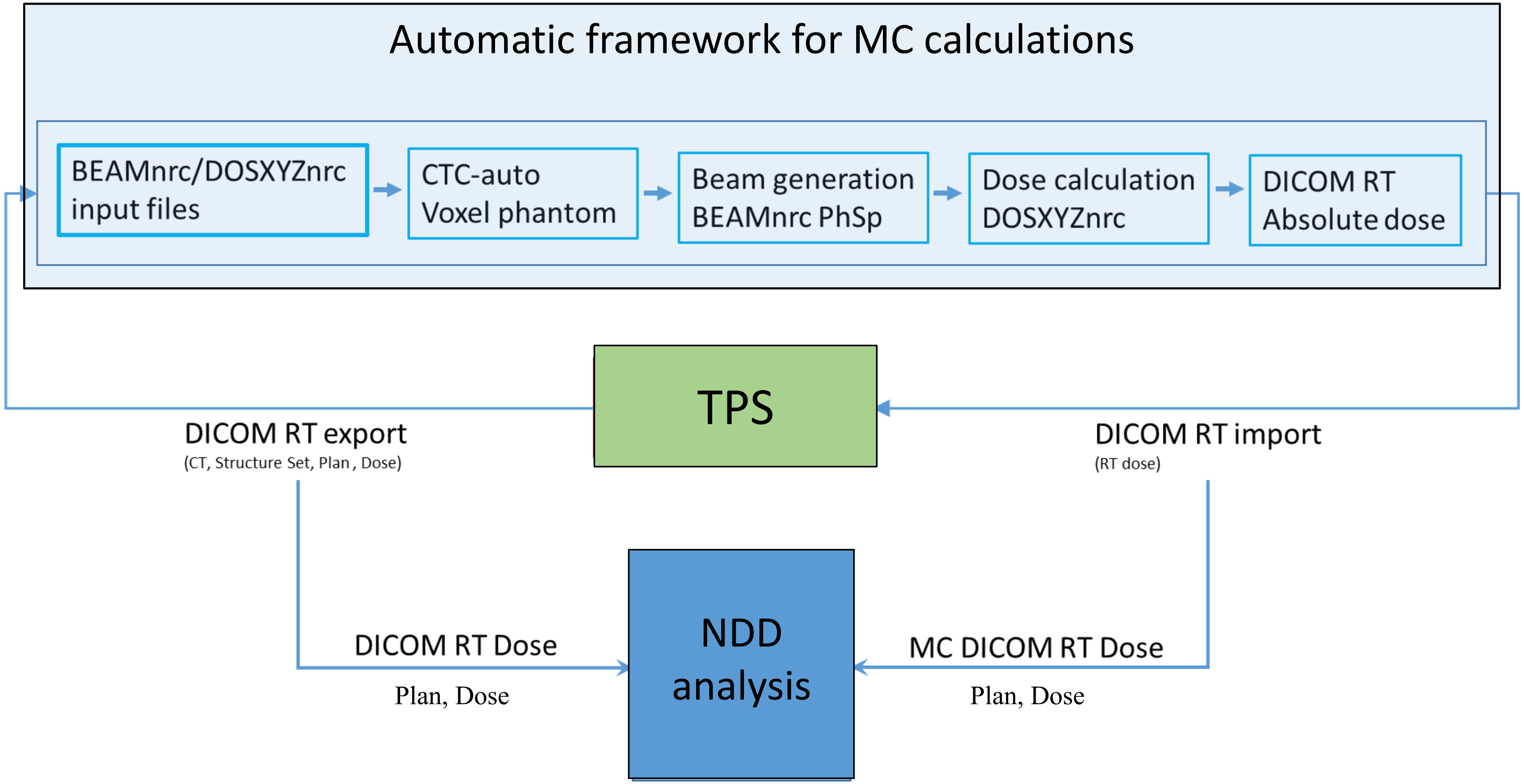
MADD concept of spatially varying normalization factors
[S. B. Jiang, et al. On dose distribution comparison. Phys Med Biol 2006; 51: 759-776]



Pass/fail map



Method & materials: MC QA workflow



An internal network including three high-performance (Haswell i7) computers installed as independent simulation servers along with the Linux based operating system Fedora 21.

Clinical material & dose distribution evaluation

Single target region or simultaneous multiple targets with different levels of prescribed dose

Four cancer sites (170 patient plans):

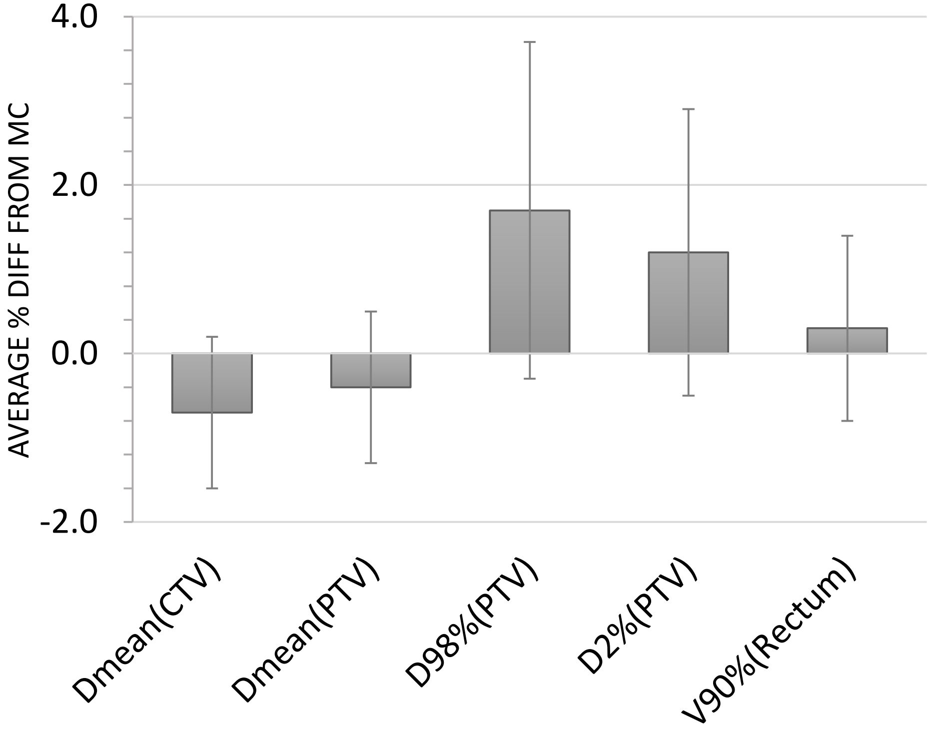
- prostate
- gynaecological
- head and neck (H&N)
- thorax

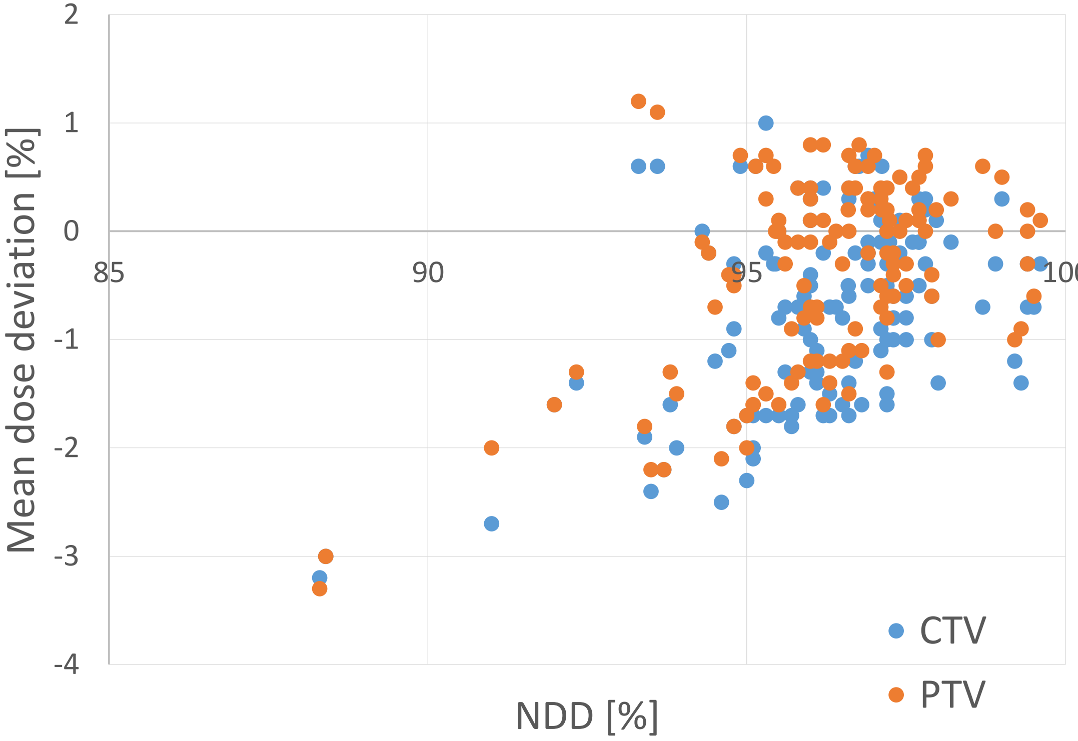
Treatment site specific DVH estimates, e.g. $D_{95\%}$ and $V_{90\%}$

- based on recommended DVH objectives and constrains
- selected on the basis of retrospective calculations of 70 plans

NDD analysis with 3%/3mm and/or 2%/3mm tolerance criteria

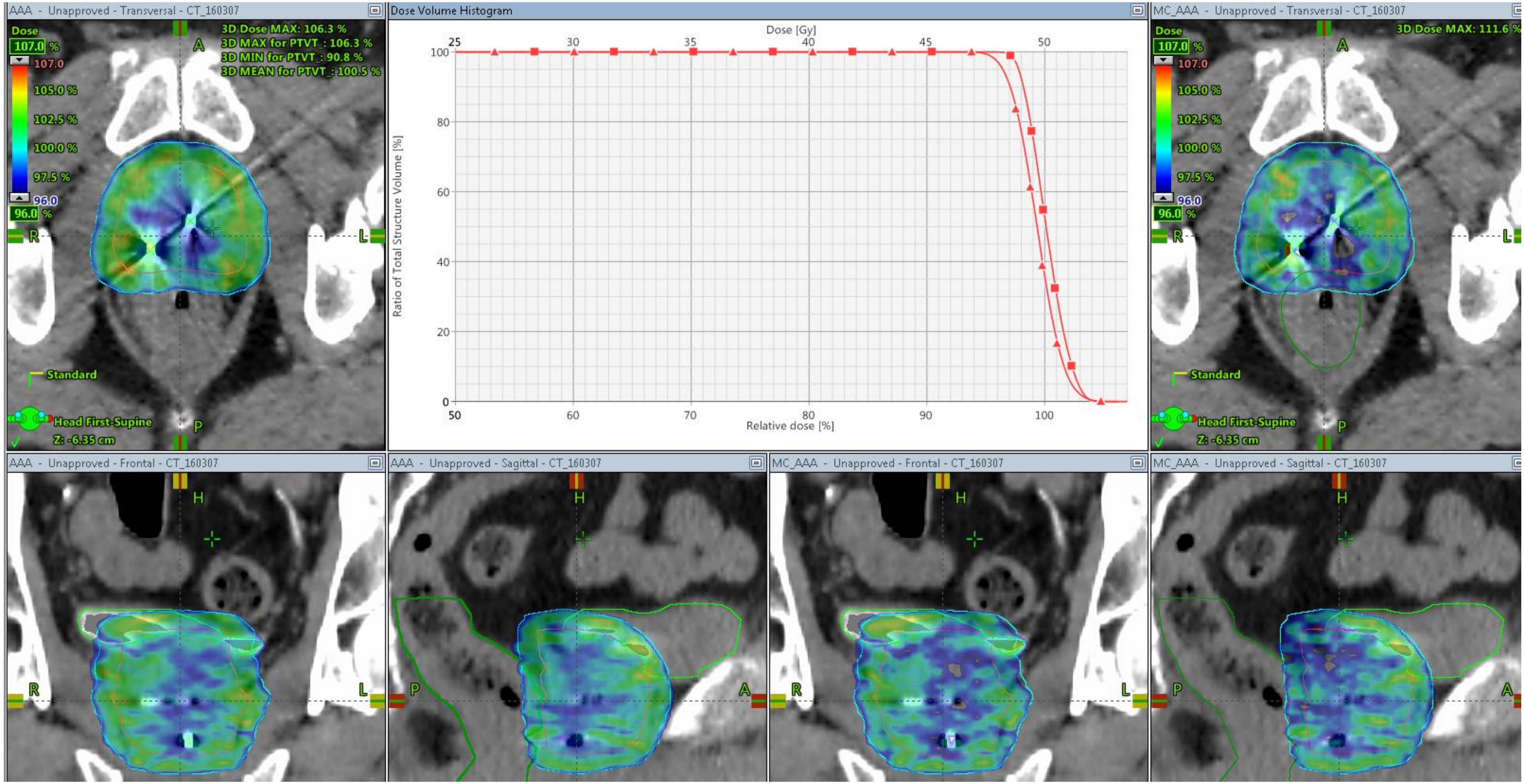
Results: prostate cancer treatment, AAA vs MC



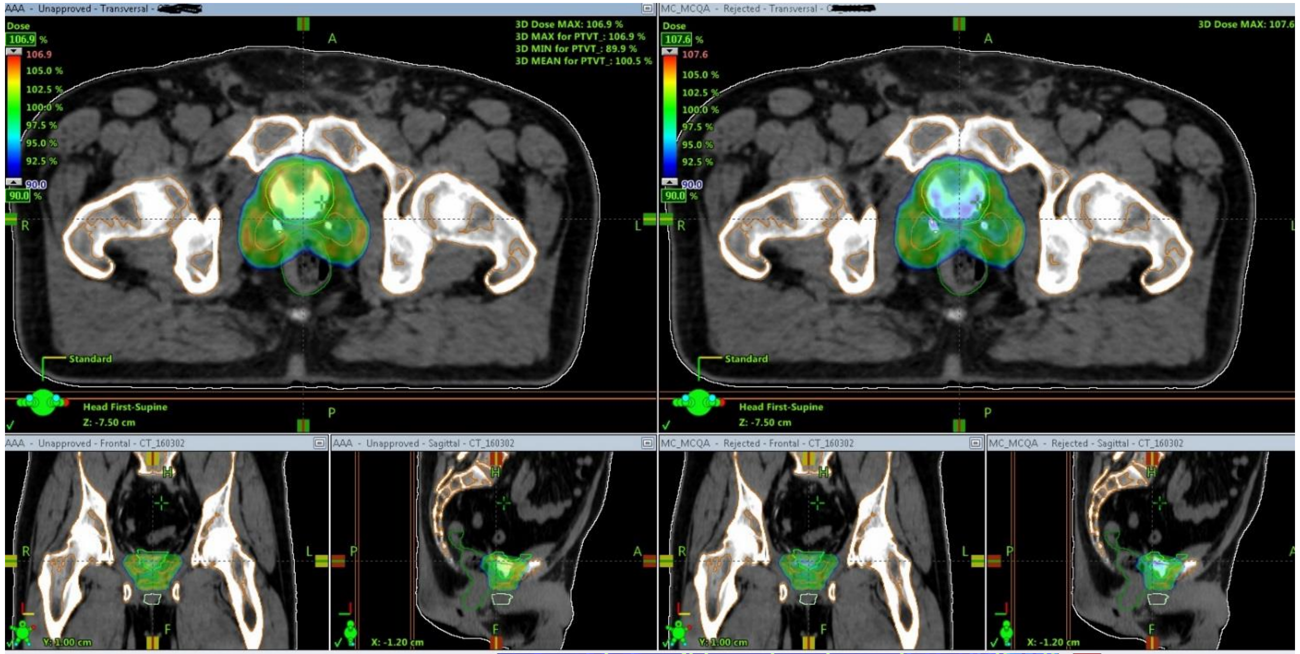


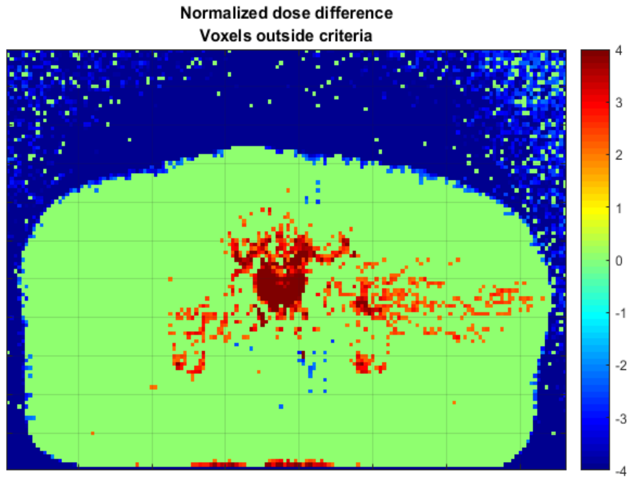
NDD pass rate, 2%/3mm:
Mean value of 96.2 [88.3, 99.6]

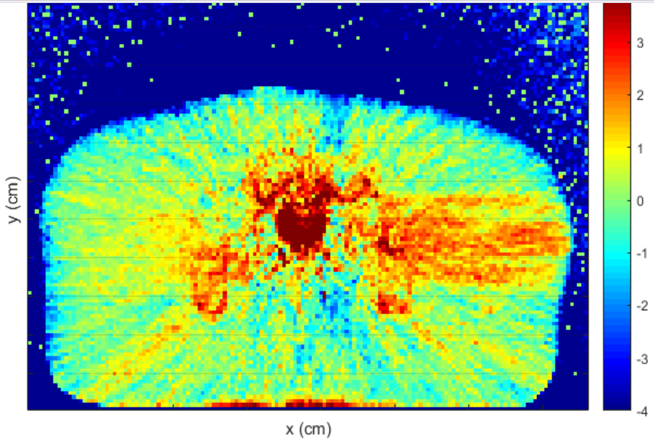
Results: Prostate cancer treatment, CT artifacts cause deviations

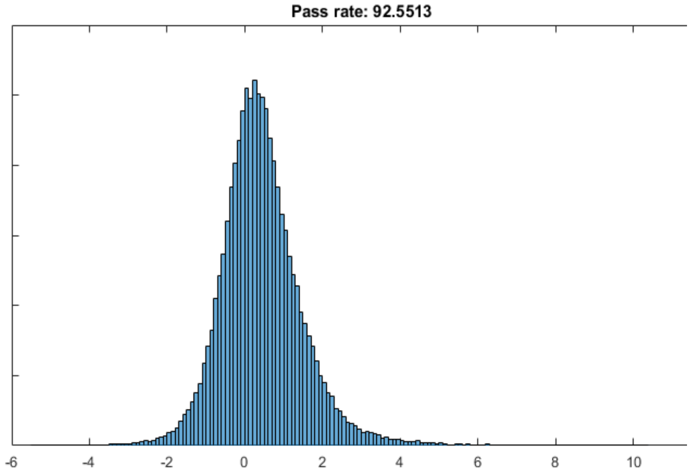


Results: Prostate cancer treatment, contrast in bladder

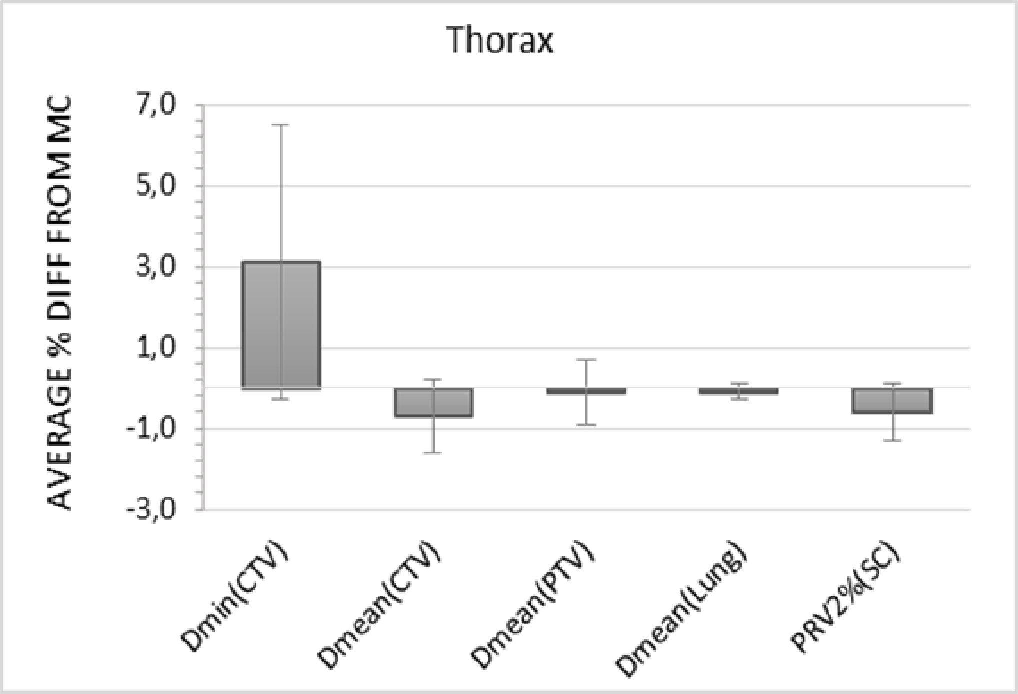


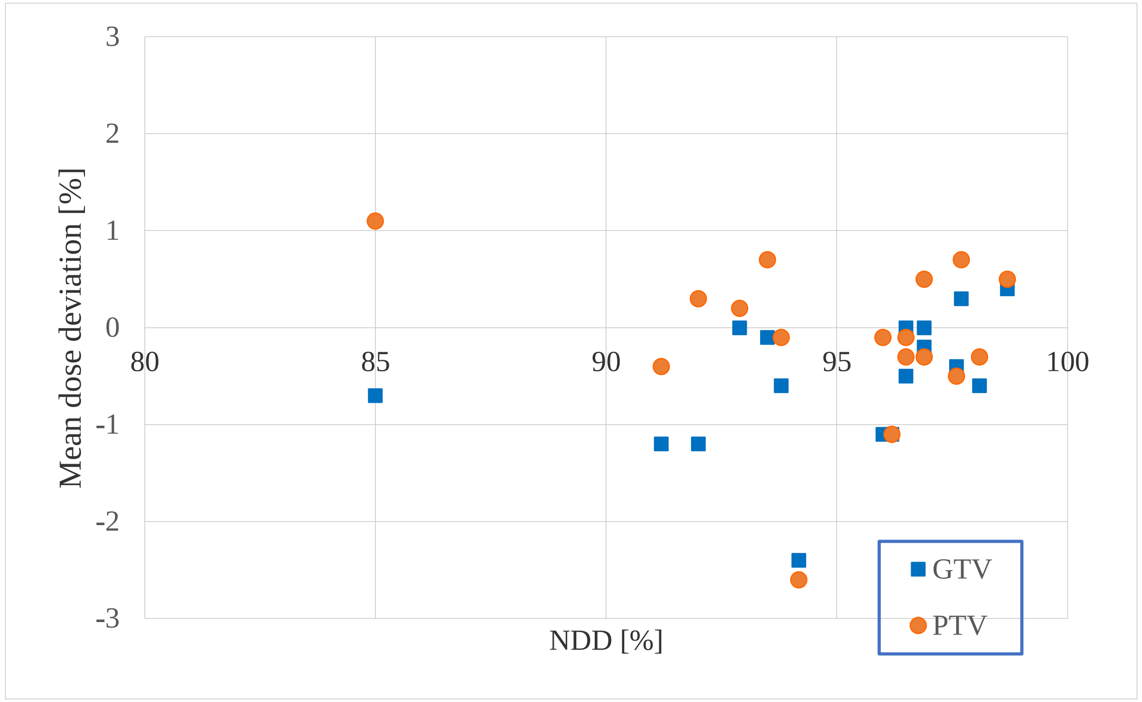






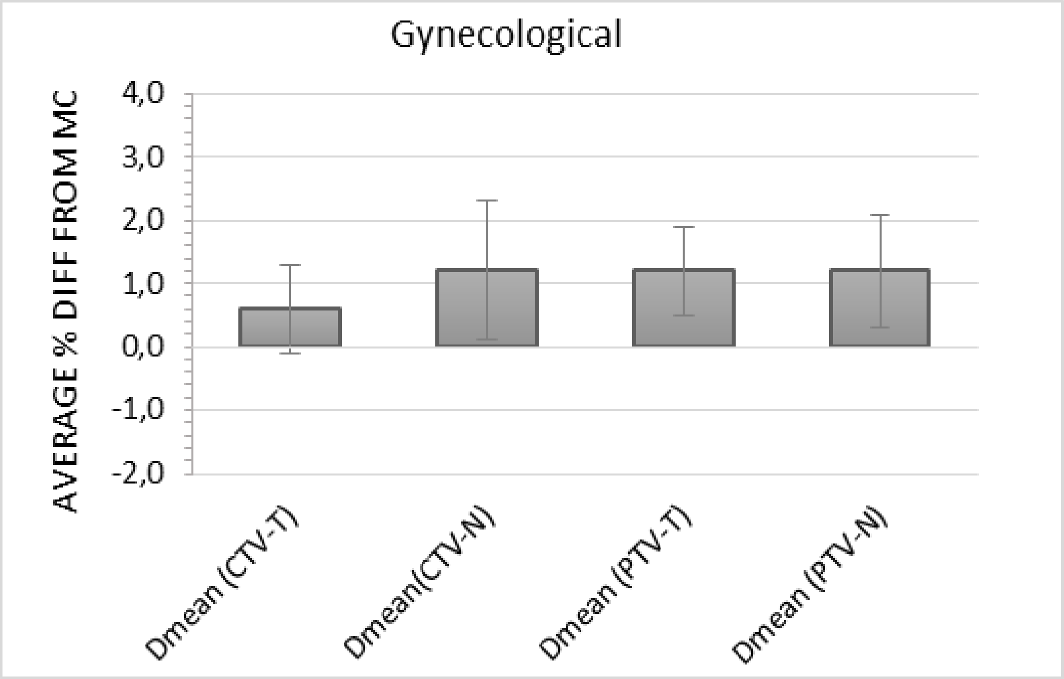
Results: thorax region, AAA vs MC





Average pass rate for 3%/3mm: 95.2%

Results: gynecological and H&N cancer treatment, AAA vs MC

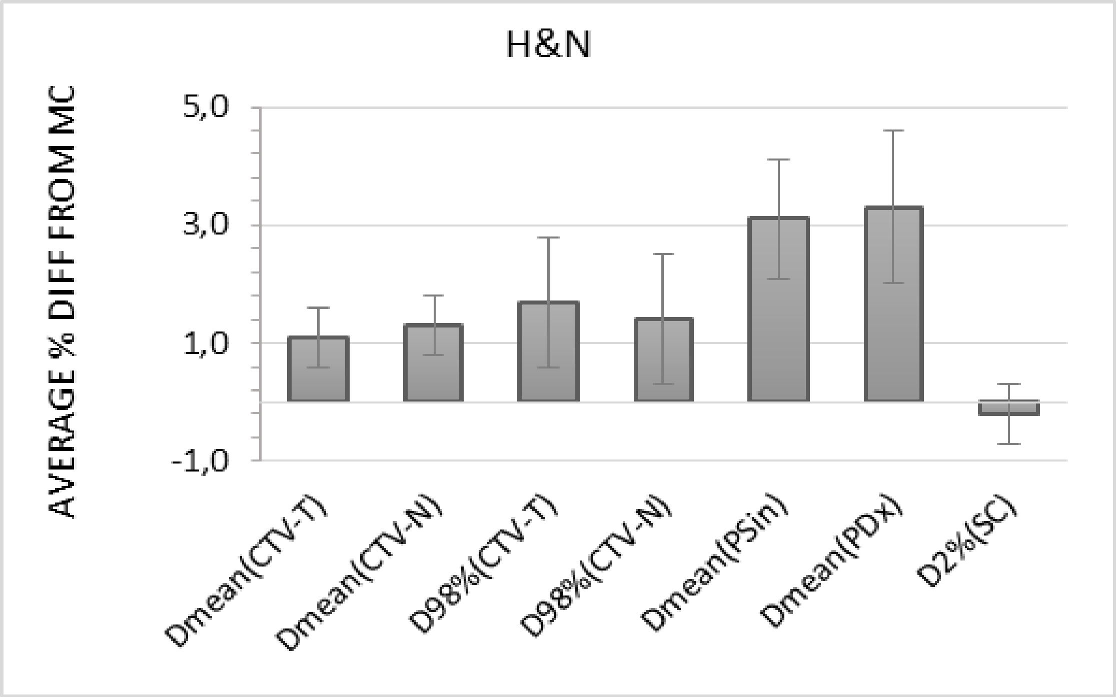


Average pass rate for 3%/3mm: 94.4%

Typical reasons for large deviations:

Prosthesis, operational clips;

HU interpretation in rectum.



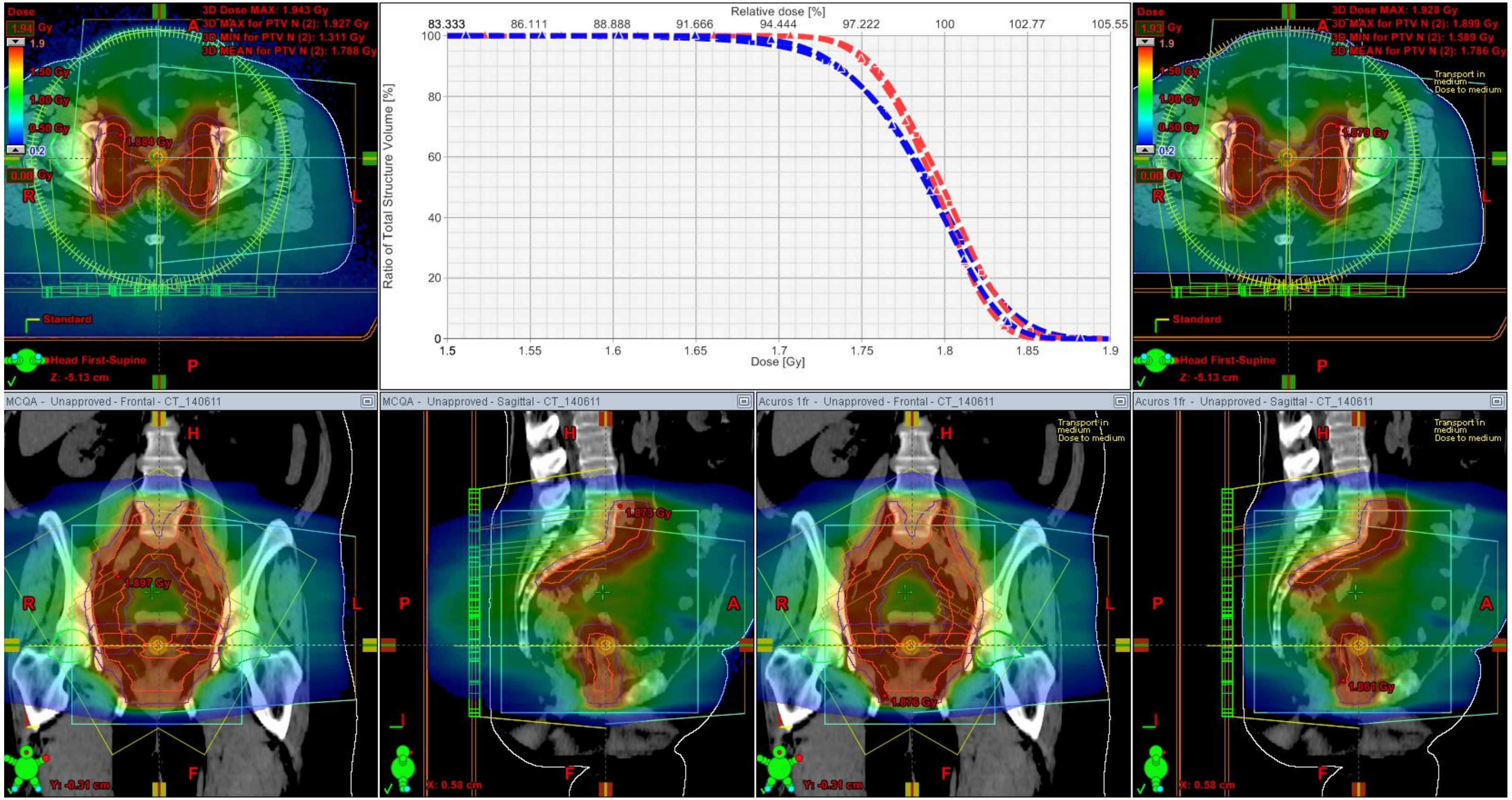
Average pass rate for 3%/3mm: 94.8%

Typical reasons for large deviations:

Air in the volume of interest;

CT artefacts due to HD dental materials.

Results: gynecological treatment: good agreement



Summary

- MC system for patient specific QA of VMAT developed and implemented
- Agreement within 1.5% found between clinical- and MC data for the mean dose to the target volumes
- Agreement within 3% found for parameters more sensitive to the shape of the DVH, e.g. $D_{95\%}$ PTV or minimum dose to CTV
- Tolerance criteria of 2%/3mm recommended for NDD analysis of prostate plans and 3%/3mm for rest of the cases
- Evaluation procedure suggested with NDD analysis as the first step. For pass rate lower than 95% the evaluation to continue with comparison of DVH parameters. For deviations larger than 2%, a visual inspection of the clinical- and MC dose distributions to be performed
- A fully automated evaluation is hindered by artefacts in the CT images, presence of contrast in the bladder, dose to air included in the target volume, interpretation of HU in rectum etc.

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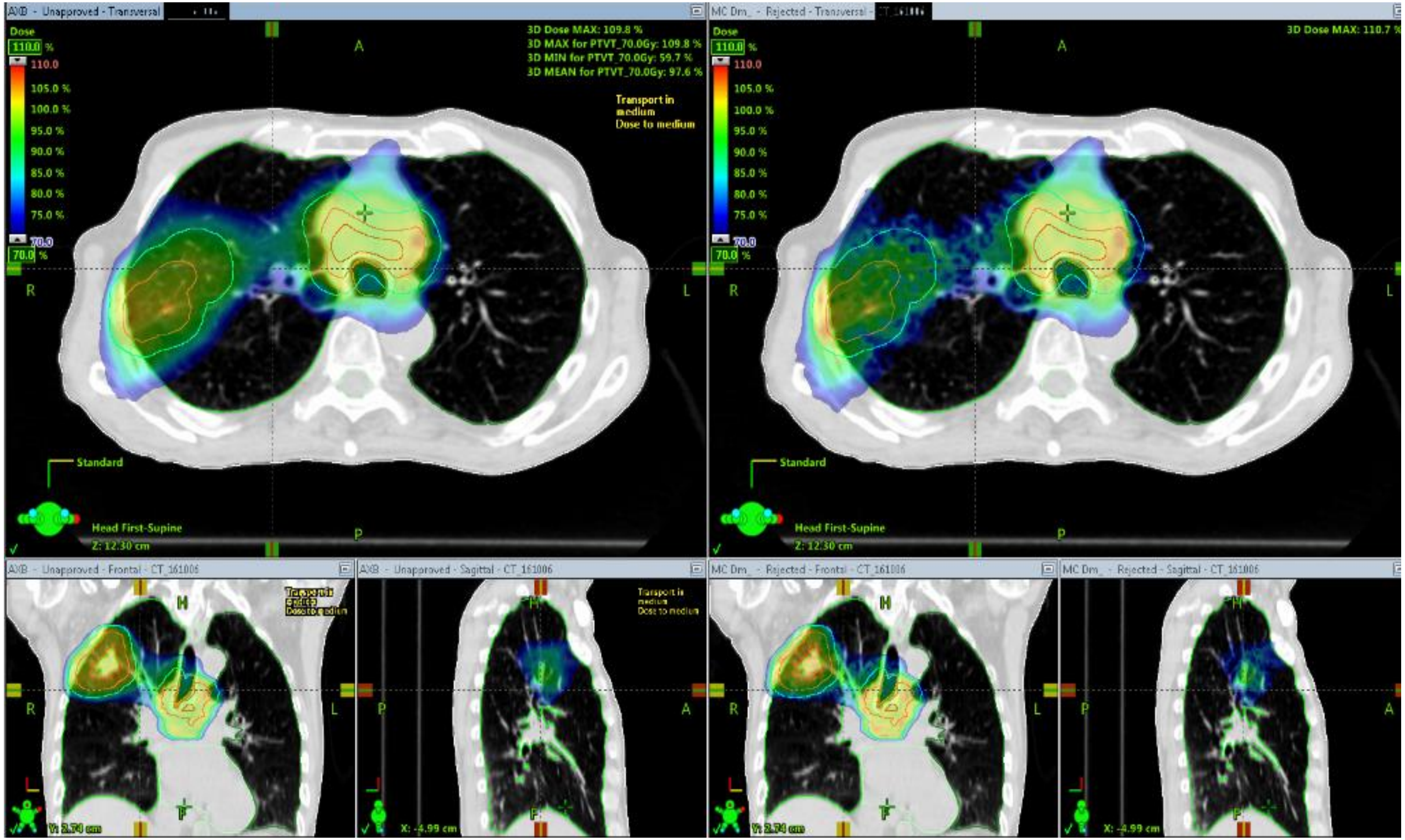
are greatly

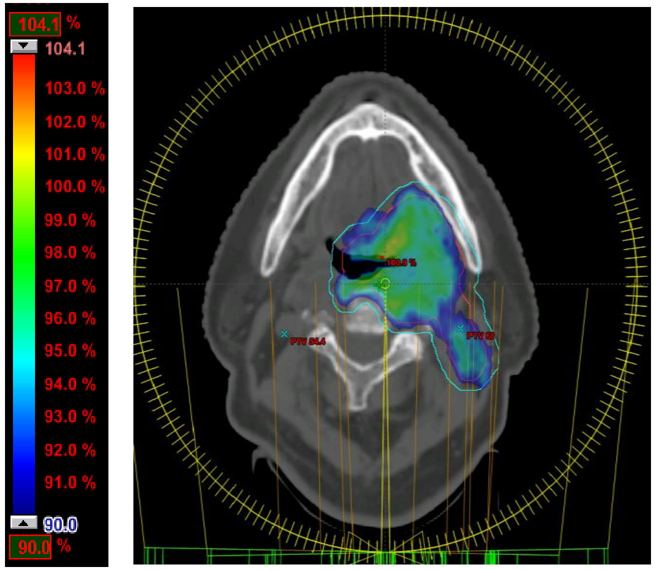
acknowledged

Results: thorax region, a case with NDD pass rate ≤ 85%

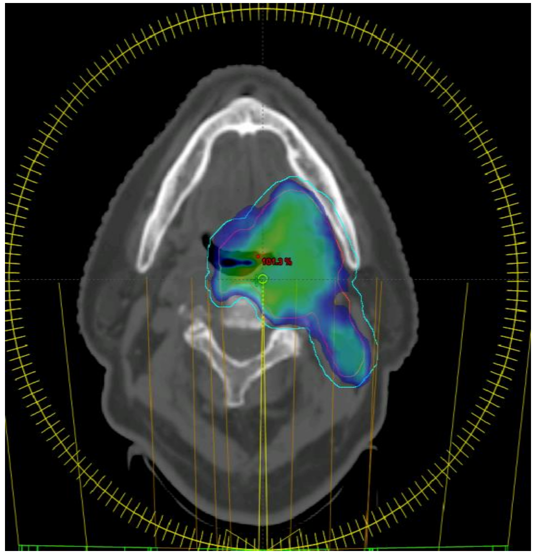
AXB vs MC (dose to medium)



Results: H&N cancer treatment: illustration of dose deviations



MC



AXB
(dose to medium)