Multi-Institutional Development and Validation of Consensus Electron Density Look-up Tables for MR-Only Radiotherapy Planning

2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

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ABSTRACT

Background and purpose:

To develop and validate multi-institutional consensus electron density (ED) look-up tables (LUTs) for MR-only and simulation-omitted radiotherapy planning.

Methods and Materials:

Relative ED (rED) values were extracted from 1,165 paired CT–MR datasets (UT Southwestern: 711; MD Anderson: 454) acquired on Elekta Unity 1.5T MR-Linac systems. Two LUTs were derived: Complex-rED with structure-specific values for 50 structures, and Simple-rED with five tissue classes. Dosimetric validation was performed in 71 patients across central nervous system, head and neck, lung, abdomen, and pelvis sites. Clinical plans were recalculated with each LUT and compared with CT-derived ED references using three-dimensional gamma analysis and dose-volume histogram metrics.

Results:

Inter-institutional rED values agreed closely (mean difference 0% ± 3%, R^2 = 0.98). With Body rED = 1.0, both LUTs achieved pass rates >99% at 3%/2 mm, >98% at 2%/2 mm, and >90% at 1%/1 mm for most structures, with no significant Complex-rED versus Simple-rED differences. All planning target volume mean-dose differences were within 0.75%. Complex-rED kept most organ-at-risk (OAR) mean-dose differences within 0.6%, and maximum dose metrics (D0.03cc, D0.5cc) were nonsignificant for the majority of OARs under both approaches. Although Simple-rED produced larger gastrointestinal deviations, exemplified by large-bowel Dmean (-1.37% ± 0.81%; -0.051 ± 0.041 Gy) and small-bowel D0.03cc (-1.59% ± 4.19%; -0.469 ± 1.244 Gy), the corresponding absolute dose differences were small. Complex-rED reduced these deviations to nonsignificant levels.

Conclusions:

Multi-institutional consensus ED LUTs achieve dosimetric accuracy comparable to CT-derived references, supporting broader clinical adoption of MR-only and simulation-omitted radiotherapy workflows.

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INTRODUCTION

Clinical gap addressed by the study

- CT-free workflows lack patient-specific CT-derived electron density for dose calculation.
- Synthetic CT/deformable mapping can be accurate, but require substantial infrastructure, commissioning, and QA.
- Bulk-density override is transparent and deployable, yet rED tables remain institution-specific.
- A consensus LUT could standardize MR-only and simulation-omitted planning across centers.

Design principle

Use real-world multi-institutional MR-Linac data to create practical, fixed rED assignments rather than relying on local ED database development.

METHODS AND MATERIALS

1. **Derivation cohort**
   1,165 paired CT-MR datasets: UTSW 711 | MD Anderson 454
2. **Consensus LUT development**
   Complex-rED: 50 structures | Simple-rED: 5 tissue classes
3. **Independent dosimetric validation**
   71 patients across CNS, H&N, lung, abdomen, pelvis
4. **Plan recalculation and comparison with CTED**
   3D gamma analysis + DVH metrics

Statistics: paired Wilcoxon signed-rank test; significance threshold $p < 0.05$.

CONSENSUS LUTS AND VALIDATION COHORT

Simple-rED LUT

Tissue class	rED
Air cavity	0.23
Lung	0.36
Soft tissue	1.01
Soft bone	1.19
Hard bone	1.47

Complex-rED examples

Structure	rED
Airway	0.18
Lung	0.35
Larynx	0.82
Liver	1.05
Mandible	1.40
Cochlea	1.52

Validation Cohort

Site	n
Total	71
CNS	9
H&N	8
Lung*	10
Abdomen	22
Pelvis	22

The full Complex-rED LUT contains 50 structure-specific assignments.
Lung values were derived from free-breathing MR-Linac workflows.

Core validation question

Can fixed multi-institutional rED LUTs reproduce CT-derived dose calculations across sites?

RESULT 1: INTER-INSTITUTIONAL ED AGREEMENT

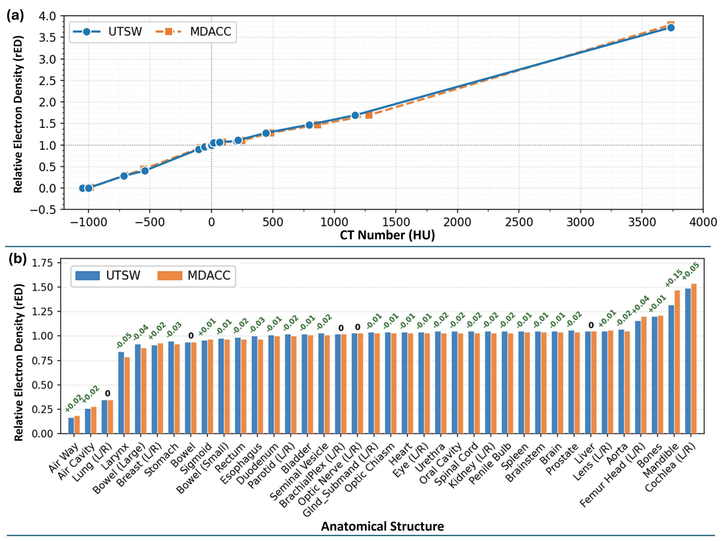

Figure 1. Inter-institutional comparison of electron density between UTSW and MD Anderson. (a) CT number–to–relative electron density (rED) calibration curves (UTSW, solid blue; MDACC, dashed orange). (b) Structure-specific mean rED per institution, sorted by ascending rED; labels above each pair give the difference (MDACC − UTSW). rED is relative to water.

Mean rED difference	Correlation	Mean absolute difference
0% ± 3%	R^2 = 0.98	0.022 ± 0.025

RESULT 2: STRUCTURE-SPECIFIC GAMMA PASS RATES

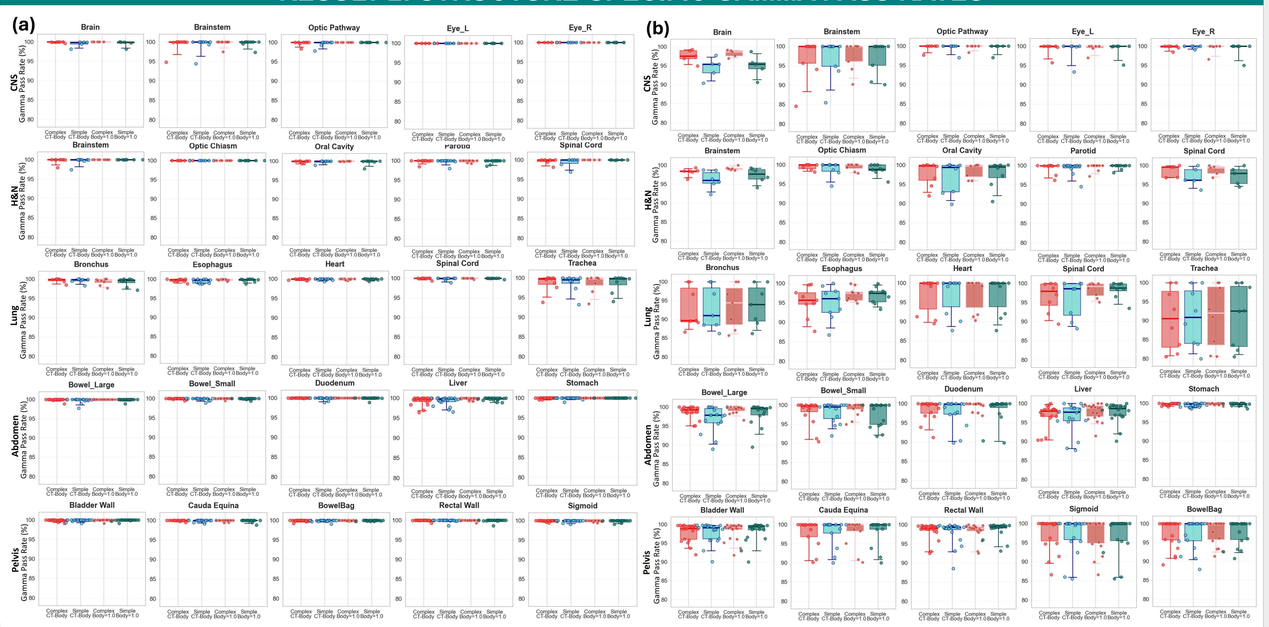

Figure 2. Structure-specific gamma pass rates for the Complex-rED and Simple-rED look-up tables. Three-dimensional gamma pass rates (γ ≤ 1) for organs at risk by site. (a) 2%/2 mm; (b) 1%/1 mm. Boxes (left to right): Complex/CT-Body, Simple/CT-Body, Complex/Body = 1.0, Simple/Body = 1.0. CT-Body, CT-derived Body rED; Body = 1.0, water-equivalent Body.

Most structures
>99% at 3%/2 mm
>98% at 2%/2 mm

Complex vs Simple
No significant gamma pass-rate differences

Body rED = 1.0
Higher pass rates and lower variability at 1%/1 mm

WHOLE-BODY GAMMA HIGHLIGHTS

Representative 1%/1 mm results showing the effect of Body rED assignment

Site	CT-derived Body Complex-rED	Body=1.0 Complex-rED	Change
Liver	88.75 ± 7.14	95.21 ± 4.44	+6.46
H&N	93.51 ± 4.43	96.08 ± 2.09	+2.57
Prostate	97.77 ± 1.67	98.62 ± 0.48	+0.85

Across all sites, Body rED = 1.0 produced equal or higher whole-body gamma pass rates and reduced inter-patient variability under stringent criteria.

Values are mean ± SD (%). CT-derived Body = density from CT HU conversion; Body=1.0 = water-equivalent Body.

DVH AGREEMENT

PTV dose metrics within 1% of CTED

- All PTV mean-dose differences within 0.75%.
- Complex-rED kept most OAR mean-dose differences within 0.6%.
- Maximum-dose metrics were non-significant for most OARs.

GI structures
Simple-rED showed larger bowel deviations, but absolute dose shifts were small; Complex-rED reduced bowel shifts to within 0.051 Gy.

CLINICAL INTERPRETATION

When the consensus LUTs are most useful

- Rapid implementation of MR-only workflows.
- Simulation-omitted workflows when CT simulation may be avoided.
- Multi-institutional harmonization of ED assignment.

When patient-specific CT remains valuable

- Atypical lung density or breath-hold workflows.
- Large gas pockets or variable hollow-organ contents.
- Metallic implants or high-density foreign material.

DISCUSSION

- Consensus rED values from >1,100 clinical MR-Linac plans align more closely with patient-specific approaches than generic reference values while preserving fixed-table standardization.
- Forcing Body rED = 1.0 is practical and robust because most non-delineated body tissue is close to water-equivalent density.
- Simple-rED supports rapid deployment; Complex-rED is preferable when higher fidelity is needed, especially in heterogeneous abdominal/GI regions.

Implementation note: these LUTs provide a practical starting point, but local clinical validation remains necessary before routine use.

CONCLUSION / KEY TAKEAWAY

✓ **First multi-institutional consensus ED LUTs derived from 1,165 MR-Linac patients.**

Complex-rED and Simple-rED achieved CT-comparable dose calculation across five anatomical sites, supporting broader adoption of MR-only and simulation-omitted radiotherapy workflows.

Bottom line: transparent, practical, and immediately deployable after local validation.