Eliminating the Need for CT Scans In Abdominal MR-Linac Treatments: Organ-Specific Electron Density Characterization

E. H. Hayes, L. J. Maloney
Department of Radiation Oncology, University of Florida, Gainesville, Florida

INTRODUCTION

Adaptive radiotherapy (ART) accounts for day-to-day anatomical changes, enabling treatment plans to be modified to reflect anatomy at the time of treatment.

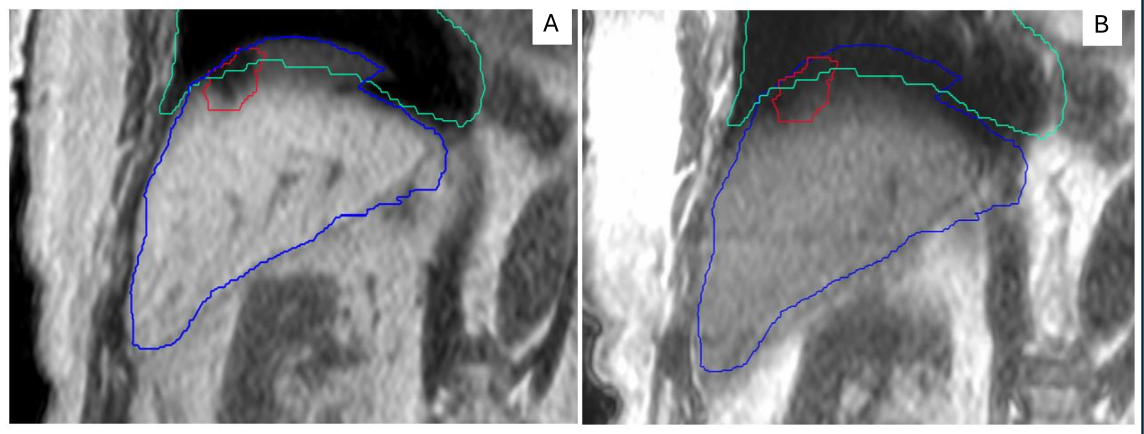

Figure 1 (a-b): Sagittal MR images acquired on consecutive treatment days demonstrating inter-fraction anatomical variation in the liver (orange) and associated GTV (red).

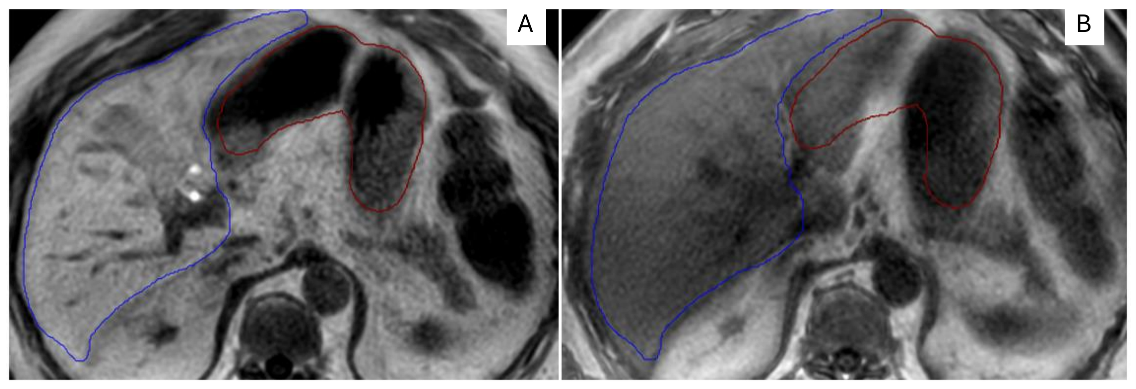

Figure 2 (a-b): Axial MR images acquired on consecutive treatment days demonstrating inter-fraction anatomical variation in the stomach (red) relative to the liver (blue).

MR-guided radiotherapy requires CT-derived electron density (ED) for dose calculation, limiting true MR-only workflows. This study develops an organ-specific ED atlas and evaluates whether atlas-derived ED values can replace patient-specific CT values while maintaining dosimetric accuracy.

AIM

Determine whether atlas-derived electron density values can replace patient-specific CT-derived electron density values for MR-guided treatment planning.

METHODOLOGY

Patient Cohort and Electron Density Atlas Development

- Retrospective analysis of 100 abdominal and thoracic cancer patients aged 41 - 98 treated on an MR-Linac.
- ED data were extracted from CT simulation scans for 13 contoured anatomical structures: external body contour esophagus, heart, lungs, liver, spinal canal, stomach, kidneys, large bowel, small bowel, and duodenum.
- Organ-specific median ED values were calculated and stratified by patient sex and age to generate a tabulated ED atlas.

Dosimetric Evaluation

- Five liver SBRT treatment plans were recalculated using atlas-derived ED values.
- Recalculated and original CT-based plans were compared using DVH metrics.
- Percent dose differences were quantified for planned target volumes (PTVs) and organs at risk (OARs).

RESULTS

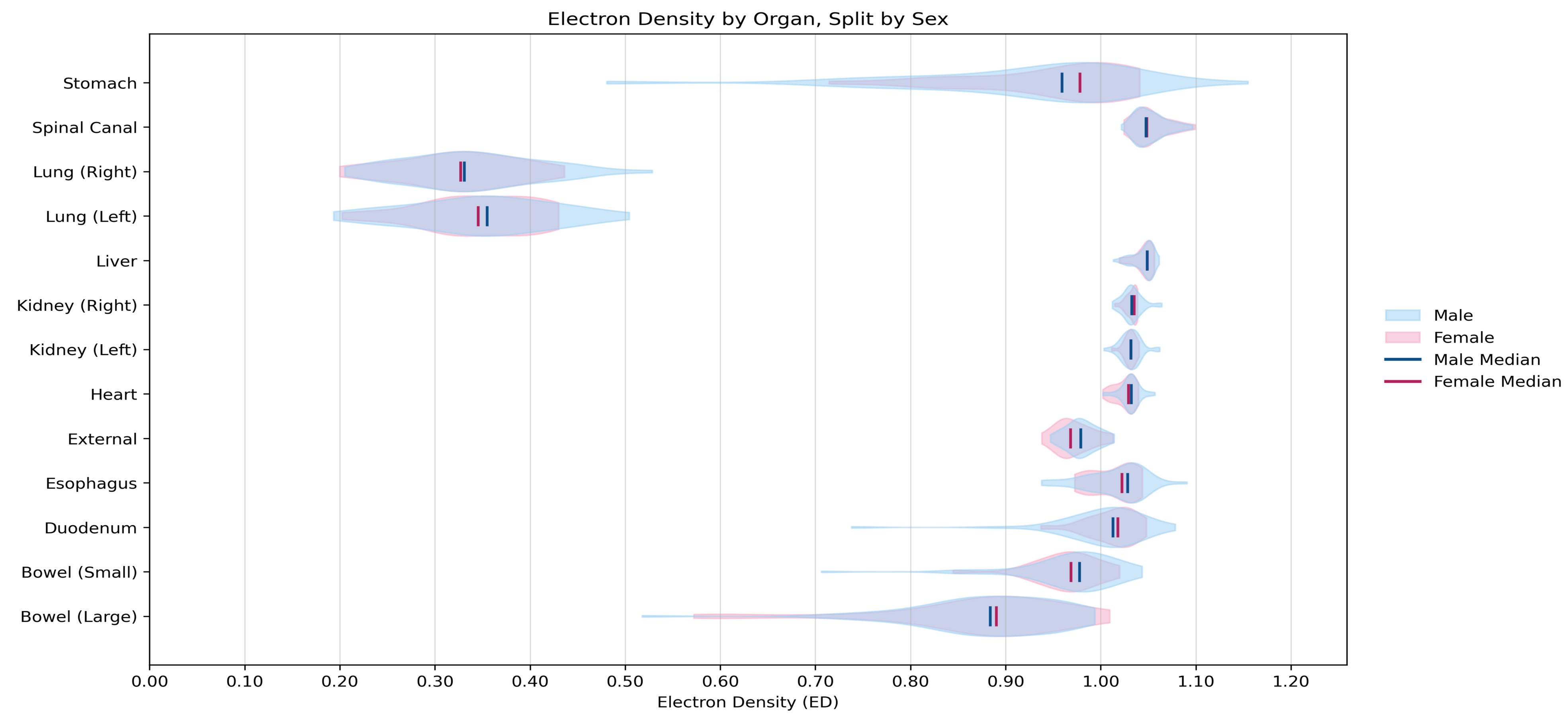

Figure 3: Relative electron density distributions for individual organs as measured on CT simulation scans, for a sample of 100 patients, split by sex.

Relative electron density distributions demonstrated substantial overlap between male and female patients for nearly all abdominal organs, indicating that organ electron density is largely independent of sex. The gastrointestinal organs (stomach, small bowel, and large bowel) exhibited the greatest variability, consistent with differences in luminal gas content between patients. Treatment plans recalculated using atlas-derived median electron density values closely matched those generated using patient-specific CT-derived values. Across all evaluated plans, the mean percent dose differences were **0.59% for PTVs** and **0.60% for OARs**. The observed ranges were **0.35–1.33%** for PTVs and **0.00–2.06%** for OARs, with the largest average organ-specific difference occurring in the heart (**0.94%**) and the smallest in the right kidney (**0.31%**). These findings demonstrate that atlas-derived electron density values produce clinically comparable dose calculations while eliminating the need for patient-specific CT electron density assignment.

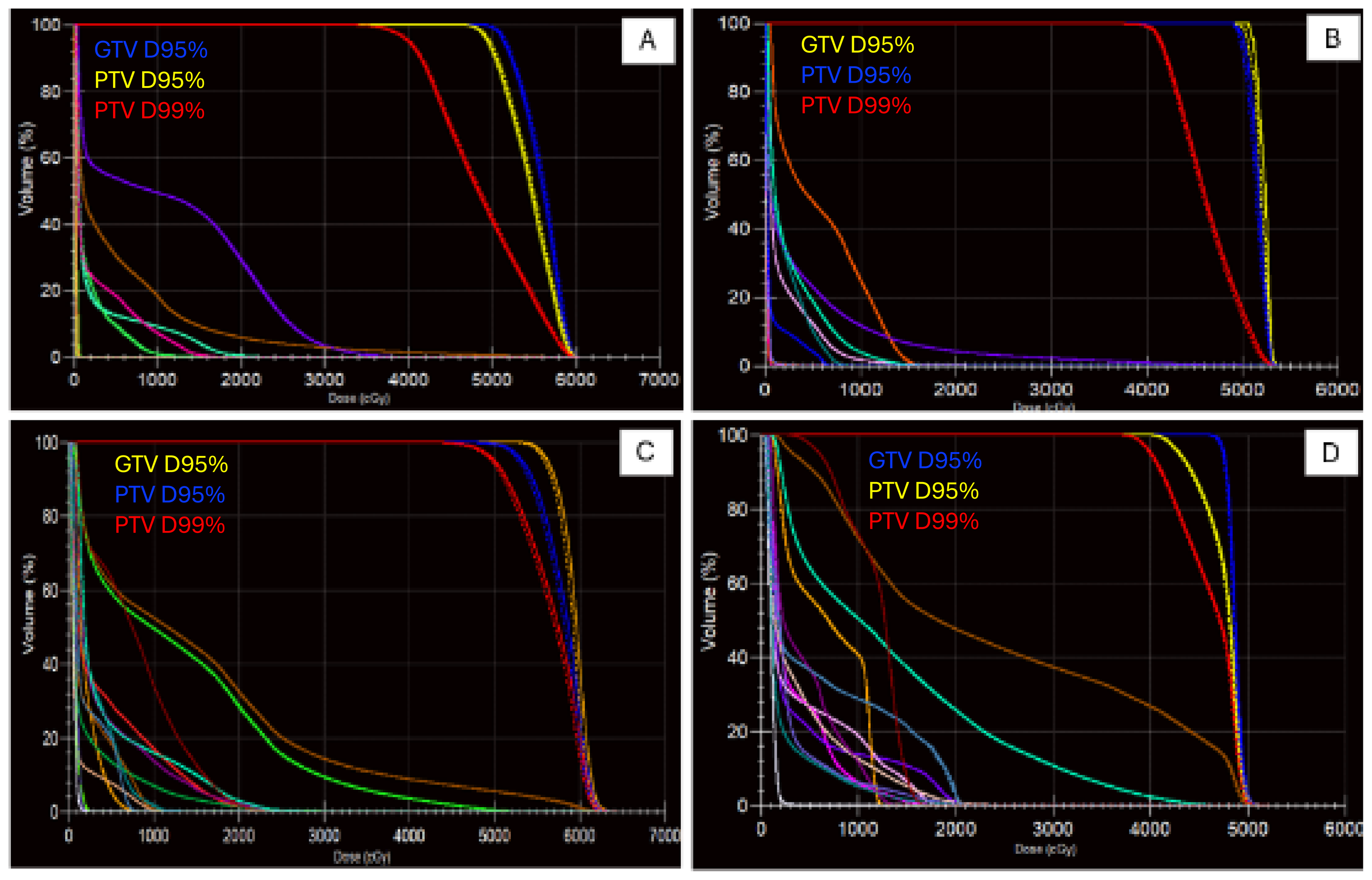

Figure 4 (a-d): Total Volume DVH comparisons of four liver lesion SBRT treatment plans using CT derived (solid) and tabulated (dashed) ED values. A) 57 y/o female 50 Gy / 5 fxns; B) 58 y/o male 40 Gy / 5 fxns; C) 71 y/o female 50 Gy / 5 fxns; D) 75 y/o male 20 Gy / 5 fxns.

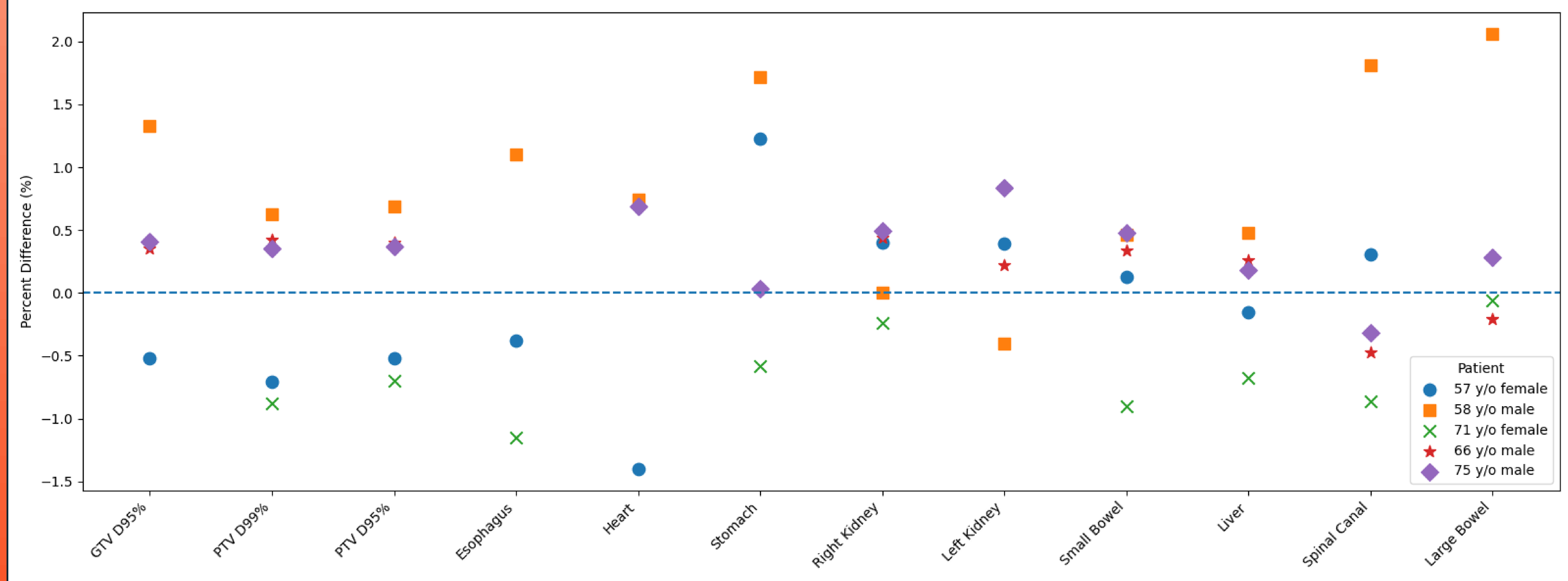

Figure 5: Percent differences of doses for GTV, PTV and organs at risk, comparing DVH statistics generated from CT simulation ED values and tabulated median ED values.

CONCLUSIONS

- Organ-specific electron density distributions demonstrated minimal variation between male and female patients for most abdominal organs.
- Atlas-derived median electron density values produced dose calculations that closely agreed with patient-specific CT-based calculations, with all evaluated dose differences remaining within **2.1%**.
- These results support the feasibility of using a population-based electron density atlas for MR-only treatment planning. These findings have potential to reduce CT simulation time and expenditure, imaging dose, and clinical workflow complexity.

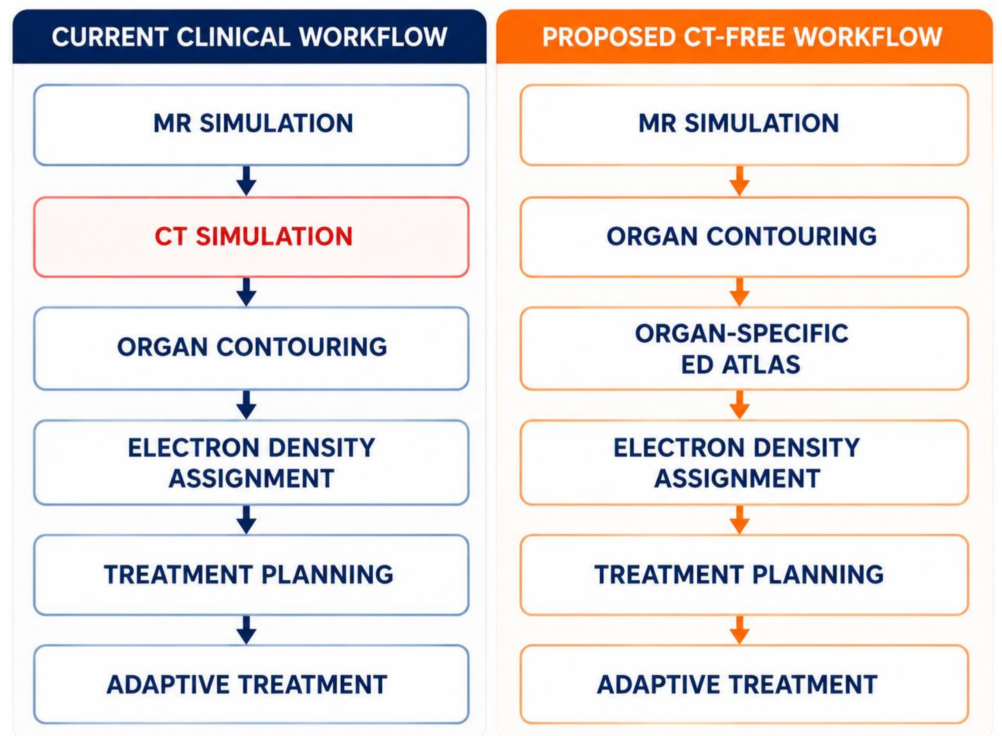

Figure 6: Current clinical workflow (left) and proposed CT-free workflow (right) using an organ-specific electron density atlas for dose calculation.

FUTURE WORK

Future studies will expand the ED atlas to additional tissue and bone structures. Polymer gels and 3D filaments with matching EDs will be determined for use in an abdominopelvic anthropomorphic phantom with three-dimensional dosimetry for quality assurance testing of MR- and CBCT based adaptive radiotherapy systems.

ACKNOWLEDGEMENTS

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REFERENCES

Karotki, A., Mah, K., Meijer, G., & Meltsner, M. (2011). Comparison of bulk electron density and voxel-based electron density treatment planning. *Journal of Applied Clinical Medical Physics*, *12*(4), 97–104. https://doi.org/10.1120/jacmp.v12i4.35222

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CONTACT

Emily Hayes: e.hayes@ufl.edu
Luke Maloney: lmal0003@shands.ufl.edu