# Characterizing the Excursion of Sensitive Cardiac Substructures due to Respiration


C. Miller *1,2, E. Morris 1,3, A. Ghanem 1,4, M. Pantelic 5, E. Walker 1, and C. Glide-Hurst1,3

(1) Department of Radiation Oncology, Henry Ford Cancer Institute, Detroit, MI (2) College of Engineering, Wayne State University, Detroit, MI (3) Department of Radiation Oncology, Wayne State University School of Medicine, Detroit, MI (4) Department of Clinical Oncology, Alexandria University, Alexandria, Egypt, (5) Department of Radiology, Henry Ford Cancer Institute, Detroit, MI

*Author contact: cmille28@hfhs.org



JULY 12–16 2020 VIRTUAL JOINT AAPM | COMP MEETING EASTERN TIME [GMT-4]


## INTRODUCTION

- Radiation dose to the heart is strongly associated with increased risk of cardiotoxicity
- Current whole-heart dose estimates used clinically are not as strongly linked to cardiac morbidities as radiation dose to individual cardiac substructures
- Yet, cardiac substructures of the heart and their movement throughout the respiratory cycle are not considered in radiotherapy treatment planning, thereby complicating effective sparing strategies

## PURPOSE

- ✓ To quantify cardiac substructure motion over the respiratory cycle using 4-dimensional computed tomography (4DCT) data (intra-fraction displacement)
- ✓ To evaluate the potential dosimetric impact of substructure motion

## METHODS

1. Cardiac gated T2-weighted magnetic resonance images (MRIs) were acquired at end-exhalation (EE) for 11 patients who underwent thoracic cancer treatment
2. The EE phase of the 4-dimensional computed tomography (4DCT) was rigidly registered with the MRI and refined with an assisted alignment surrounding the heart for delineation
3. 13 cardiac substructures were contoured by a radiation oncologist on the 4DCT using the hybrid MRI/CT information*
4. Contours were deformed to other 4DCT phases via an intensity-based deformable image registration and corrected
5. Substructure centroid locations, volumes, and dose were exported for data analysis
6. Maximum excursion between phases and statistical analyses on substructure displacement were calculated

*Morris et al. [3,4]

## RESULTS

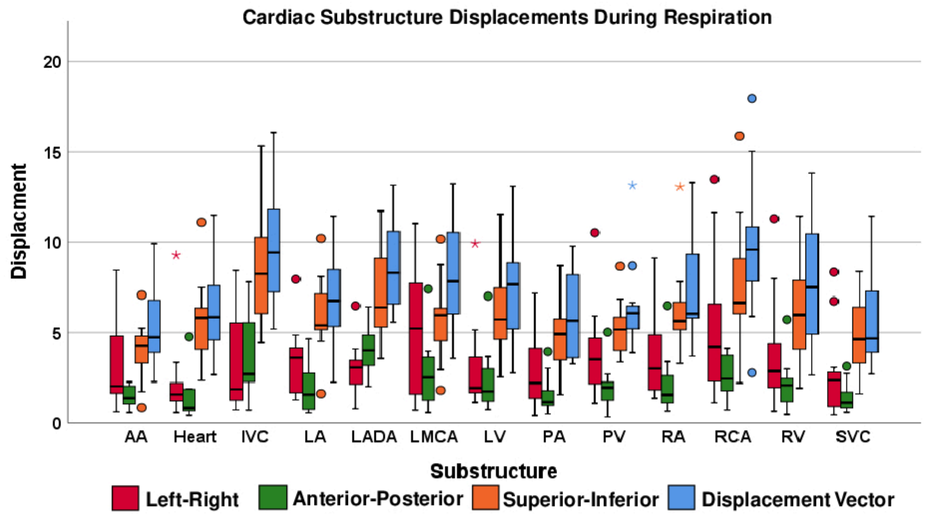



**Figure 1:** Centroid shift comparison between all thirteen substructures for each direction: left-right (L-R), superior-inferior (S-I), and anterior-posterior (A-P). Boxplots, thick line, and whiskers represent the interquartile range, median, and 5th and 95th percentiles, respectively. Data points displayed as a small circle represent a value >1.5 times the interquartile range (IQR) and the star represents a value >3×IQR.

- Overall, the largest intra-fraction displacement occurred in the Superior-Inferior axis as shown in Table 1 (right) and Figure 1 (above)
- Maximum displacements of greater than 5 mm [2] were found for 24.8%, 8.5%, and 64.5% of the cases in the L-R, A-P, and S-I axes, respectively
- 10/13 structures had median intra-fraction centroid displacements equal to or greater than 5 mm in the S-I axis
- Maximum vector displacements ranged from 5-10 mm across all substructures (Table 1)
  - Greatest for the IVC and the RCA (max displacements >15 mm)
  - Least for the great vessels (i.e. the AA, SVC, and PA)

| Substructure | L-R (mm) | A-P (mm) | S-I (mm) | Vector (mm) |
|---|---|---|---|---|
| Heart (n=9) | 2.5 ± 2.7 | 1.5 ± 1.4 | 5.9 ± 2.5 | 6.6 ± 3.1 |
| LV | 3.1 ± 2.6 | 2.4 ± 1.8 | 6.3 ± 2.8 | 7.6 ± 3.4 |
| LA | 3.4 ± 2.0 | 1.9 ± 1.3 | 6.0 ± 2.2 | 7.0 ± 2.7 |
| RV | 3.9 ± 3.1 | 2.1 ± 1.4 | 6.1 ± 3.0 | 7.7 ± 3.6 |
| RA | 3.7 ± 2.5 | 2.1 ± 1.7 | 6.2 ± 2.6 | 7.5 ± 3.1 |
| PA | 2.9 ± 2.2 | 1.6 ± 1.1 | 4.9 ± 2.0 | 6.0 ± 2.5 |
| AA | 3.1 ± 2.5 | 1.4 ± 0.6 | 4.0 ± 1.7 | 5.4 ± 2.4 |
| SVC | 2.8 ± 2.6 | 1.4 ± 0.9 | 5.0 ± 2.3 | 5.7 ± 2.8 |
| PV | 3.9 ± 2.6 | 2.0 ± 1.2 | 5.2 ± 1.6 | 6.5 ± 2.5 |
| IVC | 3.2 ± 2.7 | 3.8 ± 2.5 | 8.5 ± 3.3 | 9.8 ± 3.4 |
| RCA | 5.3 ± 4.1 | 2.6 ± 1.2 | 7.8 ± 3.7 | 9.8 ± 4.1 |
| LADA | 3.0 ± 1.5 | 4.1 ± 1.3 | 7.1 ± 2.6 | 8.7 ± 2.5 |
| LMCA | 5.0 ± 3.5 | 2.7 ± 2.0 | 5.8 ± 2.4 | 8.2 ± 3.1 |

**Table 1:** Maximum displacement of individual cardiac substructures over 11 patients throughout the respiratory cycle in each cardinal axis (left-right (L-R), anterior-posterior (A-P), and superior-inferior (S-I)) and vector displacements.

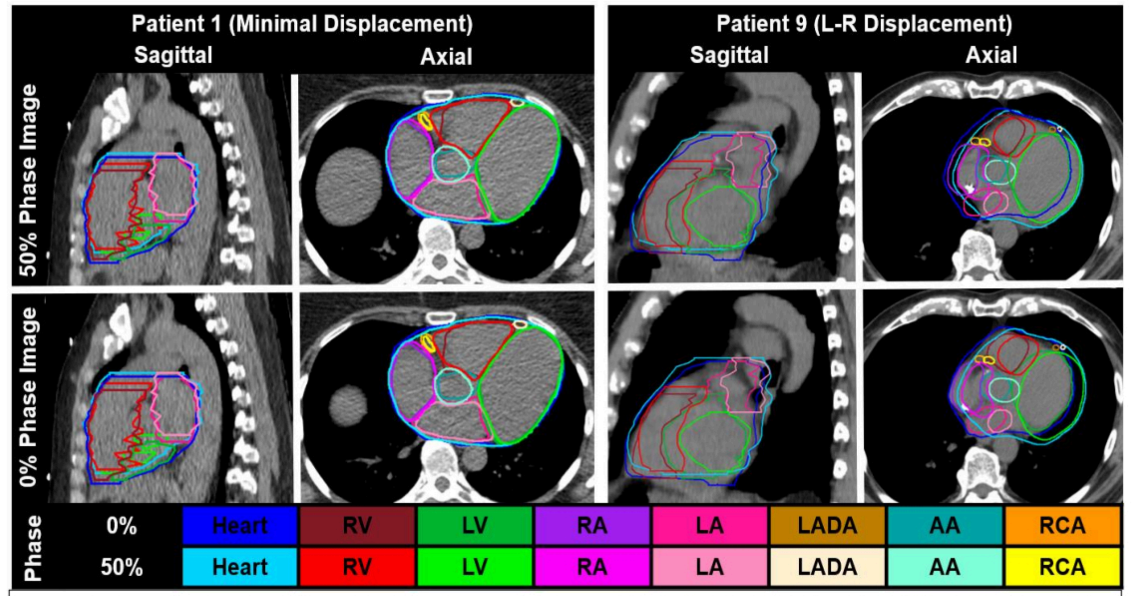


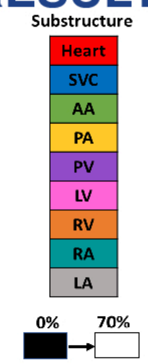

**Figure 2:** Two representative patients showing substructure excursion between 0% (bottom row) and 50% phase (top row) images with the contours from each phase shown on both image sets for the axial and the sagittal axes. Left: Patient 1 exemplified minimal displacement over respiration. Right: Patient 9 underwent the largest left-right (L-R) displacement across the cohort. Cardiac substructure abbreviations are defined in the text.

- Patient 9 (Figure 2, right) exhibited the largest substructure displacements in the L-R axis (contrary to the S-I tendency)
  - L-R displacements for 12/13 substructures were >5 mm, up to 13.5 mm for the LADA
  - Accounts for 8/9 L-R axis outliers shown in Figure 1 (red stars and dots)
- For the S-I axis, Patient 9 had displacements for all substructures > 5.0 mm and up to 8.7 mm.

**Substructure Abbreviations:**

- Left/right ventricle (**LV/RV**)
- Left/right atria (**LA/RA**)
- Pulmonary artery (**PA**)
- Pulmonary vein (**PV**)
- Ascending aorta (**AA**)
- Superior vena cava (**SVC**)
- Inferior vena cava (**IVC**)
- Right coronary artery (**RCA**)
- Left anterior descending artery (**LADA**)
- Left main coronary artery (**LMCA**)

## RESULTS



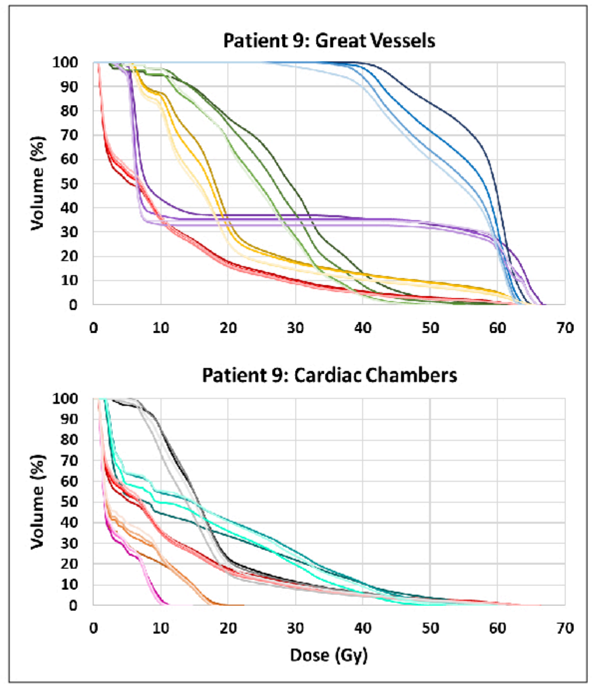




**Figure 3**: Dose volume histograms for Patient 9 showing the dosimetric variation across respiratory phases for the great vessels (top) and the cardiac chambers (bottom). Substructure color gradient transitions from dark to light as the respiratory phases pass from the 0% to the 70% phase, respectively.

- Further, dose to the substructures were evaluated between phases to show the differences across the breathing cycle
- Patient 9 (left) received lung treatment of 60 Gy in 20 fractions and had the largest changes in dose across phases with an average
  - Max dose of 3.2 ± 2.9 Gy (range: 0.46 (PA) to 9.05 Gy (RA)) across the substructures
  - Mean dose change among substructures was 2.2 ± 1.8 Gy
- Great vessels and cardiac chambers had more variation in dose throughout respiration as compared to the whole heart (red, Figure 3)
  - Specifically, the SVC (blue in Figure 3, top) had a mean dose difference of up to 5.4 Gy

## CONCLUSIONS

- This work characterized the independent intra-fraction displacement of the cardiac substructures through the respiratory cycle
- This has importance for possible cardiac substructure planning risk volume generation for patients who are unable to comply with breath-hold conditions for thoracic cancer treatments
- Future work to determine the dosimetric effect of sensitive cardiac substructure displacement in respiration is warranted.

## REFERENCES


[1] **Guzhva L**, Flampouri S, Mendenhall NP, Hoppe BS. Intrafractional displacement of cardiac substructures among patients with hodgkin lymphoma or lung cancer. International Journal of Radiation Oncology• Biology• Physics. 2017 Oct 1;99(2):S62.

[2] **Keall PJ**, Mageras GS, Balter JM, Emery RS, Forster KM, Jiang SB, Kapatoes JM, Low DA, Murphy MJ, Murray BR, Ramsey CR. The management of respiratory motion in radiation oncology report of AAPM Task Group 76 a. Medical physics. 2006 Oct;33(10):3874-900.

[3] **Morris ED**, Ghanem AI, Pantelic MV, Walker EM, Han X, Glide-Hurst CK. Cardiac substructure segmentation and dosimetry using a novel hybrid magnetic resonance and computed tomography cardiac atlas. International Journal of Radiation Oncology* Biology* Physics. 2019 Mar 15;103(4):985-93.

[4] **Morris ED**, Ghanem AI, Dong M, Pantelic MV, Walker EM, Glide-Hurst CK. Cardiac substructure segmentation with deep learning for improved cardiac sparing. Medical Physics. 2020 Feb;47(2):576-86.


## ACKNOWLEDGEMENTS


Research partially supported by the National Cancer Institute of the National Institutes of Health under Award Number R01CA204189 (PI: Glide-Hurst).