Among lung cancer patients in whom surgery is contraindicated, stereotactic ablative radiotherapy (SABR) is considered the standard of care. Due to the nature of radiation therapy, accurately targeting the tumor is important to both ensure appropriate delivery of treatment to the tumor and to avoid irradiating healthy surrounding tissue. Accurately targeting lung tumors, which exhibit continuous motion due to the breathing cycle, presents a challenge. Fiducials can be placed around the tumor for treatment targeting via the robotic SABR system. However, errors commonly cause some fiducials to remain untracked which may reduce treatment accuracy. Common errors are listed below.

**Materials & Methods**

- **Data Collection**
  - Centroid location data was obtained by threshold contouring 4DCT images using the Velocity imaging informatics software. Analysis was performed on data from 0.1-1.499 cm fiducial separation, indicating average fiducial motion based on the availability of data order. Thresholds of 1100 and 250 Hounsfield units were used for fiducials and tumors respectively. CERR was used in Matlab to perform the centroid calculations.

**Analysis**

- **Maximum Inter-fiducial distances were compared between RBE+ and RBE-treatments to determine ideal placement distances.** A similar procedure to RBE analysis using minimum instead of maximum fiducial distances was performed to analyze spacing proximity errors.

  - A Mann-Whitney U test was then performed on these results to determine significance. A chi square analysis was also performed on the percentages of treated lobes producing each type of error.

**Results**

- **Figure 1.** The percent of total treatments containing specific errors are shown. Rigid body and spacing errors appeared most frequently, and were therefore studied most extensively in this study.
- **Figure 2.** The percent chance of a subset of lung lobes displaying an uncertainty error is shown based on the number of uncertainty errors detected per lobe corrected for the number of treatments per lobe. 41.7% of LLL treatments expressed uncertainty errors compared to 11.3% in all other lobes. This deviation was found to be significant with a chi-square of 7.81 and a p value of .007.
- **Figure 3.** The maximum inter-fiducial distance per treatment are displayed, separated by those expressing RBE and those without. The mean for RBE and RBE treatments are 4.04 cm and 3.50 cm respectively. The median values are 3.92 cm and 2.48 cm respectively. A Mann-Whitney U value of 142 and a p value of .22 were found indicating significant deviance in the two data sets.
- **Figure 4.** The percentages of treatments within 1 cm intervals displaying RBE are shown. It can be seen that RBE probability rises dramatically with greater than 3 cm of separation. The deviance in the “5.5-6.49” and “6.5-7.99” data points from the general data trend is likely due to the low n value at the larger distances, and additional data would likely smooth out the curve.
- **Figure 5.** The minimum inter-fiducial distance per treatment are displayed, separated by those expressing spacing errors and those without. The mean for spacing error and spacing error treatments are 6.37 cm and 1.65 cm respectively. The median values are 6.32 cm and 1.58 cm respectively. A Mann-Whitney U value of 187 and a p value of .67 were found indicating significant deviance in the two data sets. Spacing errors were not observed for any fiducials farther than 1.533 cm apart, although some fiducials placed closer than this value did not express these errors.
- **Figure 6.** The of treatments within 0.5 cm intervals displaying spacing errors are shown. It can be seen that spacing error probabilities rise drop to 0% with greater than 2cm of separation.

**Conclusion**

Continued collection of error data from SABR treatments will allow for both the confirmation of the trends expressed for RBE and spacing errors as well as the determination of criteria for uncertainty, shadowing, and collinearity errors. Regarding shadowing, determination of the minimum angle necessary between fiducials relative to the detector to avoid shadowing errors can be determined once more data is collected. Further research can also be performed to determine the cause of increased uncertainty errors in the left lower lobe. Determination of fiducial proximity to the heart of LLL treatments with uncertainty errors versus those without will demonstrate whether the motion of the heart is responsible. Fiducial geometries involving all implanted fiducials can also be studied to determine whether particular geometries are more prone to cause errors. Clinical data can be combined with tracking data in order to create a complete criteria for ideal fiducial placement for the SABR system.

**References**
