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Geometric Errors and Effects Analysis for the INTRABEAM Source under Treatment Conditions

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Introduction: The dose prescription and the evaluation of the delivered absorbed dose in intraoperative radiation therapy (IORT) with the INTRABEAM system primarily rely on depth-dose measurements in water. The accuracy of this approach is limited because tissue heterogeneity is neglected, and the applicator is assumed to fit the tumor bed perfectly. It is also challenging to accurately quantify the dose delivered to the patient experimentally due to the steep dose gradient of the source that is highly sensitive to geometric errors. This work aims to determine the absorbed dose to the target volume and the organs at risk of a clinical breast cancer patient from treatment with the system.

Materials and Methods: A homogeneous water-equivalent CT dataset was created from the preoperative CT scan of a patient by replacing all materials in the patient volume with water-equivalent materials. The homogeneous CT data represents the current assumption of a homogeneous patient, while the original preoperative CT data is considered the ground truth (reference). The geometric errors in the simulation setup were introduced by creating a layer of air or blood between the surface of the applicator and the tumor bed. This layer was generated by setting the material and density of the selected voxels as air or blood. An in-house Monte Carlo algorithm was used to simulate and compute the absorbed dose within the patient for all the simulated configurations for a prescribed treatment dose of 20 Gy to the surface of the 3.5-cm-diameter spherical applicator.

Results: The doses received by at least 2% (D2%) of the target volume of the homogeneous patient geometry is 16.26 Gy with a mean dose value of 8.17±3.56 Gy. For the heterogeneous patient geometry, the D2% and the mean dose values are 9.33 Gy and 4.15±1.91 Gy, respectively. The D2% and the mean dose for the heart of the homogeneous CT are 0.035 Gy and 0.011±0.009 Gy, while the values for the heterogeneous patient geometry are 0.119 Gy and 0.0292±0.0295 Gy, respectively. This trend is also discovered for the other organs at risk (OARs). The 2 mm and 5 mm air between the applicator and the tumor bed increased the absorbed dose in the target volume. The D2% and the mean dose value of the target volume of the 2 mm air gap setup are 7.31 Gy and 4.0069±1.5470 Gy, while for the target volume of the 5 mm air gap setup, the values are 6.44 Gy and 4.0215±1.4040 Gy, respectively. For the rest of the left breast, the absorbed doses decreased. The D2% and the mean dose values for the rest of the left breast for the 2 mm air gap setup are 2.06 Gy and 0.3954±0.6138 Gy. The values for the 5 mm air gap setup are 2.09 Gy and 0.3957±0.6204 Gy, respectively. The absorbed dose deposited in the left lung, heart, and the right lung also shows a similar tendency. Meanwhile, the 2 mm blood escalates the D2% of the target volume to 14.10 Gy with a mean dose value of 5.1540±3.5279 Gy. The D2% of the target volume of the 5 mm blood setup is 14.99 Gy with a mean dose value of 6.2256±4.0389 Gy. The D2% and mean dose values of the reference setup are 9.43 Gy and 4.1821±1.9354 Gy, respectively. The absorbed doses in the heart because of the presence of the 2 mm and 5 mm blood are 0.1246 Gy with a mean dose value of 0.0303±0.0308 Gy and 0.1264 Gy with a mean value of 0.0311±0.0313 Gy, respectively. The absorbed doses received by the other OARs also increased in this model.

Conclusions: The assumption of a homogeneous patient might overestimate the dose to the target volume and underestimate the absorbed doses to the organs at risk. The results also reveal that the presence of air increases the absorbed dose in the target volume but reduces the absorbed doses in the rest of the breast, heart, and lungs. On the other hand, the blood present between the surface of the applicator and the tumor bed led to a dose escalation in the target volume. The absorbed doses in the rest of the left breast, heart, and both lungs also increased. These results highlight the importance of avoiding and minimizing the presence of air and blood as their presence could significantly change the absorbed doses in the target volume and the other OARs, thus potentially affecting the treatment outcomes.