Patient-Specific Bolus Fabrication for Radiation Therapy: A Novel Computational Tool Using Deep Learning and Spectral Mesh Flattening With Geodesic Distance Mapping

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Radiation therapy stands as a cornerstone in cancer treatment, serving over 10 million new patients annually and requiring precise dose delivery. Custom boluses, which are tissue-like materials placed over the skin, are critical for optimizing this radiation dose. However, traditional bolus fabrication methods can often result in 30% dose delivery errors due to air gaps, especially in complex anatomical areas, leading to potential tumor recurrence and tissue damage. While advanced solutions like 3D printing offer alternatives, their high cost and lengthy production limit widespread adoption. In this study, a novel multi-stage computational tool was developed to unfold 3D anatomical structures into 2D contours. An Auto-Encoder deep-learning model was used to simplify patient-specific complex 3D-mesh. The Fast Marching Method precisely maps geodesic distances on 3D surfaces, preserving critical intrinsic distances during transformation. Finally, the Spectral Mesh Flattening algorithm transforms the distance-mapped surfaces into 2D contours. Validation was performed using 400+ 3D models generated using geometric primitives for mathematical accuracy and was further tested using medical phantoms simulating radiation therapy settings. The tool generated precise 2D contours for challenging anatomical regions including the nose, ear, and chin. The geometric models achieved a DICE coefficient of 0.89±0.06 and the laboratory validation showed anatomical conformity with Hausdorff distance <1.3 mm, minimizing air gaps that cause dose delivery errors. With an 80% reduction in fabrication time and lower cost compared to 3D printing methods, this tool enables rapid, personalized and accessible bolus fabrication, improving radiation therapy outcomes for cancer patients globally.

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