Revolutionizing Targeted Therapeutics Using AI-Powered Origami Millirobots

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Primary liver cancer is a leading cause of cancer-related deaths worldwide. However, one of its standard treatments, transarterial chemoembolization (TACE), often has low target vessel specificity and restricted mobility, leading to excess embolization and further liver injury. As a result, millirobots are an attractive option for more precise targeting, yet are limited by human control. Using machine learning on a magnetic origami millirobot, this study aimed to improve autonomous TACE bead deposition. As a base, a Kresling origami ring was modified to enhance torque and compression, and constructed of biocompatible materials, including thermoplastic polyurethane (TPU) and polydimethylsiloxane (PDMS). These materials were tested to meet preliminary FDA biocompatibility guidelines, with a 4.90% hemolysis rate in rabbit red blood cells. To improve human-based control systems for the robot, a 3D U-Net was trained for tumor and vessel segmentation from CT images, and the resulting vessel segmentations were skeletonized to extract the best vessel path to the tumor. This model achieved a tumor and vessel segmentation dice similarity coefficient of 0.911 and 0.802, respectively. Ultrasonic transducers localized the millirobot along this path, which enabled real-time adjustments to electromagnetic coil strength to navigate and deposit the TACE beads. Of one hundred runs in various CT-based simulated vasculature and flow conditions, the millirobot navigated to the target location and deposited the polyvinyl alcohol (PVA) beads in 94 simulations. Thus, these results demonstrate the potential of origami-based millirobots to revolutionize patients' post-TACE liver outcomes through autonomous, reliable, and targeted embolic delivery.

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