A Self-Expanding 4D-Printed Biodegradable Esophageal Stent With Sequential Dual Drug Release

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Esophageal obstruction caused by cancer and benign strictures can severely impair swallowing, leading to poor nutrition and reduced quality of life. Although conventional stents are commonly used to keep the esophagus open, they are often associated with complications such as migration, tissue irritation, and the need for surgical removal. This project presents a novel smart biodegradable esophageal stent developed using four-dimensional (4D) printing with a self-expanding TPU/PCL shape-memory polymer system. The stent is designed for minimally invasive insertion in a compact form and self-expands at body temperature (37 °C) to provide support to the blocked area. In addition to mechanical support, the design incorporates a dual-drug delivery system consisting of rapid ibuprofen release for immediate anti-inflammatory action and sustained 5-fluorouracil (5-FU) release to reduce restenosis and prevent tissue regrowth. The stent was fabricated using fused deposition modeling (FDM) with a helical diamond-mesh design and evaluated for dimensional accuracy, shape-memory recovery, drug release behavior, and surface morphology using scanning electron microscopy (SEM). Results showed high dimensional accuracy, excellent shape recovery of more than 98–99%, effective sequential drug release, and a porous structure suitable for drug loading and controlled release. By combining biodegradability, self-expansion, and localized drug delivery, this design offers a safer and more cost-effective alternative to conventional stents while eliminating the need for removal procedures, showing strong potential for future clinical use.

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