Bi-Stable Auxetic Stent for Enhanced Vascular Conformability Using Machine Learning and Finite Element Analysis

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Cardiovascular diseases remain the leading cause of mortality worldwide, with most conditions requiring vascular stents to restore blood flow. However, complications such as restenosis—the re-narrowing of a blood vessel after stent placement, occur in 30% of stent patients. Restenosis often arises from the uniform radial expansion of conventional stents, which fails to account for irregular vascular geometries of stenotic regions and healthy regions, leading to uneven force distribution and damage to the vessel wall. This research proposes a stent design leveraging bi-stable auxetic mechanisms as well as patient-specific customizations to enhance performance and minimize complications. Auxetic lattice structures are characterized by a lateral extension when stretched. This property is used to enable the stent to conform more naturally to complex vascular geometries than normal metal mesh stents, distributing radial forces evenly to reduce localized stress and vascular trauma. The bi-stable mechanism is used to ensure stability in both contracted and expanded configurations so that a vessel cannot re-narrow after placement. The stent's expanded configuration is customized through machine learning and patient-specific imaging data from MRI and CT angiography. A 3D reconstruction of the blood vessel is converted into a CAD model, allowing the auxetic lattice to be tailored to deliver variable radial forces to stenotic and healthy regions. Finite element analysis (FEA) was also used to optimize stress distribution and evaluate mechanical durability under pulsatile flow conditions. Preliminary results with computational models of the stent design demonstrate a reduction in restenosis, minimized over-compression, and enhanced vascular wall support.

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