Targeted Thrombolytic Therapy Enabled by Near-Infrared Light-Responsive Microcapsules with Controlled Release Behavior

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Abstract

Venous thromboembolism (VTE) represents a major global health burden. Conventional thrombolytic drugs are severely constrained in clinical practice due to their short half-life, limited targeting specificity, and high bleeding risk. In recent years, photothermal therapy (PTT) has emerged as a promising thrombolytic strategy, which employs near-infrared (NIR) light to convert photon energy into localized heat for thrombus dissolution. Nevertheless, conventional metallic nanomaterials, despite their high photothermal conversion efficiency, are associated with potential biosafety issues that limit their translational potential. In comparison, melanin or polydopamine (PDA) nanoparticles exhibit outstanding biocompatibility and biodegradability, thus representing safer alternatives for photothermal applications. Meanwhile, nitric oxide (NO) possesses distinctive antithrombotic effects and shows great potential as an adjuvant for thrombolytic therapy. Among various NO donors, S-nitrosoglutathione (GSNO) is highly favorable owing to its superior stability and biocompatibility. In this work, two types of microcapsules were successfully fabricated via layer-by-layer (LBL) self-assembly, with NIR light acting as an external trigger for on-demand thrombolytic therapy. These microcapsules were tailored for the treatment of femoral vein thrombosis and pulmonary embolism, and displayed high drug-loading efficiency, stable photothermal performance, and controllable NO release profiles. Moreover, with the targeting capability of fucoidan, the microcapsules could be precisely delivered to thrombotic lesions. In vivo results confirmed that this microcapsule-based thrombolytic system achieved therapeutic efficacy comparable to traditional thrombolytics, while markedly alleviating the associated bleeding risk. Collectively, this study establishes a novel, precise, efficient and safe therapeutic platform for thrombus management, providing important implications for further research and clinical translation in thrombotic diseases.

Keywords

Near-Infrared Light, Microcapsules, Thrombolytic Therapy, Thrombus Targeting