Title: Redox-Responsive Boronic Acid-Based Hydrogel for Controlled Drug Delivery and Theranostic Applications

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Introduction

Redox-responsive biomaterials are gaining traction in drug delivery and theranostics due to their ability to respond to oxidative stress in pathological environments like cancer. Phenylboronic acid (PBA) derivatives are particularly attractive because of their biocompatibility and selective reactivity toward hydrogen peroxide (H_2O_2). We report a novel PBA-based polymer, poly(2-hydroxyethyl methacrylamide-co-phenylboronic acid methyl methacrylamide) (PHMPAMM), which forms injectable hydrogels with polyvinyl alcohol (PVA) for controlled drug release and imaging applications.

Methods

PHMPAMM was synthesized via radical polymerization and characterized by nuclear magnetic resonance. Biocompatibility was evaluated using glioma cell cultures. Hydrogels were prepared by blending PHMPAMM with PVA at optimized ratios and assessed for morphology, viscoelastic properties and redox responsiveness using scanning electron microscopy (SEM), rheology, and 1 mM H_2O_2, respectively. Degradation and drug release studies employed albumin (large molecule), indocyanine green (small molecule), and nanoparticle-based contrast agents.

Results

PHMPAMM exhibited excellent cytocompatibility and formed instant gels when in contact with PVA, suitable for injection via dual-syringe systems. SEM and rheology studies demonstrated excellent structural and injectable properties. Furthermore, the hydrogels degraded significantly faster in oxidative conditions compared to PBS, demonstrating strong redox sensitivity. Lastly, controlled release experiments confirmed efficient encapsulation and sustained release of both large and small therapeutic agents, as well as nanoparticle retention.

Conclusions

PHMPAMM-based hydrogels represent a promising platform for redox-responsive drug delivery and theranostics, particularly in cancer therapy. Their biocompatibility, injectability, and ability to encapsulate and release diverse therapeutic and imaging agents in a controlled manner highlight their potential for clinical translation.

Keywords: redox-responsive polymer, phenylboronic acid, injectable hydrogel, drug delivery, theranostics