IOCG 2025 Conference
The 1st International Online Conference on Gels
03–05 December 2025 | Online
MDPI

Synthesis and characterization of quaternary ammonium carboxymethyl chitosan grafted onto κ-Carrageenan Hydrogel loaded with Ciprofloxacin For Wound Healing

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INTRODUCTION & AIM

- Chronic and acute wounds require advanced biomaterials capable of ensuring moisture balance, antibacterial protection, and controlled drug delivery.
- Natural polysaccharides such as κ-carrageenan and chitosan derivatives offer excellent biocompatibility, biodegradability, and film-forming properties, making them promising candidates for wound-healing applications.
- Carboxymethyl chitosan modified with quaternary ammonium groups exhibits enhanced water solubility and strong antimicrobial activity, while κ-carrageenan provides mechanical stability and a suitable 3D network for hydrogel formation.
- In this work, we developed a novel hybrid hydrogel by grafting quaternary ammonium carboxymethyl chitosan onto κ-carrageenan and incorporating ciprofloxacin as a model therapeutic agent.
- The aim was to enhance antibacterial efficiency, improve drug-release behavior, and create a functional wound dressing with superior healing potential. Physicochemical characterization, swelling studies, and antimicrobial assays were performed to assess the hydrogel's suitability for biomedical applications.

METHOD

1. Synthesis of Quaternary Ammonium Carboxymethyl Chitosan (QCCS) — (Figure 1A)

Carboxymethyl chitosan (O-CMC) was reacted with glycidyl trimethylammonium chloride (GTMAC) at 60°C for 24 h to introduce quaternary ammonium groups. The obtained QCCS was purified, dried, and used as a cationic precursor for hydrogel formation.

2. Preparation of QCCS/κ-Carrageenan (κ-CG) Hydrogel — (Figure AB)

QCCS and κ-CG aqueous solutions were mixed at room temperature (25°C) under gentle stirring. The electrostatic interactions between cationic QCCS and anionic κ-CG induced spontaneous gelation, forming a transparent and stable hydrogel network.

3. Ciprofloxacin Loading

Ciprofloxacin (CIP) was incorporated during hydrogel formation to ensure uniform drug distribution. The loaded hydrogels were allowed to stabilize at room temperature before characterization.

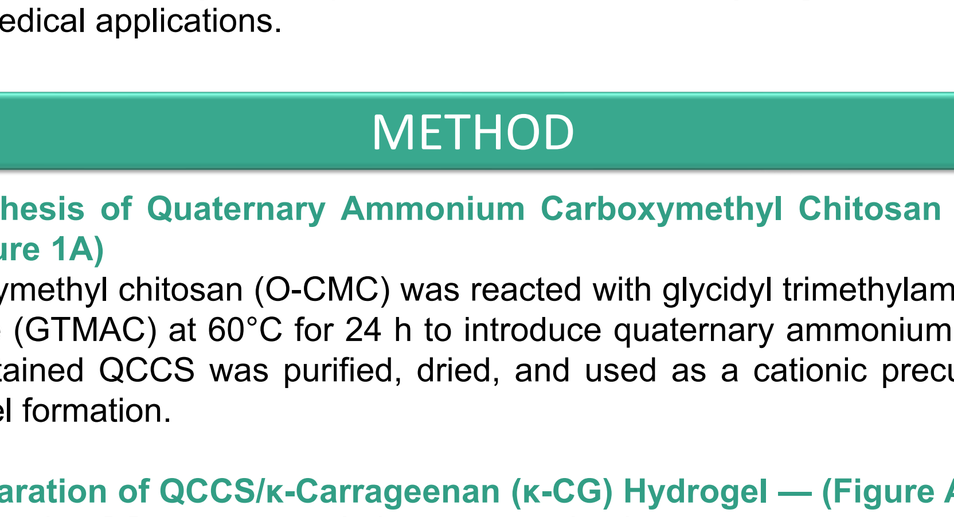

***Figure 1**. Synthesis, formation mechanism and physical properties of QCCS/K-CG injectable hydrogel*

RESULTS & DISCUSSION

- The QACMC-g-κ-carrageenan hydrogel was successfully synthesized and confirmed through FTIR, where characteristic peaks indicated efficient grafting and ciprofloxacin incorporation.
- SEM micrographs revealed a highly porous and interconnected structure, promoting exudate absorption and facilitating controlled drug diffusion.
- The hydrogel exhibited excellent swelling capacity due to the presence of hydrophilic carboxymethyl and sulfate groups, ensuring a moist environment favorable for wound repair.
- Drug-loading studies showed high encapsulation efficiency, while release profiles demonstrated an initial burst followed by sustained diffusion over time (Figure 2).
- Ciprofloxacin-loaded hydrogels displayed strong antibacterial activity against *S. aureus* and *E. coli*, confirming their therapeutic potential.
- Overall, the developed system presents a stable, bioactive, and biocompatible platform suitable for advanced wound healing applications.

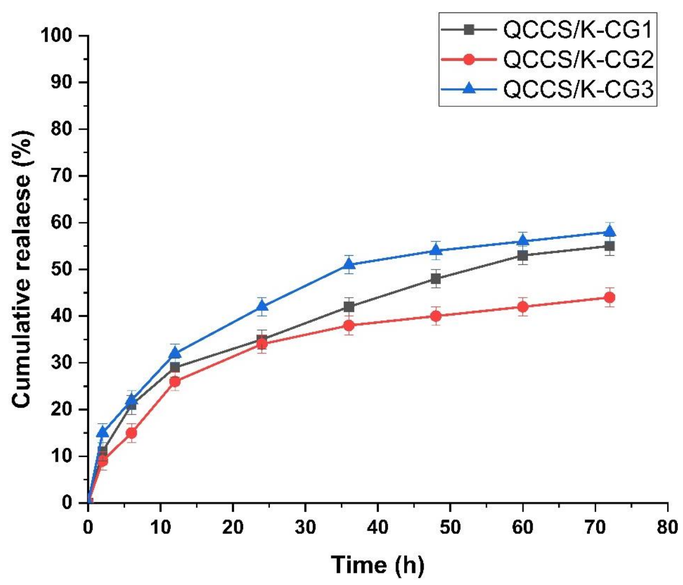

***Figure 2**. Cumulative release profile of Ciprofloxacin from QCCS/κ-Carrageenan hydrogels (QCCS/K-CG1, QCCS/K-CG2, QCCS/K-CG3) over 72 h.*

CONCLUSION

- The quaternary ammonium carboxymethyl chitosan–grafted κ-carrageenan hydrogel loaded with ciprofloxacin was successfully synthesized and characterized.
- The hydrogel exhibited excellent swelling capacity, improved mechanical stability, and sustained drug-release behavior, confirming its suitability for controlled topical delivery.
- Antibacterial evaluation demonstrated strong inhibitory activity against common wound-infecting pathogens, while biocompatibility assessments indicated safe interaction with biological tissues.
- In conclusion, this multifunctional hydrogel shows strong potential as an advanced wound-healing material with enhanced therapeutic efficiency.

FUTURE WORK / REFERENCES

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