Reversible Electric Field-Induced Adhesion of Charged Polysaccharide Gels

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Introduction

Polyelectrolyte hydrogels, composed of highly charged cationic or anionic polymers, offer unique properties for biomedical and materials science applications. Additionally, two oppositely charged hydrogels can undergo interfacial adhesion (electroadhesion) when exposed to an electrical field.

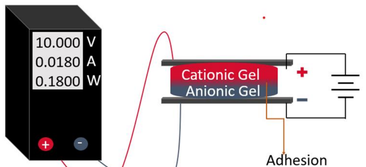


Figure 1: Electroadhesion induced using a DC power supply to pass current through the gels via graphite electrodes.

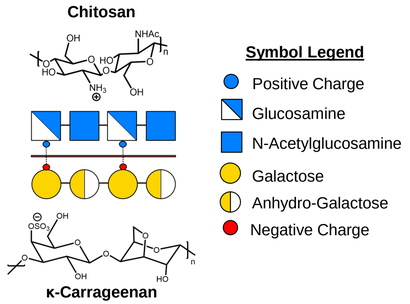


Figure 2: Model for electroadhesion through ion pairing at the gel interface depicted with chitosan and κ-carrageenan.

Polysaccharides are often used to generate polyelectrolyte hydrogels, however, it has become evident from our preliminary studies that not all charged polysaccharides can engage in electroadhesion. Our efforts are unraveling the molecular characteristics, composition and physical properties that are critical for electroadhesive activity of polysaccharides. The reversible nature and high tensile strength of electroadhered hydrogels offers new opportunities for material design related to regenerative engineering, bioelectronic devices, and biomedicine. An understanding of the driving forces for electroadhesion and an accurate model for this phenomenon are anticipated to facilitate the rational design of polysaccharides with tunable electroadhesive properties.

Research Questions

1. Why do only a few charged polysaccharides electroadhere and others with similar structures do not?
2. Which internal and external factors tune electroadhesive strength?

Methods

1. K-carrageenan gels (4% w/v) were formed by dissolving polysaccharide into water at 80˚C. Upon pouring into a glass petri dish, the solution rapidly gelled as it cooled.
2. QDM gels were prepared following published protocols.[1]
3. Electroadhesion was conducted using a DC power supply, graphite plates, and alligator clips. 10V was passed through the cationic and anionic gels gently pressed together. After 30-seconds, the gels were tested for electroadhesion by shear stress.

Results

Extrinsic Factors

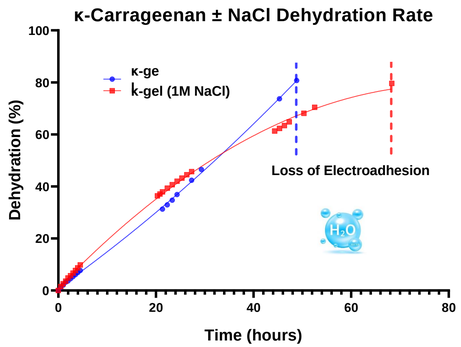


Figure 3: Dehydration testing of κ-carrageenan w/ or w/o 1M NaCl. Gels were allowed to dry at ambient temperature over several days and were tested for loss of mass attributed to water. At various time points, the strength of electroadhesion was tested. After ~80% mass loss, the gels no longer electroadhered and underwent film-casting.

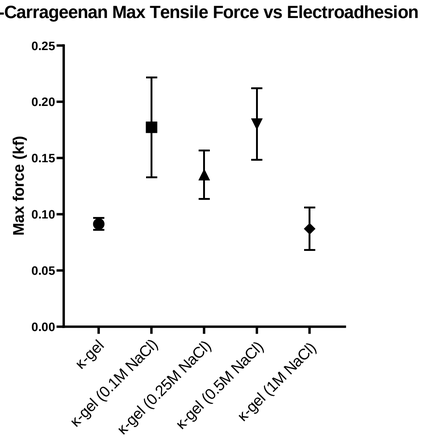
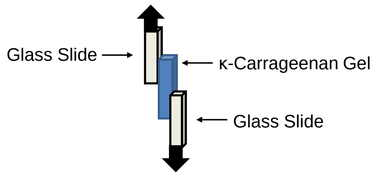
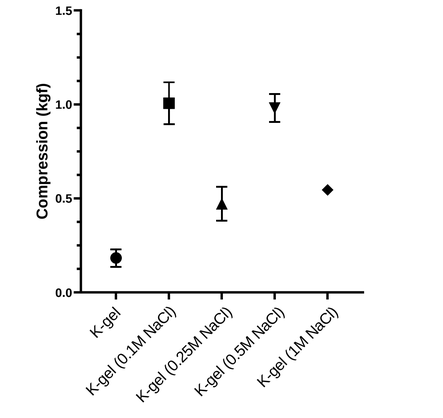


Figure 4: Max tensile strength comparison of k-carrageenan at various ionic strengths. Tensile tests measured on an Instron 3340 using a gel glued to two glass slides and pulled in opposite directions with force measurements until fracture (below). Similar electroadhesive strength was observed for all gels.





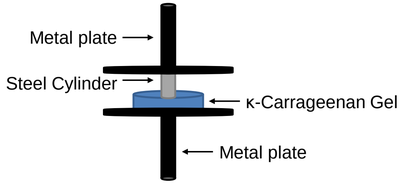
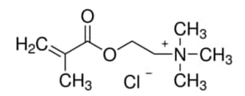


Figure 5: Compression values of k-carrageenan at 0.5 mm, at various ionic strengths. Compression tests measured on an Instron 3340 where a steel cylinder is slowly pressed into a gel and the force and displacement are measured (below).

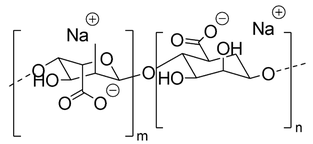
Force (kgf): 1.23
Displacement (mm): 0.5

Intrinsic Factors

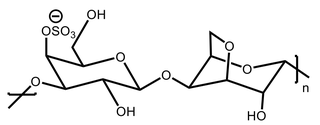
Electroadheres



Quaternized dimethyl aminoethyl methacrylate (QDM)

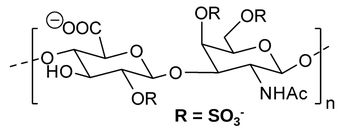


Alginate (Ca^{2+})

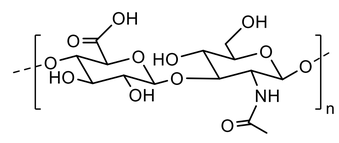


κ-Carrageenan

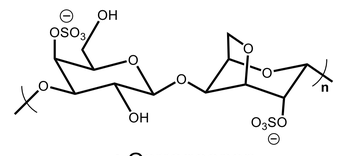
Does Not Electroadhere



Chondroitin sulfate



Hyaluronic Acid



ι-Carrageenan

Conclusions

- **Extrinsic factors:** ionic strength, gel strength, hydration, and conductivity do not tune the electroadhesive strength. However, there is a threshold for these factors where the gel is no longer conductive.
- **Intrinsic factors:** Charge density and ion-pairing are the most likely contributing parameters for electroadhesion.
- A pattern for charge/disaccharide is emerging for electroadhesion:

  (1x) SO_4^- > (2x) COO^- > (1x) COO^- = (2x) SO_4^- >>> (3x) SO_4^-.

Acknowledgement

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References

1. Borden LK et al. (**2021**) *Nat Commun.* Jul 20;12(1):4419. doi: 10.1038/s41467-021-24022-x.