Natural Polymers for Conductive Hydrogel in Electrocardiogram Applications

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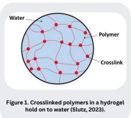
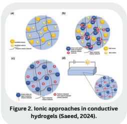
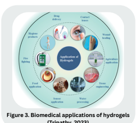
ABSTRACT

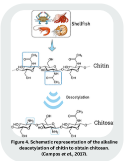
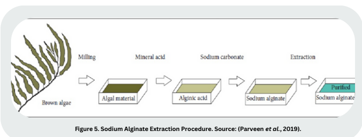
This study investigates the development of conductive hydrogels from natural polymers, chitosan and sodium alginate, as sustainable alternatives to commercial ECG electrode gels. Designed to improve biocompatibility, adhesion, conductivity, and moisture retention, the hydrogels were characterized through pH measurement, conductivity testing, impedance analysis, and viscosity evaluation. Comparative results show that sodium alginate formulations, particularly SA Form 6, achieved pH levels close to commercial gels, exhibited high permittivity, and demonstrated stable capacitive behavior, while chitosan-based gels had lower pH and conductivity outside the optimal ECG range. Several formulations approached commercial standards in viscosity and dielectric properties, though conductivity requires further optimization for accurate signal transmission. These findings highlight sodium alginate as a promising, eco-friendly candidate for biomedical and wearable applications, with targeted improvements needed to maximize performance.

INTRODUCTION

Hydrogels, a term first used to describe colloidal gels in inorganic salts in the late 1800s, have evolved from biomedical applications to bioelectronics, serving as conductive bridges between electrical devices and biological tissue. Their water-rich, polymer-based structure enables low-impedance signal transmission, improving electrode-skin contact while maintaining biocompatibility.

Natural polymers are derived from renewable biological sources such as plants, animals, and microorganisms. This investigation will compare two types of natural polymers; chitosan, extracted from the shells of crustaceans like shrimp and crabs, and sodium alginate, obtained from brown seaweed. These materials are biodegradable, non-toxic, and generally well-tolerated by the human body, making them ideal for biomedical applications. This research aims to develop a health-conscious, naturally derived formulation, tested against commercial ECG gels like Spectra 360 and Axion to improve stability and performance in bioelectronic applications. By using natural polymers like chitosan and sodium alginate, we seek cost-effective, biocompatible alternatives that overcome issues found in current conductive hydrogels, such as skin irritation, poor mechanical properties, and inconsistent adhesion that can affect signal accuracy (Moreno, 2016).


OBJECTIVES

- Develop a conducive gel by using formulations with natural polymers (chitosan and sodium alginate).
- Compare the final formulations with the commercial electrocardiogram gels (Axion and Spectra 360).
- Evaluate the measurements through different characterization methods.
- Identify if natural polymers such as chitosan and sodium alginate are viable for use in electrocardiogram gel applications.

METHODOLOGY

1. Research and Data

Gather Information from Databases:
National Institute of Health (PubMed)
Mayo Clinic, ResearchGate,
Equipment Catalogs, among others.

Use research criteria based on keywords:
Hydrogel, Conductive, Chitosan, Sodium Alginate, Electrocardiogram, and Electrode.

2. Preparation

Request chemicals and lab equipment to be used in the formulation.

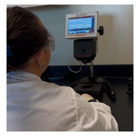
3. Formulation

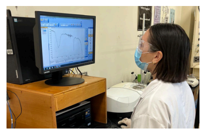
Chemicals for Chitosan Formulation
Chitosan
Acetic Acid
Deionized Water
Sodium Chloride

Chemicals for Sodium Alginate Formulation
Sodium Alginate
Deionized Water
Sodium Chloride
Calcium Chloride

Experimentation process for chitosan and sodium alginate formulations.

4. Characterization





Perform measurements using pH meter, conductometer, viscometer, and impedance analyzer.

5. Conductive Testing and Analysis

Analyzing and **evaluating** the obtained results in the characterizations.

Comparing the commercial gels to the formulated hydrogels for final conclusion.

DATA

Formulations and Commercial Gels	Images	pH	Conductivity (mS)	Permittivity	Impedance		Viscosity (cP)
					Mag of Imp	Phase Ang of Imp	
CH Form 2		4.15	10.49				864
SA Form 4		7.51	1.10				Too Viscous for Equipment
SA Form 5		7.59	1.72				Too Viscous for Equipment
SA Form 6		7.77	2.28				13,960
SA Form 7		7.88	4.97				7,727
Axion		6.48	1.289				Too Viscous for Equipment
Spectra 360		7.27	1.116				Too Viscous for Equipment

Table 1. Data Collected during characterization phase

ANALYSIS AND RESULTS

The following section analyzes the data collected (pH, Conductivity, Viscosity, Impedance and Permittivity) during the characterization phase:

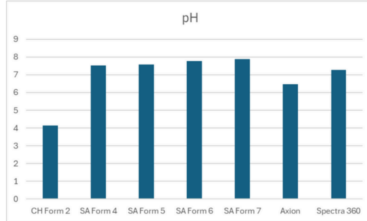


Table 2. pH Comparison of Hydrogels

Commercial ECG gels range from pH 6.5–7.5 (Spectra 360: 7.27; Axion: 6.48). CH Form 2 had a 4.16 pH, while sodium alginate formulations ranged from (7.5–7.9), showing optimal pH levels closely matching commercial standards.

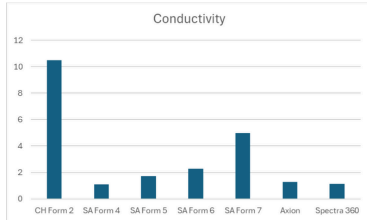


Table 3. Conductivity Comparison of Hydrogels

Formulated hydrogels conductivity values ranged from 10.48 mS from CH Form 2 and 4.97 mS from SA Form 7. However, ECG gels typically exceed 10 mS to meet the conductivity demands required for accurate signal transmission (Ivorra *et al.*, 2008).

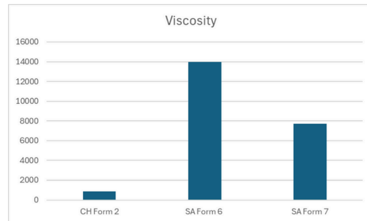


Table 4. Viscosity Comparison of Hydrogels

Highly viscous hydrogels and commercial gels like Axion (8,000–12,000 cP) and Spectra 360 (175,000–260,000 cP) exceeded the device's measurable range. Among the formulations, SA Form 6 had the most accurate viscosity reading 13,960 cP, while SA Forms 4 and 5 were too thick to measure but showed promising consistency.

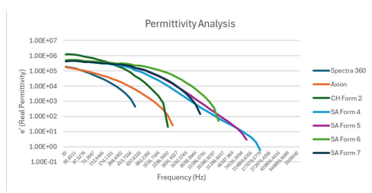


Table 5. Permittivity Comparison of Hydrogels

All hydrogels show decreasing real permittivity (ε′) with increasing frequency, typical of dielectric relaxation. SA Form 6 maintains the highest ε′, while Axion drops the fastest, indicating greater dielectric losses. High ε′ at low frequencies suggests strong charge storage, whereas rapid declines reflect reduced polarization at higher frequencies.

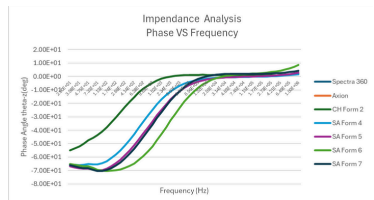


Table 6. Impedance (Phase Angle) Comparison of Hydrogels

All samples shift from strongly capacitive (≈–70°) at low frequencies to near-resistive at high frequencies. CH Form 2 and SA Form 6 recover fastest, while Spectra 360 and Axion transition more slowly. Faster recovery suits rapid signal response, while slower transitions favor stable capacitive behavior over a wider range.

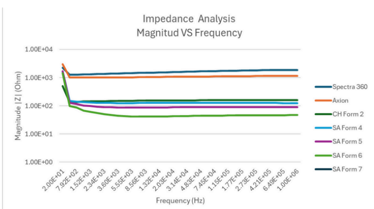


Table 7. Impedance (Magnitude) Comparison of Hydrogels

All samples shift from capacitive at low frequencies to resistive at high frequencies. CH Form 2 and SA Form 6 transition fastest, while Spectra 360 and Axion are slower, favoring stable capacitive behavior.

CONCLUSION AND RECOMMENDATION

The comparative analysis shows that naturally derived hydrogels based on chitosan and sodium alginate demonstrate promising potential as ECG gel alternatives, though further optimization is required to fully match commercial performance. Sodium alginate formulations, particularly SA Form 6, exhibited favorable pH alignment with commercial gels, high permittivity, and stable capacitive behavior, while chitosan-based gels showed lower pH and conductivity outside the optimal ECG range. Although some formulations approached commercial standards in viscosity and dielectric properties, conductivity remained a key area for improvement to ensure accurate signal transmission. Overall, the results suggest that natural polymers, especially sodium alginate, are viable candidates for biocompatible, sustainable ECG gels, provided that conductivity and consistency are further enhanced.

FUTURE WORK

- Use other characterization methods such as: mechanical testing for adhesion, contact angle measurement, biocompatibility testing and raman spectroscopy.
- Explore additional formulations by varying chemical concentrations and comparing their performance with a broader range of commercial ECG gels.

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