Chitosan–Alginate Conductive Hydrogels as Sustainable EEG Interface Materials

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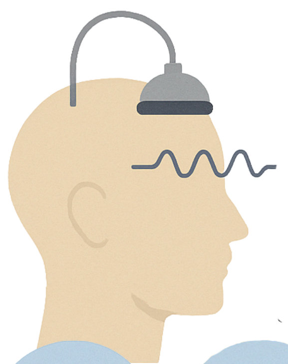
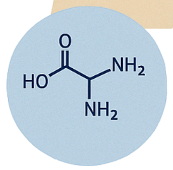
ABSTRACT

Natural polymers such as chitosan and alginate are emerging as sustainable alternatives to synthetic EEG gels. Current literature highlights their biocompatibility, hydration capacity, and ionic conductivity, suggesting potential improvements in signal stability, comfort, and environmental impact. This review summarizes key findings on natural-polymer conductive hydrogels and their relevance for next-generation EEG applications.

INTRODUCTION





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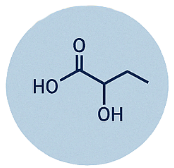


ALGINATE

EEG signal quality depends on maintaining a stable, low-impedance interface, yet commercial gels often dry out, irritate the scalp, and rely on synthetic, non-biodegradable polymers. Recent studies highlight chitosan and alginate, natural biopolymers with strong hydration capacity, high bio-compatibility, and effective ionic conductivity, as highly promising and versatile alternatives. Their combined properties suggest improved signal stability, enhanced comfort, and greater environmental sustainability compared to conventional EEG gels.

OBJECTIVES

Review the performance and limitations of commercial EEG gels in terms of conductivity, hydration, and biocompatibility.

Summarize the properties of chitosan and alginate as natural polymers with potential for conductive hydrogel formulations.

Highlight formulation strategies and characterization criteria for sustainable EEG gels based on current literature.

METHODOLOGY

Literature Search & Data Compilation

Review of articles, reviews, and technical reports (2005–2025) using keywords related to conductive hydrogels, chitosan, alginate, and EEG gels. Sources included PubMed, ScienceDirect, IEEE Xplore, Taylor & Francis, and academic textbooks.

Selection & Refinement of Information

Filtering of studies based on relevance to conductivity, hydration behavior, biocompatibility, and polymer interactions. Prioritization of data with quantitative metrics such as impedance, moisture retention, and ionic conductivity.

Organization of Subtopics

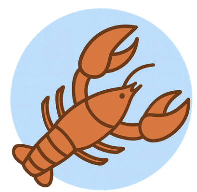
Classification of findings into core themes: natural polymer properties, conductive mechanisms, mechanical behavior, dermatological performance, and sustainability considerations. Identification of recurring trends across studies.

Comparative Analysis Framework

Benchmarking natural-polymer hydrogels against commercial EEG gels (NuPrep, Ten20, Spectra 360) to highlight performance gaps and opportunities for sustainable alternatives. Integration of mechanical, electrical, and environmental criteria.

DATA

Polymer	Source	Key Role in Hydrogel	Relevant Properties for EEG
Chitosan	Crustacean shells (chitin)	Film-forming matrix and support for conductive additives	Antimicrobial, cationic, ionic conductivity, good adhesion to skin
Alginate	Brown algae	Hydrogel network and moisture-retention backbone	High water uptake, biocompatible, gentle gelation, stable on scalp
Chitosan –Alginate blend	Combination of both	Hybrid hydrogel for balanced mechanical and electrical behavior	Improved hydration, tunable impedance, better comfort and sustainability vs. commercial gels



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ANALYSIS AND RESULTS

Chitosan and alginate hydrogels show stronger hydration, more stable impedance, and better skin compatibility than commercial EEG gels, which often dry out and irritate the scalp. Their combination forms a hybrid material with adjustable electrical behavior and improved comfort, offering a sustainable alternative with performance comparable to or better than synthetic gels.

CONCLUSIONS AND RECOMMENDATIONS

Chitosan–alginate hydrogels present a promising pathway toward replacing traditional EEG gels due to their biocompatibility, prolonged hydration, and stable signal interface. Further work should refine polymer ratios, explore conductive additives, and evaluate long-term performance under real EEG conditions to support future clinical and consumer use.

FUTURE WORK

Further development of chitosan–alginate hydrogels should focus on optimizing polymer ratios, improving long-term hydration stability, and integrating safe conductive additives to enhance signal quality. Additional studies using real EEG recordings are needed to evaluate performance under motion, sweating, and extended wear. Exploring scalable fabrication methods and assessing shelf-life will also be essential for transitioning these sustainable hydrogels toward clinical and consumer applications.

REFERENCES

Ye, R., Liu, S., Zhu, W., Li, Y., Huang, L., Zhang, G., & Zhang, Y. (2023). Synthesis, characterization, properties, and biomedical application of chitosan-based hydrogels. Polymers, 15(11), 2482. https://doi.org/10.3390/polym15112482

Ren, Y., Wang, Q., Xu, W., Yang, M., Guo, W., He, S., & Liu, W. (2024). Alginate-based hydrogels mediated biomedical applications: A review. International Journal of Biological Macromolecules, 242, 135019. https://doi.org/10.1016/j.ijbiomac.2024.135019

Colón, P., Stibie, G., & Rondón, J. (2025). Natural polymers for biomedical hydrogels: A review [Poster]. Undergraduate Research Program, Polytechnic University of Puerto Rico. https://prcr.cobimet.org/items/cc46dfdd-35fc-45b4-bf37-a62981aaf11e